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**Phonological Memory in Young Children Who Stutter**

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Highlights

- Inconsistent nonword repetition performance reported in the literature for CWS.
- Several factors can influence performance on nonword repetition tasks.
- Groups were carefully matched on language, sex, and SES.
- CWS performed significantly less well on nonword repetition tasks than CWNS.

Abstract

This study investigated phonological memory in 5- and 6-year old children who stutter. Participants were 11 children who stutter matched on general language abilities, maternal education level, and sex to 11 typically fluent children. Participants completed norm-referenced nonword repetition and digit span tasks, as well as measures of expressive and receptive vocabulary and articulation. The nonword repetition task included stimuli that ranged from 1 to 7 syllables, while the digit naming task contained number strings containing 2 to 10 digits. Standardized tests of vocabulary and articulation abilities were tested as well. Groups were comparable on measures expressive vocabulary, receptive vocabulary, and articulation. Despite the fact that the majority of participants scored within typical limits, young children who stutter still performed significantly less well than children who do not stutter on the nonword repetition task. No between-group differences were revealed in the digit naming task. Typically fluent children demonstrated strong correlations between phonological memory tasks and language measures, while children who stutter did not. These findings indicate that young children who stutter may have sub-clinical differences in nonword repetition.

Keywords: *phonological encoding; stuttering; phonological memory; nonword repetition*

# 1.0 Introduction

## *1.1 Phonological memory and phonological encoding*

Several theories implicate motoric, temperamental, and linguistic differences that may contribute to the disruption of the forward flow of speech in stuttering (Bloodstein & Bernstein Ratner, 2008). In particular, theories involving psycholinguistic abilities suggest that a breakdown or delay may occur during the process of *phonological encoding*, or the retrieval and construction of the phonological segments of words. According to these theories, breakdowns or delays at the level of phonological encoding may then result in disfluent speech (Howell & Au-Yeung, 2002; Perkins, Kent, & Curlee, 1991; Postma & Kolk, 1993). Many researchers propose that the construction of phonological segments during phonological encoding requires the use of *phonological memory*, or the ability to maintain phonological and auditory information for short-term retrieval while the entirety of the phonological code is constructed (Acheson & MacDonald, 2009; Alt & Plante, 2006; Bajaj, 2007; Haberlandt, Thomas, Lawrence, & Krohn, 2005). Several authors have also suggested that phonological memory abilities are lower in young children who stutter than in young children who do not stutter (Anderson & Wagovich, 2010; Anderson, Wagovich, & Hall, 2006; Spencer & Weber-Fox, 2014), although the findings are inconsistent (Bakhtiar, Ali, & Sadegh, 2007; Smith, Goffman, Sasisekaran, & Weber-Fox, 2012). A better understanding of phonological memory abilities in young children who stutter will allow for determination of underlying cognitive mechanisms that may be affected in children who stutter.

*1.2 Phonological memory*

A prominent model of working memory by Baddeley (2000; 2003) proposes a four-component memory system that consists of a supervisory component (*central executive*) and three subservient systems (*visuospatial sketchpad*, *phonological loop,* and *episodic buffer*). The central executive mediates attention and directs resources to the subservient systems that operate as relatively passive stores of information. The visuospatial sketchpad stores visual and spatial information, while the phonological loop stores auditory and speech-based information. The phonological loop is comprised of two additional components: a *phonological store* and an *articulatory rehearsal mechanism*. The phonological store temporarily maintains auditory information for short-term retrieval, but is subject to rapid decay after approximately 2 seconds. The content in the phonological loop can be refreshed via silent or overt articulatory rehearsal to allow the phonological code to be recycled and maintained for longer periods of time (Baddeley, 2000; Baddeley & Larsen, 2007). The episodic buffer, a recently added component to the model, provides a link to long-term memory stores (e.g., the lexicon) and integrates the visual and auditory information from the other subservient systems regardless of the input mechanism (Baddeley, 2000). Some researchers argue that access to long-term stores may also help refresh the content in the phonological store by accessing the phonological code found in the lexicon (Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Hoffman, Jefferies, Ehsan, Jones & Lambon Ralph, 2009; Martin & Gupta, 2004; Martin, Lesch, & Bartha, 1999; Patterson, Graham, & Hodges, 1994; Thorn, Gathercole, & Frankish, 2005). That is, access to the phonological code in pre-existing lexical entries may be used along with silent or overt articulatory rehearsal to help refresh and maintain the content held in the phonological store. This can occur even when attempting to remember nonword stimuli (Coady & Aslin, 2004). Phonological working memory requires input from several aspects of Baddeley's model, including access to long-term memory stores via the episodic buffer and attentional control via the central executive. Although differences in attentional control have been identified in children who stutter that could influence the processing of the central executive (Anderson, Pellowski, Conture, & Kelly, 2003; Anderson & Wagovich, 2010; Embrechts, Ebben, Franke, & van de Poel, 2000; Karrass et al., 2006), the focus of the current study explores whether inefficient or disrupted phonological memory may lead to difficulty in the maintenance of the phonological code for subsequent use in speech and language planning, thereby contributing to stuttering (e.g., Bajaj, 2007).

