Journal of Fluency Disorders 37 (2012) 188–201

Contents lists available at SciVerse ScienceDirect

Journal of Fluency Disorders

# Nonword repetition and phoneme elision in adults who do and do not stutter

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A R T I C L E  I N F O

*Article history:*
Received 21 December 2011
Received in revised form 14 March 2012
Accepted 18 March 2012
Available online 29 March 2012

*Keywords:*
Phonological working memory
Nonword repetition
Phoneme elision
Adults who stutter

A B S T R A C T

The purpose of the present study was to explore the phonological working memory of adults who stutter through the use of a non-word repetition and a phoneme elision task. Participants were 14 adults who stutter ($M = 28$ years) and 14 age/gender matched adults who do not stutter ($M = 28$ years). For the non-word repetition task, the participants had to repeat a set of 12 non-words across four syllable lengths (2-, 3-, 4-, and 7-syllables) ($N = 48$ total non-words). For the phoneme elision task, the participants repeated the same set of non-words at each syllable length, but with a designated target phoneme eliminated. Adults who stutter were significantly less accurate than adults who do not stutter in their initial attempts to produce the longest non-words (i.e., 7-syllable). Adults who stutter also required a significantly higher mean number of attempts to accurately produce 7-syllable non-words than adults who do not stutter. For the phoneme elision task, both groups demonstrated a significant reduction in accuracy as the non-words increased in length; however, there was no significant interaction between group and syllable length. Thus, although there appear to be advancements in the phonological working memory for adults who stutter relative to children who stutter, preliminary data from the present study suggest that the advancements may not be comparable to those demonstrated by adults who do not stutter.

*Educational objectives:* At the end of this activity the reader will be able to (a) summarize the nonword repetition data that have been published thus far with children and adults who stutter; (b) describe the subvocal rehearsal system, an aspect of the phonological working memory that is critical to nonword repetition accuracy; (c) employ an alternative means to explore the phonological working memory in adults who stutter, the phoneme elision task; and (d) discuss both phonological and motoric implications of deficits in the phonological working memory.



## 1. Introduction

Although the etiology of stuttering remains unknown, research suggests that young children who stutter may differ from their normally fluent peers in their ability to process phonological, lexical/semantic, and/or syntactic information (Anderson & Byrd, 2008; Anderson & Conture, 2004; Byrd, Conture, & Ohde, 2007; Hartfield & Conture, 2006; Ntourou, Conture, & Lipsey, 2011; Paden, Yairi, & Ambrose, 1999). Similar evidence exists in the adult literature, with the speech-language

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http://dx.doi.org/10.1016/j.jfludis.2012.03.003

processing systems of adults who stutter tending to be slower and/or less accurate than adults who do not stutter (Newman & Ratner, 2007; Sasisekaran, De Nil, Smyth, & Johnson, 2006; Weber-Fox, Spencer, Spruill, & Smith, 2004). Given that the speech-language processing system is closely linked to the person's ability to temporarily retain/maintain verbal information (i.e., phonological working memory) (Jacquemot & Scott, 2006; Montgomery, Magimairaj, & Finney, 2010), it is not surprising that children who stutter have been shown to perform more poorly than their peers on measures of non-word repetition (Anderson & Wagovich, 2010; Anderson, Wagovich, & Hall, 2006; Hakim & Ratner, 2004), a commonly used means of estimating phonological working memory skills (Dollaghan & Campbell, 1998; Gathercole & Baddeley, 1996; Gupta, 2003). However, the extent to which these differences in non-word repetition performance between children who do and do not stutter persist into adulthood is not clear, especially considering that phonological working memory capacity continues to increase with age (Fry & Hale, 1996; Gupta, 2003; Sasisekaran, Smith, Sadagopan, & Weber-Fox, 2010). Thus, we explored whether the phonological working memory skills, as measured using non-word repetition and phoneme elision tasks, of adults who stutter, like their younger counterparts, continue to differ from their fluent peers.

The phonological working memory system is comprised of a phonological store and a sub-vocal rehearsal system (Baddeley, 2003). The phonological store facilitates the ability to hold material to be remembered in a phonological code. This phonological code is vulnerable to decay over time, which is why the sub-vocal rehearsal system is needed. The sub-vocal rehearsal system is a silent verbal repetition process that refreshes the phonologically encoded material, allowing it to be preserved in memory for a longer period of time. As previously indicated, phonological working memory is commonly measured using non-word repetition tasks. Phonological working memory, however, is not the only process recruited in the repetition of novel word forms. Rather, the ability to repeat a non-word accurately also depends on a number of other auditory-perceptual, phonological, and motor planning operations (Coady & Evans, 2008; Gathercole, 2006). For upon hearing the non-word, the listener must encode the serial order of the sound segments, store and retrieve the segment sequence from memory, and then plan and execute the requisite movements for reproduction (Gupta & Tisdale, 2009; Shriberg, Lohmeier, Dollaghan, Green, & Moore, 2009).

Several researchers have found that children who stutter tend to be less successful than their normally-fluent peers in their ability to accurately repeat non-words, particularly when the non-words are 2–3 syllables in length (Aboul Oyoun, El Dessouky, Shohdi, & Fawzy, 2010; Anderson & Wagovich, 2010; Anderson et al., 2006; cf. Bakhtiar, Ali, & Sadegh, 2007; Hakim & Ratner, 2004[1]). Findings from these studies have largely been interpreted to suggest that children who stutter have weaknesses in phonological working memory relative to their typically developing peers. Although additional research is still warranted regarding the non-word repetition in children who stutter, our knowledge regarding the non-word repetition accuracy of adults who stutter is significantly more lacking.

Ludlow, Siren, and Zikria (1997) completed what appears to be one of the first preliminary investigations of the non-word repetition abilities of adults who stutter. Five adults who do and do not stutter repeated two 4-syllable non-words multiple times. As both groups repeated these two novel words, both groups improved in production accuracy. That is, both groups exhibited a practice effect. However, the degree of improvement differed. Adults who stutter did not appear to receive as much benefit from the practice, as their percentage of consonants correct was still lower than that of adults who do not stutter after each group completed multiple productions of the two novel words. The authors suggested this difference in practice effect lends support to the notion that adults who stutter have less efficient phonological encoding skills than adults who do not stutter.

Namasivayam and Van Lieshout (2008) also reported a difference in practice effects between adults who do and do not stutter when producing a non-word, but, in contrast to Ludlow et al. (1997), the difference they described was specific to movement stability (S.D. of inter-gestural relative phase) and strength of coordination patterns (inter-gestural mean coherence) (p. 46). They had five adults who do and do not stutter repeat one 2-syllable non-word multiple times at fast versus typical speech rates over a varied time period (1 day vs. $\geq$1 week). The variability in coordination of movements required to produce the non-word did not decrease in adults who stutter to the same degree as adults who do not stutter. In addition, the frequency coupling strength between the required articulatory movements did not increase in adults who stutter in the manner in which it did for adults who do not stutter. Results further revealed that the adults who stutter did not retain the same degree of integrity of the production over time as did the adults who do not stutter. Thus, the authors suggested that adults who stutter demonstrate unique difficulty in the motor learning of novel sound sequences.