*1.2.1 Measures of phonological memory*

Nonword repetition tasks essentially measure the quality of the phonological representations held in working memory. That is, how well a person can maintain and access novel phonological code (i.e., nonwords) from the phonological store (Archibald & Gathercole, 2006; Dollaghan & Campbell, 1998; Gathercole & Baddeley, 1993). Typical tasks of nonword repetition require a participant to listen to and perceive the acoustic signal of the nonword and repeat it back exactly as it was heard. After hearing the nonword, a novel phonological and articulatory plan is assembled while articulatory rehearsal refreshes the signal continuously in the phonological store until the nonword stimuli can be repeated. During this process, the episodic buffer can also access phonological information from pre-existing lexical entries to help refresh decaying phonological code of the nonword during articulatory rehearsal. The more phonological characteristics a nonword shares with a real word (i.e., "word-like" nonwords) the more the lexicon can help support nonword repetition, particularly in young children (Coady & Aslin, 2004; Gathercole, 2006; 2007). Once the nonword is repeated by the participant, it is scored as correct or incorrect. A percentage of correct phonemes can also be calculated (e.g., Anderson et al., 2006; Anderson & Wagovitch, 2010; Hakim & Bernstein Ratner, 2004).

Digit span tasks are also frequently used in phonological memory research and can be used to measure the capacity of a person's phonological working memory (Jones & Macken, 2015). Capacity is a measure of how much phonological information can be held and accessed from the phonological store before the signal decays beyond retrieval (e.g., Conway, Cowan, Bunting, Therriault, & Minkoff, 2002). Digit span tasks use numbers or other "closed set" stimuli (i.e., stimuli with a limited number of items in a set, such as letters or numbers) that are presented in series of increasing lengths. The participant perceives the auditory signal of the stimuli, stores and rehearses the signal in the phonological loop, and then repeats back what was heard in the exact order it was given.

### *1.2.2 Factors that influence performance on phonological memory tasks*

Phonological memory can be assessed in children as young as 2 when using a modified nonword repetition task (Hoff, Core, & Bridges, 2008; Torrington Eaton, Newman, Bernstein Ratner, & Rowe, 2015). Studies show that this skill continues to develop until approximately age 10 (Chiat, 2006; Gathercole, Service, Hitch, Adams, & Martin, 1999; Snowling & Hulme, 1994). Clear developmental differences exist in children's phonological memory abilities, with younger children possessing more limited skills than older school-age children. Although matching participants by chronological age is a fairly common practice, empirical evidence suggests that several additional factors influence performance on phonological memory tasks (Dollaghan, Biber, & Campbell; 1995). For example, a strong reciprocal relationship exists between general language and phonological memory abilities that is particularly pronounced in young children 4

– 6 years old (Gathercole, 2006; 2007). Children with strong language skills tend to have strong phonological memory skills, while children with less robust but still typically developing language systems tend to have poorer phonological memory skills (Gathercole, Service et al., 1999). Socioeconomic status (SES) is another factor that is highly correlated with phonological memory ability (Dollaghan et al., 1999; Engel, Santos & Gathercole, 2008; McDowell, Lonigan, & Goldstein, 2007). Children from lower SES backgrounds tend to perform less well on nonword repetition tasks than children from higher SES backgrounds. The influence of sex differences in performance on digit naming tasks, a measure of phonological memory capacity, is also evident. Female children tend to perform better than male children on digit naming tasks. These differences are evident in children five years of age yet disappear for older children and adults (Lynn & Irwing, 2008).

Evidence suggests that the linguistic differences reported for children who stutter can be characterized as subtle and "sub-clinical" (Hakim & Bernstein Ratner, 2004; Hall, Wagovich, & Bernstein Ratner, 2007; Hakim & Bernstein Ratner, 2004; Ntourou, Conture, & Lipsey, 2011; Pelczarski & Yaruss, 2014; cf. Nippold, 2012), indicating that children who stutter are not presumed to exhibit clinically identifiable disorders in their language and phonological processing abilities. The subtlety of these reported differences require researchers to pay close attention to several participant and task factors that may mask subtle yet potentially meaningful differences in the phonological memory skills of children who stutter.

In addition to the individual factors that influence phonological memory discussed above (general language ability, SES, and sex), the characteristics of the nonword stimuli themselves can influence performance (Cholin, Levelt, & Schiller, 2006; Dollaghan & Campbell, 1998, 2003; Moore, Tompkins, & Dollaghan, 2010; Vitevitch & Luce, 2005). Modifying phonotactic probability (the likelihood of occurrence of a phonological sequence), phonemic complexity (early vs. late developing phonemes; single consonants vs. consonant clusters), the length of the nonword stimuli (short vs. long), and lexical similarity (more or less “word-like”) can make a nonword repetition task easier or more challenging for participants to complete. Accuracy of nonword repetition increases in relationship to the number of features a nonword shares with existing lexical entities (Coady & Aslin, 2004). Thus, nonwords that are less “word-like” (using infrequently heard phonological segments with low phonotactic probability), more phonologically complex (containing later-developing phonemes or consonant clusters), and longer (in number of segments or syllables) are more difficult to produce accurately than more “word-like” nonwords with higher phonotactic probability that are phonologically simple and shorter in length (e.g., Bowey, 2001; Coady & Aslin, 2004; Gathercole, 1995, 2006).

The *Comprehensive Test of Phonological Processing* (CTOPP) is a standardized test that contains subtests designed to measure phonological memory by manipulating these characteristics of nonwords. The stimuli used in the nonword repetition task of the CTOPP contain less “word-like” stimuli, later-developing phonemes, and gradual increases in length (from one-syllable to seven-syllable nonwords) throughout the task. The result is that the CTOPP contains stimuli that are more challenging than nonword repetition tasks that do not consider these factors. It is particularly important to consider these characteristics of nonwords when examining children of different ages to ensure that task difficulty is not too advanced for younger children yet still advanced enough to allow for a differentiation of subtly different phonological abilities. When these factors are not controlled in the stimuli, results are more difficult to interpret, because any findings could be explained by the characteristics of the stimuli rather than actual differences in children's phonological abilities.

*1.3 Phonological memory and children who stutter*

Several recent studies have provided empirical evidence supporting the claim that phonological memory in children who stutter is significantly different from that seen in children who do not stutter (Anderson & Wagovich, 2010; Anderson et al., 2006; Hakim & Bernstein Ratner, 2004; Oyoun et al., 2010; Spencer & Weber-Fox, 204). Still, the evidence is not conclusive, for other studies have found no significant differences (Bakhtiar et al., 2009; Smith et al., 2012). These discrepancies may be due in part to differences in the age of the participants and the tasks used, as well as general language development factors that can greatly influence performance.

Hakim and Bernstein Ratner (2004) administered the Children's Nonword Repetition task (CNRep; Gathercole, Willis, Baddeley, & Emslie, 1994) to children ages 4 to 8 years. They reported generally lower scores for children who stutter overall, with a significant between-group difference at the 3-syllable level. The authors concluded that there were no between-group differences for four- and five-syllable nonwords due to floor effects (i.e., children in both groups found the task too difficult, so error levels were high for all participants). Anderson et al. (2006) also administered the CNRep to 12 children who stutter between the ages of 3;0 and 5;2 matched by age, sex, and SES to 12 children who do not stutter. Children who stutter produced significantly fewer correct productions of two- and three-syllable nonwords than their nonstuttering peers and demonstrated nearly twice as many phoneme errors in 3-syllable nonwords as compared to children who do not stutter. No between-group difference was reported for four- or five-syllable stimuli. Anderson and Wagovich (2010) also reported similar performance on the CNRep in preschool children when investigating 9 children who stutter and 14 children who do not stutter, ages 3;6 to 5;2, with significant differences reported for two- and three-syllable stimuli. The authors also reported significantly more errors overall for children who stutter. Oyoun et al. (2010) investigated nonword repetition in children who stutter ages 5 to 13. They reported significant differences between children who stutter and children who do not stutter on 2- and 3- syllable nonword stimuli and in a visual memory picture-number task, but they found no differences on other measures of working memory (i.e., digit and letter span tasks).

Spencer and Weber-Fox (2014) conducted a prospective longitudinal study on children aged 3;9 to 5; 8 that explored speech and language factors that may contribute to the persistence or recovery of childhood stuttering. Several standardized tests of speech and language were administered including the Test of Auditory Comprehension of Language, (TACL-3; Carrow-Woolfolk, 1999), Structured Photographic Expressive Language Test (SPELT-3; Dawson, Stout, & Eyer, 2003), Bankson-Bernthal Test of Phonology (BBTOP; Bankson & Bernthal, 1990), Nonword Repetition Task (NRT, Dollaghan & Campbell, 1998), and Test of Auditory Perceptual Skills – Revised (TAPS-R; Gardner, 1985). The authors reported significantly reduced performance on the NRT and BBTOP for the children who persisted in stuttering as compared to the children who later recovered and suggested that articulation and nonword repetition abilities may be helpful in identifying young children who are at greater risk for continuing to stuttering. Authors also reported no significant differences in a digit span task between children who persisted in stuttering and children who do not stutter.

Unlike the findings reported above that found that children who stutter performed less well on nonword repetition tasks than children who do not stutter, some studies did not reveal differences in performance on nonword repetition tasks. Bakhtiar et al. (2009) investigated the phonological memory skills of 5- to 8-year old children who stutter utilizing 2- and 3-syllable nonwords. Lower overall scores for children who stutter were reported; however, no significant differences were found. Use of only 2- and 3- syllable nonwords in the older children may have resulted in a ceiling effect. Thus, the study may not have been able to identify potential differences in phonological memory that become apparent under a larger cognitive processing load. Smith et al. (2012) did not report any differences between 4- and 5-year old children who do and do not stutter with typical language abilities for a number of phonological memory measures that included auditory digit- and word-span tasks, the NRT, and kinematic measures. Only children who stutter who also exhibited concomitant speech or language disorders performed significantly less well than the children with typical language skills on the tasks.