More recently, Smith, Sadagopan, Walsh, and Weber-Fox (2010) had 17 adults who do and do not stutter complete a non-word repetition paradigm wherein they first had to produce 16 non-words, which vary from 1- to 4-syllables in length, from the Non-word Repetition Test (NRT; Dollaghan & Campbell, 1998). Recall that previous research with children who do and do not stutter has shown that the two groups differ at the 2- and 3-syllable length, but the 4-syllable length non-words tend to be equally taxing for both groups. In contrast, the adults who do and do not stutter in the Smith et al. study did not differ in production accuracy across the 1- to 4-syllable lengths; they were comparably accurate in their productions at each length.

Following the completion of the NRT, the adults in the Smith et al. study also had to repeat a new series of novel words, which were adapted from the NRT so as to include bilabial consonants varying in length (1- to 4-syllables) and phonological

[1] Bakhtiar et al. (2007) found no difference in the non-word repetition abilities of children who do and do not stutter. However, as was noted by Anderson and Wagovich (2010), the conflicting findings likely reflected the differences in complexity of the stimuli used across the studies.

complexity, embedded within a carrier phrase. The authors found that the accuracy with which the two groups of participants repeated the non-words in this task was similar, at least on a descriptive basis. However, the adults who stutter exhibited more inconsistency in articulatory coordination during the production of longer (i.e., 3- and 4-syllable length), more phonologically complex non-words compared to adults who do not stutter, which suggests, according to the authors, that there is a critical interplay between phonological encoding and motoric stability in the speech production of adults who stutter.

Although the findings from the non-word repetition studies that have been conducted with adults thus far are intriguing, these studies are not without limitations, particularly with respect to the behavioral findings. First, the majority of adults who participated in these studies were only mild or very mild in stuttering severity. Second, the NRT has been shown, in a meta-analysis of studies examining the non-word repetition performance of children with and without specific language impairment, to be among the least sensitive measures of non-word repetition (Estes, Evans, & Else-Quest, 2007). Third, the longest non-word employed across these studies was only 4-syllables in length. The likelihood that this syllable length is not sufficient to reveal behavioral differences in accuracy is highlighted by the fact that the participants' accuracy at this length is markedly high (cf. Sasisekaran et al., 2010). Fourth, the relatively low number of words that the participants were required to produce may have precluded the ability to identify variability in production abilities both within and between talker groups. Based on these limitations, it seems reasonable to suggest that had the participants in the past research studies been more severe in their stuttering and a more sensitive measure of non-word repetition been used, along with longer and a higher number of non-word stimuli, it would have been more likely that in addition to the practice effect differences, differences in production accuracy, if present, would have emerged between the two groups of speakers.

In the present study, we attempt to extend past research by employing a non-word repetition task consisting of 2-, 3-, 4- *and* 7-syllable non-words. Previous research has revealed that typically fluent adults are capable of repeating 7-syllable non-words (Gupta, 2003). The use of this longer length should ensure that the task is sufficiently challenging enough to allow for a potentially distinguishing demand on phonological working memory. Our non-word repetition task also differs from previous studies of adults who stutter in the amount and in the phonologically diversity of the non-word stimuli, which should further increase the possibility of finding meaningful differences between the two groups. In addition, the adults who stutter who participated in the present study demonstrated more variability in stuttering severity. We also controlled for comparable wordlikeness within and across all syllable lengths as research has demonstrated that non-words considered to be highly similar to real words tend to be significantly easier to repeat and also cannot be exclusively attributed to the functioning of the working memory (e.g., Gathercole, 1995). Finally, rather than only allowing one attempt at accuracy as has been the standard protocol in past research, we also allowed multiple attempts. With this additional analysis we were able to determine whether or not having the ability to practice the production would result in comparable performance in accuracy between the two groups even at more challenging production levels.

Further, although non-word repetition tasks appear to be able to differentiate between children who do and do not stutter, we recognize that this task alone may not be as effective in demonstrating differences in adults, especially given the advances in phonological working memory that occur with age (Fry & Hale, 1996; Gupta, 2003; Sasisekaran et al., 2010) and the recent findings by Smith et al. (2010). In other words, we were concerned that, despite the fact that we extended the number, length, and phonological diversity of the non-word stimuli and controlled for other potentially confounding variables, such as wordlikeness and phonotactic probability, there still might be significant ceiling effects on this task in adults. Therefore, in addition to the non-word repetition task, participants were also required to repeat the non-words without specific sounds in the non-word, a task that is commonly referred to as phoneme elision.

Phoneme elision involves the omission of one or more phonemes in the production of a word (Wagner, Torgesen, & Rashotte, 1999). In a phoneme elision task, the participant is asked to produce a word or non-word after a specific phoneme is removed. For example, in the case of a non-word, "Say fackton without the /f/." In this case the answer would be "ackton." The elimination of a phoneme from a non-word first requires that the person accurately encode the non-word in their working memory. To demonstrate the accurate encoding of the initial non-word, the person must first provide an overt production of that non-word prior to being instructed which phoneme to remove in the subsequent production. Thus, to produce the revised non-word, the person must be able to accurately verbally rehearse the initial non-word, and hold it in his/her memory long enough to allow for accurate segmentation and manipulation of that non-word, all within a timeframe that allows for accurate production of the revised non-word.

The phoneme elision task has been used in the literature by researchers who have wanted to explore the sophistication of the person's phonological working memory relative to the verbal rehearsal system, and to their segmentation abilities (Jones, Lucker, Zalewski, Brewer, & Drayna, 2009). However, to date, it has not been used with persons who stutter. Thus, results from the phoneme elision task will further enhance our understanding of the phonological working memory of adults who stutter as it will allow an additional opportunity to expose the on-line operational workings in a manner that, to these authors' knowledge, has not yet been explored in adults who stutter.

In summary, this study aims to examine the phonological working memory of adults who stutter as compared to adults who do not stutter through the use of non-word repetition and phoneme elision tasks. These tasks require the participant to encode verbal information in phonological working memory, separate and manipulate phonemic units, and articulate the same and/or a modified non-word. This information will contribute a more comprehensive account of the role of phonological working memory in the ability of adults who stutter to establish and maintain fluent speech production.