In summary, all but two studies (Bakhtiar et al., 2009; Smith et al., 2012) have reported lower scores for children who stutter, although not all of the differences reached statistical significance, and the patterns of difference vary across the studies. Altogether, the studies discussed above suggest that differences in phonological memory ability exist; however, the evidence is not conclusive. Although the majority of the participants in the studies discussed above included young children (e.g., 4 – 6) as well children older than 6 years of age, the results of the studies with older children may not be directly compared to studies with only young children who stutter. Additionally, discrepancies in the literature may be due to the influences of specific factors described above (sex, SES, and language abilities), as not every study controlled for all these variables. Further study using carefully matched pairs of children who stutter and children who do not stutter, as well as sufficiently challenging stimuli, is needed to determine if phonological memory is a factor that contributes to stuttering. The current study was designed to address this need by answering the following research questions:

1) Are the phonological memory (nonword repetition and digit span) skills of children who stutter different from children who do not stutter?
2) Do children who stutter demonstrate the expected strong relationship (Coady & Evans, 2008**)** between phonological memory and other language measures (i.e. articulation abilities, expressive/receptive vocabulary)?

## 2.0 Method

### *2.1 Participants and matching variables*

Sixteen children who stutter (11 male, 5 female; mean age: 5 years, 5 months; SD: 5.8 months) and 13 children who do not stutter (7 male, 6 female; mean age: 5 years, 8 months; SD: 7.3 months) were recruited for participation in the study. The children had previously participated in a larger study examining the phonological processing skills of children who stutter. Participants were monolingual, spoke Standard American English, and did not possess any speech, language, hearing, or neurological disorders other than stuttering. A subset of this larger sample was selected for examination in this particular study to allow for careful matching of participants based on factors reviewed above (general language abilities, SES, and sex) that are known to influence performance on nonword repetition tasks. The matching process resulted in a group of 11 children who stutter (7 male, 4 female; mean age: 5 years, 5 months; SD: 4.213) matched on general language abilities, SES, and sex to 11 children who do not stutter (7 male, 4 female; mean age: 5 years, 9 months; SD: 7.826).

*2.1.1 Speech fluency*

Each child's fluency status was determined through analysis of a spontaneous speech sample of at least 500 syllables in length to determine the percent of syllables stuttered and to assign the speaker to a participant group (stuttering or non-stuttering). The Stuttering Severity Instrument (SSI-3; Riley, 1994) was also utilized to assign a severity rating to the children who stutter. Of the 11 children who stutter, 6 were rated as mild, 1 as moderate, and 4 as severe. Participants were assigned to the stuttering group if they: (1) received a score of at least 11 (mild) on the SSI-3; (2) demonstrated at least three stutter-like disfluencies (part-word repetitions, sound prolongations, or blocks; e.g., Yairi & Ambrose, 1992) per 100 syllables of conversational speech; and (3) at least one adult familiar with the child had expressed concerns about stuttering (e.g., Yaruss & Conture, 1996). Participants were assigned to the nonstuttering group if they: (1) received a score of 10 or below (i.e., less than mild) on the SSI-3, (2) demonstrated less than three stutter-like disfluencies per 100 words of conversational speech, and (3) adults familiar with the child reported no concern about the child's fluency.

*2.1.2 Matching variables*

Participants were matched on general language abilities, maternal education level, and sex due to the influence these factors have on nonword repetition tasks (Coady & Evans, 2008). General language ability was the first matching variable instead of age (the variable more commonly used in prior literature on this topic) because performance differences on phonological memory tasks can be attributed to even subtle differences in language skills (Bowey, 2001; Coady & Evans, 2008; Cooper, Rother, Speece & Schatchneider, 2002; Dollaghan et al., 1999; Gathercole, Service et al., 1999; Gathercole, Willis, & Baddeley, 1991;

Gupta & MacWhinney, 1997). Children from each group were paired together based on the combined scores of the "Quick Test" from the *Clinical Evaluation of Language Fundamentals – Preschool* (CELF-P; Wiig, Secord & Semel, 1992). The Quick Test screens for receptive language through the *Linguistic Concepts* subtest (CELF-P LC), while expressive language is screened through the *Recalling Sentences in Context* subtest (CELF-P RS). The two subtest scores were combined to determine a *Language Matching Score*. Participants were matched (plus or minus one standard point) on the Language Matching Score to form well-controlled pairs. Table 1 provides the language matching scores and demographic information for each participant pair. The second matching variable controlled for SES through the use of maternal education level as a measure of SES. Maternal education was characterized as (a) less than high school graduate, (b) high school graduate, or (c) college graduate (Dollaghan et al. 1999). All mothers were college educated which resulted in equally-matched pairs for SES. Finally, participants were matched by sex, as females tend to score higher on tests of language and digit span tasks than males (Burman, Gitan, & Booth, 2008; Dionne, Dale, Boivin, & Plomin, 2003; Lynn & Irwing, 2008).