## 2. Method

### 2.1. Participants

To qualify for inclusion, participants had to meet the following criteria: (a) native English speaker ($n$ = 12 for the group of adults who stutter; $n$ = 13 for the group of adults who do not stutter) or, if exposed to another language in addition to English, an English speaker with native competency ($n$ = 2 for the group of adults who stutter; $n$ = 1 for the group of adults who do not stutter); (b) between the ages of 17 and 50 years old; (c) no speech or language disorders (with the exception of stuttering for the adults who stutter); and (d) no neurological, social, emotional, or psychiatric disturbances. Receptive and expressive vocabulary was assessed using the *Peabody Picture Vocabulary Test, Fourth Edition* (Dunn & Dunn, 2007) and the *Expressive Vocabulary Test-Second Edition* (Williams, 2007). We administered these tests to insure that: (1) there were no participants in either group who had receptive or expressive vocabulary skills that were below normal limits; and (2) we had a similar distribution of vocabulary performance between the two groups of participants (see Table 1). We did not administer a digit span task as we felt that data would be supplementary to the information we would gain from the participants' performance on the non-word repetition and the phoneme elision task. That is, any difference we may have seen in the digit span task would have been magnified in the non-word repetition and phoneme elision tasks.

One adult who does not stutter and two adults who stutter were excluded from participation because of failure to meet one or more of the aforementioned inclusion criteria. This resulted in twenty-eight adults who do ($n$ = 14; $M$ = 28 years; range = 17–44; $n$ = 2 females; $n$ = 12 males) and do not stutter ($n$ = 14; $M$ = 28 years; range = 20–46; $n$ = 2 females; $n$ = 12 males) who were age (± 3 years) and gender matched and who met the aforementioned criteria and, thus, participated in the present study.

Stuttering severity was determined from an audio and video recorded, 5-min conversational speech sample that occurred just prior to beginning the speech-language testing and experimental tasks. Severity ratings were assigned to each participant who stutters by the second author using a 9-point stuttering severity rating scale (i.e., 1 = no stuttering, 2 = very mild stuttering, 9 = extremely severe stuttering) that was developed by O'Brian, Packman, Onslow, and O'Brian (2004) and that has been used to describe severity (e.g., Byrd, Logan, & Gillam, 2012; Logan, Byrd, Mazzocchi, & Gillam, 2011; Sussman, Byrd, & Guitar, 2011). The mean rating for all 14 participants who stutter was 4.25 ($SD$ = 1.89), with 6 participants receiving ratings of 2 or 3 (which would correspond to relatively mild stuttering), 5 participants receiving ratings of 4, 5, or 6 (which would correspond to relatively moderate stuttering) and 3 participants receiving ratings of 7 or 8 (which would correspond to relatively severe stuttering). Interjudge reliability for the severity ratings was assessed by having a graduate student rate 7 of the 14 samples that had been rated previously by the second author. Overall, 5 of the 7 ratings were identical to the

**Table 1**
Participant characteristics for adults who do not stutter (AWNS) and adults who stutter (AWS).

| Participant | Age | Gender | Severity | PPVT-4 | EVT-2 |
|---|---|---|---|---|---|
| 1 | 27;6 | Male | N/A | 106 | 97 |
| 2 | 20;8 | Male | N/A | 117 | 114 |
| 3 | 21;9 | Female | N/A | 104 | 105 |
| 4 | 38;8 | Male | N/A | 107 | 101 |
| 5 | 27;0 | Male | N/A | 105 | 115 |
| 6 | 27;2 | Male | N/A | 128 | 113 |
| 7 | 20;5 | Male | N/A | 117 | 118 |
| 8 | 46;11 | Male | N/A | 110 | 120 |
| 9 | 27;9 | Male | N/A | 101 | 116 |
| 10 | 26;7 | Female | N/A | 106 | 114 |
| 11 | 21;1 | Male | N/A | 117 | 114 |
| 12 | 30;1 | Male | N/A | 112 | 122 |
| 13 | 39;11 | Male | N/A | 99 | 91 |
| 14 | 23;2 | Male | N/A | 117 | 113 |
| 15 | 20;5 | Male | VML | 114 | 120 |
| 16 | 38;6 | Male | ML | 101 | 100 |
| 17 | 44;6 | Male | VML | 106 | 116 |
| 18 | 23;7 | Female | SV | 140 | 129 |
| 19 | 40;4 | Male | ML-MOD | 107 | 106 |
| 20 | 24;3 | Female | SV | 106 | 97 |
| 21 | 28;7 | Male | MOD-SV | 115 | 97 |
| 22 | 24;1 | Male | ML | 122 | 116 |
| 23 | 18;1 | Male | MOD-SV | 120 | 134 |
| 24 | 27;1 | Male | ML-MOD | 124 | 125 |
| 25 | 21;3 | Male | ML-MOD | 107 | 111 |
| 26 | 33;3 | Male | ML | 108 | 105 |
| 27 | 39;0 | Male | VML | 112 | 118 |
| 28 | 17;9 | Male | MOD-SV | 111 | 77 |

*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). Severity: VM = very mild, ML = mild, MOD = moderate, SV = severe.

original ratings, and the remaining two ratings were within 1 scale point of the original ratings that were performed by the second author. In addition to this rating scale, the participant's conversational sample ($N = 300$ words) was analyzed by the first author using the more commonly used measure of stuttering severity, Stuttering Severity Instrument-3 (Riley, 1994). The severity rating results using this tool replicated the findings reported with the 9-point scale above with the exception of one of the participants who was rated as "mild-moderate" receiving a score of "mild" on the SSI-3.

General details about treatment history were available for all adults who stutter. Ten of the fourteen adults who stutter had reportedly received speech therapy for stuttering. The authors chose not to exclude adults on the basis of treatment history for two key reasons (see Byrd et al., 2012; Logan et al., 2011 for a similar argument regarding including children who stutter who had history of treatment). First, there was no reason to suspect that exposure to fluency therapy would differentially affect individual adult's performance on the tasks employed in the study. Second, it is not uncommon for adults who stutter to report participation in fluency therapy particularly during the school years; thus, inclusion of adults who had participated in therapy adds to the ecological validity of this study.

Approval for the completion of this study was provided by the first author's university Institutional Review Board and informed consent was obtained for each participant. Participant characteristics and performance on standardized test measures are summarized in Table 1.

### 2.2. Stimuli development

#### 2.2.1. Non-word stimuli

A total of 48 non-words consisting of an equal number ($n = 12$ for each syllable length) of 2-, 3-, 4-, and 7-syllable non-words were selected for use in the present study. Thirty-six of the 48 non-words were selected from among the Gupta (2003) non-word stimuli, as were 12 of the 48 non-words from Dollaghan and Campbell (1998). All of the consonant clusters in the non-words from the Gupta study were reduced to singletons. The 3-syllable non-words were created by either reducing the 7-syllable non-words provided by Gutpa or by combining the 2-syllable non-words provided with an additional syllable from one of the other non-words of varying lengths provided by Gupta (2003) (see Table 2 for a complete listing of the stimuli used in the present study).

Non-words were 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 1.217 for the 2-syllable non-words, 1.293 for the 3-syllable non-words, 1.437 for the 4-syllable non-words, and 1.676 for the 7-syllable non-words. The mean sum of the biphone probabilities was 1.009 for the 2-syllable non-words, 1.021 for the 3-syllable non-words, 1.024 for the 4-syllable non-words, and 1.029 for the 7-syllable non-words. Thus, the segmental and biphone sums for all syllable length categories were low in phonotactic probability.

The non-words were also controlled for real wordlikeness. Twenty adults rated the non-words according to the word-likeness scale used by Gathercole (1995). Participants were instructed to rate the spoken non-word on a 5-point scale with 1

**Table 2**
Non-word repetition task stimuli with the phoneme elision task in parentheses.

| Two syllable words | Three syllable words |
|---|---|
| 1. KEN.TAID (without the /k/) | 1. KAF.TOG.ROP (without the /k/) |
| 2. SUP.WIG (without the /w/) | 2. SIK.AN.THOD (without the "th") |
| 3. AF.TYSS (without the /s/) | 3. AM.BER.ILL (without the /b/) |
| 4. FACK.TON (without the /f/) | 4. FO.VIL.AN (without the /n/) |
| 5. GEIN.CHER (without the "ch") | 5. GINS.TA.BUL (without the /g/) |
| 6. HEEL.ON (without the /n/) | 6. HES.TO.MEE (without the /t/) |
| 7. JOM.BINN (without the "j") | 7. INK.IS.TA (without the /t/) |
| 8. IS.TUM (without the /t/) | 8. JELL.AN.TIF (without the /f/) |
| 9. TAY.VAUK (without the /k/) | 9. CHEE.NOY.TOWB (without the "ch") |
| 10. NOI.TOWF (without the /n/) | 10. NY.CHO.VAYB (without the "ch") |
| 11. CHO.VAG (without the /v/) | 11. DOY.TOW.VAB (without the /v/) |
| 12. VA.CHAYP (without the /p/) | 12. TAY.VOI.CHYG (without the /g/) |
| **Four syllable words** | **Seven syllable words** |
| 1. JIG.VEN.TO.XILE (without the "j") | 1. ZOO.BEN.IF.FER.AL.TO.PINE (without the /z/) |
| 2. CAS.TI.PAIL.TY (without the /p/) | 2. VAM.PON.TIG.EEZ.I.TRI.CAY (without the /k/) |
| 3. AN.TIS.KOL.DATE (without the /k/) | 3. AS.KEN.I.DO.BIS.KU.LATE (without the /d/) |
| 4. DIG.AN.TUL.IN (without the /d/) | 4. DAY.BISH.OCK.SIN.ALL.O.BIT (without the "sh") |
| 5. FIN.RAP.TO.KING (without the /k/) | 5. FO.MMI.GA.VE.LON.TI.PAN (without the /l/) |
| 6. GUN.DOC.TIP.EEL (without the /d/) | 6. GIS.TOR.AK.I.DO.PU.LIN (without the /n/) |
| 7. HISS.Y.DO.GENE (without the /h/) | 7. HUN.DI.NO.TER.AL.I.TY (without the /h/) |
| 8. IM.LAC.SO.DOCK (without the /s/) | 8. IN.FAS.KO.VI.JI.DE.ENT (without the /t/) |
| 9. VAY.TAW.CHI.DOYP (without the /d/) | 9. JED.A.BUL.OS.KER.A.MIC (without the /b/) |
| 10. DA.VON.OY.CHIG (without the /g/) | 10. KA.DDEN.I.SO.NO.MA.CY (without the /d/) |
| 11. NY.CHOY.TOW.VUB (without the "ch") | 11. SA.CON.IM.BEN.A.LO.PY (without the /l/) |
| 12. TAV.A.CHEE.NYG (without the /g/) | 12. UM.PICK.ERR.ANN.I.TI.ZER (without the /z/) |

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 non-word's sound pattern could exist in the English language. The mean wordlikeness rating was 2.718 for the 2-syllable non-words, 2.442 for the 3-syllable non-words, 2.474 for the 4-syllable non-words, and 2.833 for the 7-syllable non-words. Thus, similar to the phonotactic probability, all words were comparable in their rating of wordlikeness, ranging from "very unlike a real word" to "unlike a real word."

The non-words were further controlled by ensuring that the phonemic onsets and offsets of the stimuli were consistent across all syllable lengths. Two of the 12 non-words at the 2-, 3- and 4-syllable length had a vowel onset and 3 of the 12 non-words at the 7-syllable length had vowel onsets. Three to six non-words at each syllable length began with a stop consonant. Three to five non-words were fricative initiated at each syllable length. Affricate onsets ranged from one to two per syllable length. Regarding offset consistency, for each syllable length, seven to nine of the non-words ended with a stop consonant, one to two ended in a liquid or glide, and one to four ended in a vowel. In addition, a fricative offset occurred on two non-words at the 2-syllable length and one non-word at the 3-syllable length. Finally, the recorded production of the non-words was also controlled for prosodic variation. Stress was placed on the first syllable of each non-word across all syllable lengths.

#### 2.2.2. Phoneme elision stimuli

As was previously described, phoneme elision requires that a person repeat a word or non-word with a sound or phoneme missing (Wagner et al., 1999). The target non-words for the phoneme elision task were created by requiring the participant to alternately delete the initial consonant sound from the first syllable, the initial consonant sound from the second through seventh syllables, and the final consonant sound in the same non-words that were used for the non-word repetition task. The end result was that the participant would have to eliminate an initial phoneme at each syllable boundary across all lengths from the beginning to the end of the shortest to the longest non-words. Thus, elision was based on location, not on phonological property. For example, the initial consonant phoneme elision task for the first syllable of the 2-syllable length non-words would include the person having to "say fackton without saying /f/" with the accurate production being "ackton." The initial consonant phoneme elision task from the second syllable for the two-syllable non-word lengths would then be, for example for the participant to say "say kentaid without saying /t/," resulting in the production of "kenaid." Finally, to complete all potential loci for the phoneme elision task at the 2-syllable length category, the participants would then be asked, for example, to say, "supwig" without the /g/" and then the cycle of loci for the eliminated phoneme would repeat itself until all potential locations were covered at least twice across the syllable lengths. For example, for the 2-syllable length non-words the loci of elimination of first, second, last could be completed 4 times but at the 7-syllable length wherein there 8 potential locations for elimination, the majority of those loci could only be cycled through one time. A complete list of the stimuli used in the phoneme elision tasks is included in Table 2.