*2.2 Test battery*

*2.2.1 Nonword repetition and digit span*

The CTOPP is a standardized, norm reference test that reports standard scores for the two subtests used in the study: Nonword Repetition (M=10, SD=3) and Memory for Digits (M=10, SD=3). The standard score takes into consideration the child's performance (raw score) as well as the child's age when assigning the value, allowing for comparison to both an age-matched group (via the standard score) and to the control group (i.e., children who do not stutter) matched for language. The CTOPP subtests are subject to ceiling rules; once three consecutive errors are made the task is discontinued.

Phonological memory was assessed using the *Nonword Repetition* and the *Memory for Digits* subtests of the CTOPP. The Nonword Repetition subtest required the children to listen to digital recordings of nonword stimuli that ranged in length from 1-syllable nonwords (e.g., “jup” / ʤup/) to 7-syllable nonwords (“dookershatupietazawm” /dukɚʃætəpɑɪtɑzɔm/). Children were instructed to repeat the nonwords as accurately as possible immediately after hearing each stimuli. Three practice items preceded the initiation of the test stimuli to provide participants with an opportunity to receive corrective feedback. Nonwords were presented one at a time until the child produced three in a row incorrectly, reaching ceiling. Once three consecutive errors occurred, the subtest was discontinued as per CTOPP manual instructions. The item was marked as incorrect if *any* phoneme in the nonword was pronounced inaccurately. In an effort to control for speech sound errors that might influence the results, participants were given an articulation test prior to completion of the nonword repetition task to ensure the participants possessed typical speech sound abilities. All children scored within typical limits and did not possess consistent phonological errors. Thus any speech sound errors made during nonword repetition were counted as incorrect. No stuttering was observed from any participant while completing the nonword repetition task.

The *Memory for Digits* subtest required the child to listen to digital audio recordings of numeric strings and repeat them back exactly as they were heard. The digit span task began with strings that contained two numbers (e.g., “1-6”) and became progressively longer up to 10 digits (e.g., “4-9-6-7-3-1-8-2-6-5”). Corrective feedback was given during the four practice items as necessary. Participants repeated the numeric strings until three digit strings were produced incorrectly and ceiling was reached. Per CTOPP manual instructions, administration of the stimulus items were discontinued once three consecutive errors occurred. Only one participant demonstrated any disfluencies during the digit span task. The intention of the digit span task was to test working memory, not fluency. Thus, items were marked as correct if the digits named were named in the appropriate order, regardless of the stuttering.

*2.2.2 Language measures*

Measures of expressive vocabulary (Expressive Vocabulary Test; EVT; Williams, 1997), receptive vocabulary (Peabody Picture Vocabulary Test – III; PPVT-III; Dunn & Dunn, 1997) and speech-sound ability (Goldman-Fristoe Test of Articulation – 2; GFTA-2; Goldman & Fristoe, 2000) were also administered to both groups of children. Participants were not matched on these additional measures, since they were already matched on general language ability via the CELF-P language screener (Language Matching Score). Still, the data were collected to ensure that any differences in phonological memory could not be attributed to the confounding influence of these well-known factors (e.g., Coady & Evans, 2008).

*2.3 Data analysis*

Analyses were conducted to explore the importance of matching general language abilities and their effect on the performance of nonword repetition tasks. Testing revealed that the data collected were heteroscedastic and did not meet the assumption of normality. Therefore, nonparametric statistics were used throughout to ensure more robust analyses. The matched groups of children who stutter and children who do not stutter were analyzed with the *Wilcoxon Signed-Ranks* test for between-group comparisons, while the *Spearman's rho* was used for within-group correlational analyses. Further, a Fisher's r- to z- transformation was also conducted to compare if the magnitude of the within-group correlational coefficients were significantly larger between children who do and do not stutter.

## 3.0 ***Results***

### *3.1 General language ability*

All children performed within typical limits (i.e., not scoring less than 1 SD below the mean) on the matching variable (Language Matching Score from the CELF-P), as well as all the other speech and language standardized tests (GFTA-2; PPVT-III; EVT). As expected, no significant differences were present for any of the descriptive language measures for expressive vocabulary (EVT; $Z = -.979$; $p = .328$), receptive vocabulary (PPVT-III; $Z = -.445$; $p = .656$), or speech-sound skills (GFTA-2; $Z = -.222$; $p = .824$). Table 2 outlines the means, SD, and range of standard scores, and statistics for all measures. These results confirm that the groups possessed similar language abilities.