### 2.3. Stimuli recording and presentation

A female native speaker of Standard American English recorded the non-word and phoneme elision stimuli on a Dell computer using Computerized Speech Lab equipment in a sound treated room. The microphone was placed approximately one and a half feet from the speaker. For the non-word repetition task, the carrier phrase, "Say ___" was used for each non-word. For example, "Say 'fackton'. For the phoneme elision task, the carrier phrase, "Say ____ without saying /__/" was used for each non-word. For example, say 'fackton' without saying /f/."

Stimuli presentation order for each syllable length was randomized using Microsoft Excel. Intelligibility of the recorded non-words was verified by an undergraduate speech-language pathology student who listened to and phonetically transcribed the non-words. The undergraduate's transcriptions were compared to the first and second author's transcriptions of the non-words and no discrepancies were found.

### 2.4. Pilot study

Six adults who do not stutter and one adult who stutters (ages 20–50) completed a pilot study before the 28 participants completed the experimental tasks. (None of the six participants used in the pilot study were participants in the experimental study.) The pilot study allowed us to test the quality of the recordings of the instructions for production of each of the non-words at each length for both the non-word and the phonemes elision task. This pilot investigation also helped us to determine the number of presentations participants needed in order to accurately repeat a given non-word (see Section 2.5) as in order to be able to eliminate the phoneme you must first demonstrate that you can produce the target word in its entirety (Wagner et al., 1999).

After administering the experiment to one adult who stutters and four adults who do not stutter, consistent errors on fricatives were noted by the examiners (first and second authors); that is, these participants had difficulty correctly identifying the recordings of the non-words that included fricatives. The second author re-recorded the stimuli using the same Dell computer and CSL software, with the microphone placed approximately 6 in. from her mouth. Administration of the re-recorded stimuli yielded accurate fricative discrimination among the same pilot group as well as from the additional two adults who do not stutter who had not yet completed the pilot study prior to this change in stimuli. In addition, the six adults who do not stutter accurately repeated non-words at all syllable lengths in four or fewer attempts. In contrast, the adult who stutters required a maximum of five attempts to accurately repeat the non-words. Based on these pilot data, all participants were allowed a maximum of six attempts to listen to and attempt to produce each of the non-words during the non-word repetition task and the data analysis for this task was based on the mean number of attempts rather than only allowing one attempt to produce the target non-word. This procedure was employed so as to insure that the task requirements were not unfairly biased to one group and also to allow for optimal potential for each participant to be able to complete both the non-word task and the phoneme elision task (see Section 2.5).

### 2.5. Experiment

The non-word repetition and phoneme elision tasks were completed in a quiet room. The participants listened to the recorded stimuli through Optimus speakers on a Dell computer. The following directions were read to the participants prior to beginning the experiment: “I want you to listen to some made-up words. After you hear each made-up word, please repeat it as clearly as you can. Even if the word is hard to say, give it your best try. After you finish repeating the word, you will then be asked to repeat it with one of the sounds in the word missing. Listen carefully to the recordings. Are you ready to begin?” Before beginning the experimental tasks, the adults completed two practice sets: one practice set for the non-word repetition task and one for the phoneme elision task. In each practice set, participants were presented with a non-word at each syllable length. Participant responses were recorded by hand and also with an Olympus digital voice recorder.

Participants were given a maximum of six attempts to listen to and accurately repeat the non-word before advancing to the phoneme elision task. We had the participant first produce the non-word in its entirety prior to having them eliminate one of the phonemes in the production as this is the standard protocol for completion of phoneme elision (Wagner et al., 1999). Once the participant repeated the non-word correctly or after the participant had listened and incorrectly produced the non-word six times, the phoneme elision task was administered. We moved forward with the phoneme elision task whether the participant produced the non-word correctly or not as we did not want the participants to be able to determine and potentially become discouraged by the (in)accuracy of their performance in the non-word task. However, the phoneme elision data included in the final data corpus only consisted of non-words for which the participant was able to accurately produce the non-word prior to completing the phoneme elision task. In addition, unlike the non-word repetition task, the phoneme elision task was administered only once. Completion of the non-word repetition and phoneme elision task took approximately 45 minutes to an hour.

### 2.6. Coding

The participant’s responses to the non-word repetition and phoneme elision tasks were scored as either correct or incorrect. If the response was incorrect, a phonetic transcription of the response was recorded. The incorrect responses of each participant that were recorded online during the experiment by hand were verified via review of the audio file to ensure accuracy in transcription.

### 2.7. Reliability

Reliability was analyzed relative to the scoring of the response as disfluent or fluent, and accurate or inaccurate for both the non-word repetition task and the phoneme elision task. Reliability was also analyzed for the number of attempts required for accurate production for the non-word repetition task. A graduate student trained in the identification of disfluent speech listened to 30% of each participant’s audio-recorded responses in both the non-word and the phoneme elision task and recorded the fluency and accuracy of those responses. The graduate student’s identification of the fluency of productions matched the second author’s ratings of fluency 100% of the time for both the non-word repetition and the phoneme elision task. The graduate student’s identification of accurate responses matched 99% of the second author’s responses in the non-word repetition task and 93% of the author’s responses in the phoneme elision task. The same graduate student also identified the number of attempts required to accurately produce each non-word with her recording of attempts being consistent with 100% of the second author’s recordings.

## 3. Results

To review, the purpose of the present study was to explore the phonological working memory of adults who do and do not stutter using two experimental tasks. First, the participants had to repeat a set of 12 non-words across four syllable lengths (2-, 3-, 4-, and 7-syllables) ($N = 48$ total non-words). Second, the participant repeated the same set of non-words at each syllable length, but with a designated sound eliminated (phoneme elision). We were interested in comparing the ability of adults who stutter versus adults who do not stutter to accurately produce non-words of varying syllable lengths and their ability to accurately produce these non-words with a phoneme eliminated. Thus, we included all accurate responses, regardless of whether they were fluent or not, in the final data corpora.

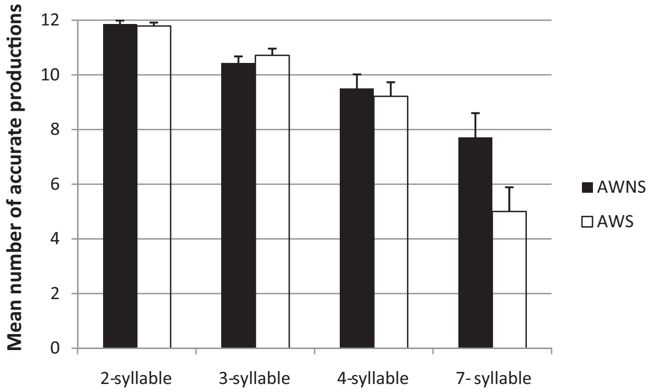


**Fig. 1.** The mean number of accurate productions on the first attempt to produce the non-word at each syllable length for adults who do not (AWNS) and adults who stutter (AWS).

### 3.1. Non-word repetition task

Recall that participants were allowed a maximum of six opportunities to listen to and attempt to produce the non-word repetition accurately. Therefore, we analyzed the production accuracy relative to the first attempt at producing the non-word and also the mean number of production attempts required to accurately produce the non-word.

#### 3.1.1. Accuracy of initial production attempt

A Repeated Measures ANOVA with the between-subjects factor of Group (adults who stutter vs. adults who do not stutter) and a within-subjects factor of Syllable Length (2-, 3-, 4-, and 7-syllables), was conducted. The dependent variable was the mean number of accurate initial productions (i.e., first attempt) of the non-word. Results revealed a main effect for Syllable Length $F(3,78) = 54.011$, $p \leq .0001$, partial $\eta^2 = .675$. There was not a significant between-subjects difference $F(1,26) = 1.843$, $p = .186$, partial $\eta^2 = .066$. However, there was a significant interaction between Group and Syllable Length $F(3,78) = 4.598$, $p = .005$, partial $\eta^2 = .150$ (see Fig. 1).

A decomposition of the interaction between Group and Syllable Length using an independent samples *t*-test revealed a significant difference between the adults who stutter versus the adults who do not stutter at the 7-syllable length; no differences were noted at the 2-syllable, or 4-syllable lengths. The mean number of accurate productions of the non-word on the first attempt was significantly higher for the adults who do not stutter than the adults who stutter at the 7-syllable length.

#### 3.1.2. Mean number of production attempts

A Repeated Measures ANOVA, with the between-subjects factor of Group (adults who stutter vs. adults who do not stutter) and a within-subjects factor of Syllable Length (2-, 3-, 4-, and 7-syllables), was conducted. The dependent variable was the mean number of production attempts at each syllable length required for accurate production. There was a significant main effect for Syllable Length, $F(3,78) = 28.715$, $p \leq .0001$, partial $\eta^2 = .525$. In addition, there was a significant interaction between Syllable Length and Group, $F(3,78) = 3.993$, $p = .011$, partial $\eta^2 = .133$. There was no between-subjects effect for Group $F(1,26) = 3.009$, $p = .095$, partial $\eta^2 = .104$ (see Fig. 2).

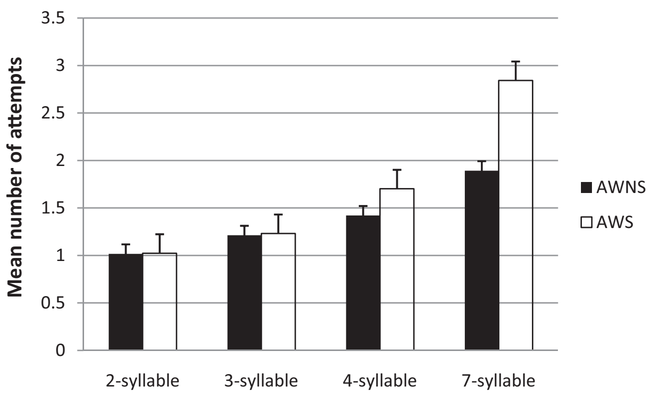


**Fig. 2.** The mean number of attempts (out of six possible per target non-word) needed to accurately produce the non-words at each syllable length for adults who do not stutter (AWNS) and adults who stutter (AWS).

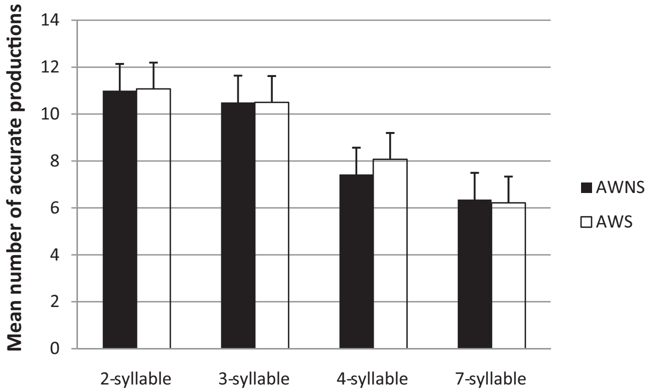


**Fig. 3.** The mean number of accurate productions of the non-word with the target phoneme eliminated at each syllable length for adults who do not (AWNS) and adults who stutter (AWS) when the participant only needed one attempt to produce the non-word accurately prior to completing the phoneme elision task.

A decomposition of the interaction between Group and Syllable Length using an independent samples *t*-test revealed a significant difference between the adults who stutter versus the adults who do not stutter at the 7-syllable length; no differences were noted at the 2-syllable, 3-syllable, or 4-syllable lengths. The mean number of attempts needed to accurately produce the non-word was significantly higher for the adults who stutter than the adults who do not stutter at the 7-syllable length.

### 3.2. Phoneme elision task

Although the participants were only provided one attempt to complete the phoneme elision task, they were allowed six attempts to produce non-word accurately. Thus, some participants were exposed to the non-word multiple times (up to 6) prior to then being asked to produce the non-word with a specified phoneme excluded. Recall that for the phoneme elision productions to be included in the final data corpus, the participant had to have demonstrated accurate production of the non-word prior to the production of the non-word with the target phoneme eliminated. Therefore, we completed our analysis in two ways. We analyzed the accuracy of phoneme elision productions when the participant only needed one attempt to accurately produce the non-word. We also examined the accuracy of phoneme elision productions when the person needed more than one attempt to produce the non-word accurately.

#### 3.2.1. Accuracy when only one attempt needed to produce non-word

A Repeated Measures ANOVA, with the between-subjects factor of Group (adults who stutter vs. adults who do not stutter) and a within-subjects factor of Syllable Length (2-, 3-, 4-, and 7-syllables), was conducted. The dependent measure was the mean number of correct productions of the non-word with the target phoneme eliminated that were produced by the participant when he or she only needed one attempt to accurately produce the non-word prior to completing the phoneme elision task. Results revealed a main effect for Syllable Length $F(3,78) = 101.983$, $p \leq .0001$, partial $\eta^2 = .797$. However, there was not a significant between-subjects difference $F(1,26) = 0.029$, $p = .867$, partial $\eta^2 = .001$. In addition, there was not a significant interaction between Group and Syllable Length $F(3,78) = 1.723$, $p = .169$, partial $\eta^2 = .062$ (see Fig. 3).