### *3.2 Research question #1*

The first research question examined whether children who stutter differed from children who do not stutter in phonological memory skills. A Wilcoxon Signed-Ranks test indicated that children who stutter performed significantly less well than children who do not stutter on the Nonword Repetition subtest ($Z = -2.825$; $p = .005$). No significant between-group differences were observed for the Memory for Digits subtest (Z = -1.799; $p = .072$). Table 2 provides further details regarding the means, SD, and range of standard scores, and statistics for these measures.

### *3.3 Research question #2*

The second research question examined whether children who stutter demonstrated the expected strong relationship between nonword repetition and other language measures. Spearman's rho was used to conduct a correlational analysis between the two CTOPP subtests (nonword repetition and digit span scores) and the language measures (EVT, PPVT-III, GFTA-2, and Language Matching). Details of the within-group correlations can be found in Tables 3 and 4. Strong, positive relationships between language abilities (EVT, PPVT-III, GFTA-2, and Language Matching) and both the Nonword Repetition and Memory for Digits scores were anticipated (e.g. Coady & Evans, 2008). Indeed, the children who do not stutter demonstrated many of the expected significant correlations (nonword repetition, *rho* ranged from .57 to .68; *p* ranged from .02 to .07; digit span, *rho* ranged from .64 to .68; *p* ranged from .02 to .03). Children who stutter, however, only exhibited statistically significant correlations between nonword repetition and the GFTA-2 (nonword repetition, *rho* ranged from .44 to .62; *p* ranged from .04 to .18; digit span, *rho* ranged from .06 to .48; *p* ranged from .14 to .87). Digit span was not correlated with any other language measure for the children who stutter. These findings suggest that the children who stutter exhibit a different relationship between phonological memory abilities and language abilities when compared to children who do not stutter.

In an effort to ensure that the matching variable (Language Matching score derived from the CELF-P) was measuring expressive and receptive language as intended, the Language Matching score was correlated with performance on the additional standardized measures of speech and language (GFTA-2, *rho* ranged from .34 to .92; *p* ranged from < .001 to .31; PPVT-III, *rho* ranged from .40 to .80; *p* ranged from .003 to .22; EVT, *rho* ranged from .62 to .87; *p* ranged from .001 to .04). Table 3 outlines the results of the correlational analyses. Children who do not stutter demonstrated the expected robust correlation between Language Matching scores and performance on all speech-language measures. Children who stutter, however, did not display this same relationship, indicating differences in the relationships between various aspects of language ability in children who stutter even though the children were judged to be developing typically based on standardized testing.

Finally, a Fisher's r- to z- transformation was used to compare the difference between correlation coefficients in the same pair of variables, comparing if the magnitude of the association was significantly larger between children who do and do not stutter. This z statistic is a function of the magnitude of the difference in correlation coefficients by the sample size. A significant z corresponds to two pairs of correlation coefficients that significantly differ from each other in magnitude. The transformation statistic was individually computed for each of the 15 comparisons of correlation coefficients. Three of the 15 comparisons revealed significant differences between the correlation coefficients of children who stutter, relative to children who do not stutter. The three significant associations were between (1) CELF-P and GFTA-2 ($z$ = 2.48, $p$ = < .01), (2) GFTA-2 and digit span ($z$ = 1.76, $p$ = .04), and (3) PPVT-III and digit span ($z$ = 1.83, $p$ = .03). These analyses indicate that these relationships were significantly stronger for the children who do not stutter as compared to children who stutter.

## 4.0 Discussion

This study investigated specific aspects of phonological memory (nonword repetition and digit span) in children who do and do not stutter. Children who stutter were carefully matched to children who do not stutter according to factors that have previously been shown to influence performance on phonological memory tasks (i.e., general language abilities, SES, and sex,). Four main findings were revealed. First, children who stutter performed significantly less well than children who do not stutter on the nonword repetition task, although no differences were observed in the digit span task. Second, despite the significant differences reported, the majority of the nonword and digit naming scores were within typical limits (+/- 1 *SD*), reflecting a subtle, yet robust difference in nonword repetition ability. Third, both groups of children performed similarly in language abilities on the descriptive language measures, scoring within typical limits (+/- 1 SD) on the EVT, PPVT-III, and GFTA-2. Finally, although all children demonstrated typical language abilities, children who do not stutter demonstrated the expected strong correlations between phonological memory and descriptive language measures (EVT, PPVT-III, GFTA-2, Language Matching Score from the CELF-P), while children who stutter did not demonstrate the same strong relationship.