#### 3.2.2. Accuracy when multiple attempts needed to produce non-word

A Repeated Measures ANOVA, with the between-subjects factor of Group (adults who stutter vs. adults who do not stutter) and a within-subjects factor of Syllable Length (2-, 3-, 4-, and 7-syllables), was conducted. Participants were only given one attempt to successfully complete the phoneme elision task. For this reason, we calculated the total number of accurate responses, with the maximum number of 12 per syllable length per participant. The resultant dependent variable was the mean number of accurate responses at each syllable length. Results revealed a significant main effect for Syllable Length $F(3,78) = 60.464$, $p < .0001$, partial $\eta^2 = .699$, but no between-subjects effect for Group $F(1,26) = 0.001$, $p = .973$, partial $\eta^2 = .000$. There also was no significant interaction between Group and Syllable Length $F(3,78) = 0.078$, $p = .782$, partial $\eta^2 = .003$ (see Fig. 4).

## 4. Discussion

In contrast to previous findings with children who do and do not stutter, findings from the present study demonstrate that adults who do and do not stutter produce 2-, 3- and 4-syllable length non-words with comparable accuracy. However, at the 7-syllable length, adults who stutter had significantly more difficulty producing accurate responses than adults who do not stutter. These preliminary findings suggest that when examining the non-word repetition performance of adults

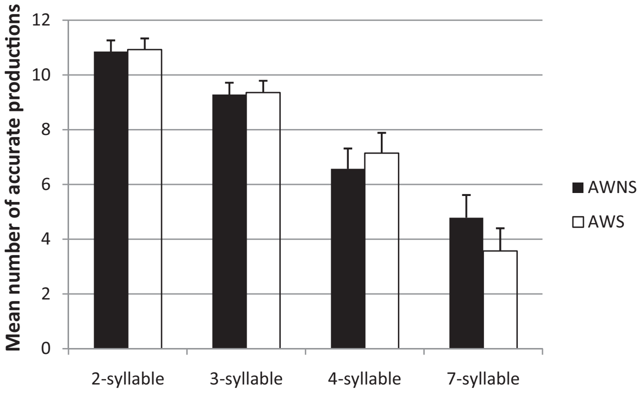


**Fig. 4.** The mean number of accurate productions of the non-word with the target phoneme eliminated at each syllable length for adults who do not (AWNS) and adults who stutter (AWS) when the participant required multiple production attempts to produce the non-word accurately prior to completing the phoneme elision task.

who do and do not stutter, non-words that are 7 or more syllables in length may be needed to differentiate the two groups, whereas in children who stutter it appears that the 2–3 syllable length non-words are the key differentiating lengths. Data from the present study also indicate that the phoneme elision of non-words at least in the way in which it was examined in the present study is similarly challenging for both talker groups across all syllable lengths.

### *4.1. Non-word repetition task*

The non-words used in the present study were controlled at each syllable length for segmental phonotactic probability, biphone phonotactic probability, phonemic onset, and wordlikeness. Thus, the main difference across syllable lengths was the length of the non-words. Both adults who do not stutter and the adults who stutter decreased in accuracy as the length increased. They exhibited comparable accuracy at the 2-, 3-, and 4-syllable word lengths. However, the non-word comprised of 7-syllables, the longest length, proved to be significantly more difficult for the adults who stutter. The adults who stutter produced significantly fewer accurate productions on their initial attempt to produce 7-syllable non-words and they also required significantly more attempts to produce non-words of this length accurately than the adults who do not stutter. These findings lend support to the notion that the phonological working memory may be a source of difficulty for adults who stutter.

For persons who do not stutter, research suggests that there is more time for rehearsal when producing shorter words. Specifically, there is more opportunity for multiple covert productions which in turn increases the likelihood of recall accuracy (Baddeley, Chincotta, Stafford, & Turk, 2002). Thus, it is expected that words of longer lengths would be produced with less accuracy. However, present data indicate that the degree to which recall accuracy is affected by length is greater in adults who stutter than adults who do not stutter suggesting that the subvocal rehearsal system of adults who stutter is not as efficient at retaining the integrity of the auditory input; a suggestion regarding the subvocal rehearsal system for which there is additional support in the literature (Bosshardt, 1990; Ludlow et al., 1997).

The difference in the number of attempts needed to be able to produce the non-word accurately reflect the findings that suggest the repeated exposure to the auditory presentation of the word as well as repeated attempts at production is distinctively more beneficial for adults who do not stutter than adults who stutter (Ludlow et al., 1997; Namasivayam & Van Lieshout, 2008; Smith et al., 2010). Nevertheless, it still remains unclear how this difference(s) in phonological working memory contributes to stuttered speech (see Bajaj, 2007 for discussion). Although non-word repetition clearly places a premium on storage and retrieval abilities, factors associated with auditory-perceptual, phonological, and motor planning processes also influence the quality of phonological representations in short-term memory (Gathercole, 2006). Thus, the precise source of difficulty for adults who stutter in their ability to accurately repeat novel words is still less than clear, and warrants further investigation. What is, perhaps, more clear is that if we had employed a non-word repetition task *that did not extend beyond 4-syllables*, as did previous researchers, then we may have deduced that the ability of adults who stutter to produce non-words is comparable between the two groups, which they are not—at least at the longer syllable lengths.

Further, to plan and execute the correct articulatory movements for the target non-word, the person has to be able to accurately encode and repeat the word enough times such that the representation is maintained long enough to allow for accurate programming. However, the factors that influence the integrity of the phonological representation cannot be limited exclusively to the phonological encoding of the auditory input. That is, while it may be true that phonological information that is presented in an auditory manner is subject to a more rapid rate of decay in persons who stutter, it is also possible that a temporal instability in motor programming is occurring to such a degree that the resultant program is faulty and the subsequent recall is inaccurate. In fact, there are data to suggest that the act of subvocal rehearsal does indeed involve/require motor processing (Wilson, 2001). Additionally, the findings by Namasivayam and Van Lieshout (2008) and Smith et al. (2010) indicate that there are significant differences in the motor movement of adults who stutter during non-word repetition tasks.

Smith et al. (2010) found that though the accuracy of non-words of 1- to 4-syllable lengths were comparable between adults who do and do not stutter, motor coordination was still less stable in adults who stutter than adults who do not stutter when producing non-words of increasing length and motoric complexity. Similarly, Namasivayam and Van Lieshout (2008) found that the variability in coordination of movements required to produce the non-word did not decrease with multiple productions in the same manner in which it did for adults who do not stutter. We see from the present study that it takes significantly more attempts for the adults who stutter to produce the 7-syllable non-words and, thus, it would be of interest to examine motoric factors such as lip aperture variability, and coordination of movement variability across responses to determine if adults who stutter are more variable across responses rather than showing the consistency in stability that would be expected of adults. However, again, given that other auditory-perceptual and long-term lexical/sublexical knowledge processes also impact the ability to accurately repeat non-words, these factors should be examined as well to determine why adults who stutter have difficulty repeating non-words.