*4.1 Phonological memory*

Children who stutter performed significantly less well than children who do not stutter on the nonword repetition task used here as a measure of phonological memory. One possible explanation is that a delay or disruption in Baddeley's phonological loop (affecting the quality of the phonological representation) is responsible for children who stutter's reduced performance. The phonological code for the nonwords may have been intact when received at the level of the phonological loop, but a disruption during articulatory rehearsal could have resulted in the rehearsal of an inaccurate phonological code. Children who stutter, however, did not have difficulty on the digit span task, and a disruption during articulatory rehearsal should have impacted recollection of the numbers as well. Reduced performance on nonword repetition but not digit span tasks may also exist due to use of a different phonological memory strategy. Children who stutter may rely more on assistance from the episodic buffer than children who do not stutter. One of the main functions of the episodic buffer is to provide access to long-term memory stores. A number of researchers have argued that pre-existing lexical knowledge (i.e., phonological code for existing items in the lexicon) may be used to refresh or bolster decaying phonological code (Dell et al., 1997; Hoffman et al., 2009; Martin & Gupta, 2004; Martin et al., 1999; Patterson et al., 1994; Thorn et al., 2005). Children who stutter may depend on the episodic buffer to bolster the phonological code through access to the lexicon. Access to pre-existing lexical knowledge would not help in the performance of nonword repetition tasks because nonwords require the assembly of novel phonological codes not currently found in the lexicon. Digit span tasks on the other hand, access complete phonological representations. Thus, children who stutter may use the episodic buffer in a compensatory manner during memory tasks involving real words which may contribute to differences found in nonword repetition only. Finally, it is possible that the phonological code retrieved may have been less robust, or that the effort of assembling the novel phonological segments (either linguistically or motorically) was an aspect of the task that may have contributed to the significant differences reported. Further research is needed to determine the exact underlying processes may be impaired.

The type of nonword stimuli used for the task may also have contributed to the statistically significant results between groups. If more "word-like" nonwords are used, then the strategy of refreshing phonological code in phonological memory through access to the lexicon (via the episodic buffer) might result in a better performance on nonword repetition tasks. The nonwords used in the CTOPP can be considered to be "less word-like" since they do not contain many segments that contain real words. The "less word-like" nature of the nonwords used in the CTOPP did not allow pre-existing lexical knowledge found in the lexicon to aid in the assembly and repetition of the novel phonological code. This might explain why the present study found differences in nonword repetition**,** whereas prior studies that may have used more word-like nonwords have not reported similar differences. Any one, or several, of these factors may have contributed to the results. Further exploration of the complexities of phonological memory and its underlying mechanisms is necessary to fully understand the role phonological memory may play in stuttering.

*4.1.1 Nonword repetition*

Differences in nonword repetition ability found in the present study are similar to many studies that have investigated nonword repetition in young children who stutter (Anderson et al., 2006; Anderson & Wagovich, 2010; Hakim & Bernstein Ratner, 2004; Spencer & Weber-Fox, 2014). However, Smith et al., (2012) also controlled closely for language skills but did not report any differences in nonword repetition ability for the typically developing children who stutter (without speech and language disorders). The reported results may differ due to the length and complexity of the nonwords used in the respective studies. The current study utilized nonwords that ranged from 1 - 7 syllables, contained late-8 phonemes, and consonant clusters, while the nonwords in the Nonword Repetition Task used in Smith et al.'s study contained 1 - 4 syllables, no consonant clusters, and no late-8 phonemes (Moore et al., 2010). Another potential explanation for the differences in results from Smith et al. may have to do with persistence and recovery from stuttering. Spencer and Weber-Fox (2014) recently reported that reduced performance on articulation and nonword repetition tasks was predictive in determining persistence or recovery in young children who stutter. The majority of children who stutter in the current sample were receiving services from a speech clinic, had been stuttering for at least one year (some for longer) prior to participation, and possessed a positive family history for stuttering. Thus, it is possible that the children in the present sample may have been more inclined to persist in stuttering (Yairi & Ambrose, 1999**)**, which could potentially account for the current results that differ from Smith et al. (2012).

*4.1.2 Digit span*

Baddeley's working memory model would suggest that successful completion of digit span tasks requires sufficient storage capacity in the phonological loop. One measure of working memory capacity is the digit span task. No significant differences were revealed between participant groups on the digit span task suggesting that limitations in memory capacity did not appear to play a role. This result is congruent with the findings of several other studies that have also reported no between-group differences for similar digit span tasks (e.g., Smith et al., 2012, Spencer & Weber-Fox, 2014). Several factors could account for why no differences in digit span have been found in children who stutter. Digit span tasks use a "closed set" of numbers that are well-known to five- and six-year olds, phonologically simple, and characterized by short articulatory durations. Wagner et al. (1999) indicated that the CTOPP digit span task has a faster presentation rate than many other digit span tasks. A faster presentation rate may aid in recall because the digits are provided quickly in a shorter period of time resulting in more opportunities for articulatory rehearsal in the phonological loop. The limited number of digits used, combined with reduced articulatory demand and rapid presentation rate may have allowed the children who stutter to perform as well as the children who do not stutter. Finally, nonword repetition requires additional linguistic planning and motoric execution of novel phonological segments that are not required to the same extent when repeating back strings of digits. Thus, the digit span task may not have sufficiently taxed the phonological loop of either group of children in the same manner as the nonword repetition task.