### 4.2. Phoneme elision task

Words of increased syllable lengths appeared to be comparably challenging for both adults who stutter and adults who do not stutter to manipulate and re-produce with a specific phoneme deleted. This comparable challenge was demonstrated when the participant only required one attempt to produce the non-word accurately and also when the participant required multiple attempts prior to completing the phoneme elision task.

To review, the phoneme elision task was significantly more cognitively demanding than the non-word repetition task in that the participant had to hold the initial, complete non-word in memory and then had to internally manipulate the phonemes, and hold the manipulated production in memory long enough to insure accurate programming and production. Considering the word length effect in subvocal rehearsal (Baddeley et al., 2002) it is not too surprising that this task proved to be difficult for both groups. However, we still presumed that if the phonological working memory of persons who stutter was less efficient then, with this more challenging task, the persons who stutter would have been out-performed by the persons who do not stutter. But, they, in fact, were not. Although we concede that it is entirely possible that the phoneme elision task was simply equally taxing for both groups of participants, there are a few methodological factors that need to be considered when interpreting these null findings.

First, recall that participants had only one attempt to repeat the non-word with a missing phoneme but they were provided with more than one attempt to produce the non-word (prior to phoneme elision) accurately. Although this procedure is consistent with other standardized phoneme elision tests, such as the Comprehensive Test of Phonological Processes (CTOPP; Wagner et al., 1999), one could argue that if we had allowed multiple attempts at production of the word with the target phoneme eliminated, we may have been more likely to see differences between the two groups.

One could also argue that having the experience producing the non-word prior to the phoneme elision task was facilitating to both groups. That is, if we had not followed the standard protocol for phoneme elision and had simply asked the participants to for example, "Say fackton without the /t/" without having them first complete the non-word production of the entire word, then this may have been uniquely challenging for the persons who stutter as it would have further increased the cognitive demand required to produce the target (Bosshardt, 2006).

On the other hand, it is also possible that having the opportunity to say the non-word prior to eliminating the phoneme may have been inhibitory as they may have had traces of the full non-words in memory. Future research employing the phoneme elision task should consider allowing multiple attempts at producing the non-word with the target phoneme eliminated and should also consider requiring that the participant produce the non-word with the phoneme eliminated without first being given the opportunity to produce the non-word in its entirety.

Another consideration that may have precluded the ability to find group differences was in the present study we only had the participants delete individual phonemes across syllable lengths. We may have been more likely to detect differences if we had varied the phoneme elision task such that we were able to examine performance differences relative to the amount of acoustic phonetic information that the participants were required to delete (i.e., entire syllables versus individual phonemes across syllable lengths). For example, say fackton with without "fack" versus say "fackton" without "f". Such a task would extend the findings of Sasisekaran et al. (2010) regarding the difficulties adults who stutter have in their ability to monitor target phonemes. These findings would also provide insight into whether adults who stutter are similar to children who stutter in the tendency to encode at a more holistic as opposed to incremental level (Byrd et al., 2007).

## 5. Conclusion

Adults who stutter were significantly less accurate in their first attempt at producing 7-syllable non-words and also required a significantly higher mean number of attempts to accurately produce the 7-syllable non-words than the adults who do not stutter. Thus, for adults who stutter, differences in phonological working memory may not appear until the system is sufficiently challenged at a longer syllable length. In contrast to the non-word repetition task, the phoneme elision task failed to demonstrate performance differences between the two groups. This lack of distinction may be related to methodological issues including but not limited to only having had one attempt at production prior to production of the unmodified novel word, and the amount of acoustic information required for deletion. Thus, although these preliminary findings indicate that adults who stutter demonstrate differences in their non-word repetition abilities, additional research is warranted to further enhance our understanding of the contribution of the phonological working memory to the difficulty adults who stutter have in establishing/maintaining fluent speech production.

**CONTINUING EDUCATION**

QUESTIONS

1. Which of the following is an accurate statement regarding the nonword repetition abilities of children who stutter?
   a. Children who stutter are able to produce phonologically similar nonwords with greater accuracy than children who do not stutter.
   b. Children who stutter demonstrate lower recall accuracy of nonwords of increasing lengths than children who do not stutter.
   c. Children who stutter demonstrate comparable recall accuracy of nonwords of increasing lengths as children who do not stutter.
   d. Although children who stutter demonstrate comparable recall accuracy of nonwords of increasing lengths, they demonstrate more temporal instability than children who do not stutter.
   e. Children who stutter are able to produce phonologically similar nonwords with comparable accuracy to children who do not stutter.
2. Which of the following aspects of the phonological working memory appears to be a unique contributor to recall accuracy of novel words?
   a. The subvocal rehearsal system.
   b. The episodic buffer.
   c. The articulatory buffer.
   d. The visual spatial system.
   e. The syllabary.
3. Which the following provides an accurate example of a phoneme elision task?
   a. Instruct client to produce a real or nonword that begins with a fricative sound.
   b. Instruct client to produce a nonword immediately following auditory exposure to the nonword.
   c. Instruct client to produce a word that rhymes with the target word.
   d. Instruct client to produce a word that begins with the same sound as the target word.
   e. Instruct client to produce the target word with one of the phonemes in that target word deleted from the production.
4. Results from the present study demonstrated which of the following for the nonword repetition task?
   a. Adults who stutter are able to produce nonwords of increased lengths with comparable accuracy as adults who do not stutter.
   b. Adults who stutter are able to produce nonwords of increased lengths with greater accuracy than adults who do not stutter.
   c. The recall accuracy of adults who stutter is lower than adults who do not stutter in 7-syllable length words.
   d. The recall accuracy of adults who stutter is lower for nonwords of all syllable lengths.
   e. The recall accuracy of adults who stutter is higher than adults who do not stutter in 7-syllable length words.
5. Results from the present study demonstrated which of the following for the phoneme elision task?
   a. Performance was comparable between the adults who stutter and the adults who do not stutter.
   b. The phoneme elision task appeared to be equally challenging.
   c. The manner in which the phoneme elision task was completed may have compromised the results.
   d. Both the adults who stutter and adults who do not stutter had difficult completing the phoneme elision task on nonwords of increased length.
   e. All of the above.

**Acknowledgments**

This research was funded in part by the Grant F32 DC006755-01 (Phonological Encoding of Children who Stutter) from the National Institutes of Health (NIH). We would like to thank Elizabeth Hampton, M.S., CCC-SLP, who assisted us with the recruitment and testing of participants as well as the graduate students who assisted with the testing, transcription and data coding process. We would also like to thank Dr. Michael Mahometa for his assistance with the statistical analyses. Most of all, we would like to thank the adults who do and do not stutter who were willing to give their time to participate in this study and help us to further our knowledge of the underlying nature of stuttering.

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