*4.2 Relationship between nonword repetition and language*

The present study differs from prior investigations of phonological memory in the use of a norm-referenced test and accompanying standard scores. Other studies have used percent phoneme correct as a scoring rubric (e.g. Hakim & Bernstein Ratner, 2004) which allows for a comparison of participant scores regardless of age. The use of CTOPP's norm-referenced subtests allowed for comparison of the participants' performance to an age-matched normative sample using the standard scores, as well as to the language-matched control group of children who do not stutter. The majority of children who stutter's standardized scores for nonword repetition fell within one standard deviation from the mean (i.e., standard scores 7 – 13). This indicates that the phonological memory skills of children who stutter are not deficient, but rather exhibit slightly depressed or "sub-clinical" differences (Hakim & Bernstein Ratner, 2004; Hall et al., 2007; Hakim & Bernstein Ratner, 2004). Children who stutter are also reported to demonstrate subtle differences in attentional focus, phonological encoding, linguistic planning, and speech-motor execution (Eggers, de Nil, & van den Bergh, 2012; Ntourou, Conture, & Lipsey, 2011; Pelczarski & Yaruss, 2014; Smith et al., 2012; Weber-Fox et al., 2008). Taken together, the combination of several sub-clinical systems in children who stutter may interact and further contribute to an unstable speech system, particularly when those systems are taxed or overwhelmed. These subtle differences support the idea that depressed phonological memory ability may be one factor, along with differences in attention, phonological encoding, language, and speech motor control that may contribute to a relatively unstable speech system in young children who stutter (Smith & Kelly, 1997, Smith et al., 2012).

No significant between-group differences were revealed for any of the descriptive language measures (EVT, PPVT-III, GFTA-2). All children in this study demonstrated typical, age-appropriate abilities on language measures (i.e., scored 85 or above on a standardized test with *M* = 100 and *SD* = 15). These findings are similar to other studies that reported differences in nonword repetition performance (Anderson & Wagovich, 2010; Anderson et al., 2006; Hakim & Bernstein Ratner, 2004; Oyoun et al., 2010; Spencer & Weber-Fox, 204). The strong relationship between language abilities and phonological memory tasks was expected to be replicated with both groups of participants. Indeed, for children who do not stutter, strong, statistically significant correlations between speech and language measures (Language Matching Score, EVT, PPVT-III, GFTA-2) were present. Correlations between language measures and digit span were significant, while relationships between the language measures and nonword repetition approached, but never reached, significance. The presence of a strong relationship between speech and language measures was largely absent for children who stutter despite similar scores on standard language measures. The lack of expected strong correlations may reflect the ways in which the language abilities of children who stutter may subtly interact and present subclinically.

When examining the analysis of the correlation coefficients between groups via the Fisher's r- to z- transformation, it was revealed that articulation abilities were in two of the significant between-group correlational differences. Although all children scored within typical limits on the standardized GFTA-2, the children who stutter generally scored in the lower end of typical as compared to children who do not stutter. These generally lower, but still typical, articulation abilities for children who stutter may have accounted for the significant differences in between-group correlations including articulatory abilities. As mentioned above, Spencer &

Weber-Fox (2014) reported that articulation and nonword repetition abilities significantly predicted whether a child might persist in stuttering or recover. Further exploration using a larger sample size may provide additional insight in the future.

*4.4 Limitations*

An inevitable limitation when investigating linguistic processing in children who stutter is the difficulty in fully separating the influence of the motoric system from the linguistic system. There is evidence to suggest that the speech motor systems in children who stutter are different from those in nonstuttering children (e.g., Smith et al., 2012). Still, the finding that linguistic factors such as word-likeness can influence the accuracy with which nonword stimuli can be repeated in children who stutter indicates that the motor system is influenced by lexical factors (Smith et al., 2010). The multifactorial nature of stuttering suggests then that these differences in phonological memory may contribute to or exacerbate other deficits or delays that may exist in speech motor planning and execution.

Another limitation in the current study is that the participants all came from relatively affluent households where the mothers had a high level of education. Although this does not provide a diverse SES background, the high level of education may have contributed to a home environment that was ideal to foster pre-literacy skills such as phonological memory (see review in Dollaghan et al., 1999). The influence of SES on the phonological processing skills of children who stutter has not yet been studied explicitly, although lower SES has been found to negatively influence performance on phonological processing tasks (Engel et al., 2008; McDowell et al., 2007). It is possible that greater diversity in SES may have resulted in increased variability that may have altered the current results.

The authors endeavored to control as many contributing factors as possible. Language abilities can affect performance on phonological memory tasks; however, a child's age can play a role as well. Several pairs of participants differed in age by several months, and some differed by greater than a year. The age of the participants was controlled as much as possible by limiting the age of the participants to 5 and 6 years old and through the use of standardized scores that take into consideration a child's age and performance. Still, it is impossible to control for every factor, and it is possible that age differences between matched participants contributed to differences in performance.

Although it seems clear that subtle differences exist in nonword repetition, the findings may have been influenced by differences in attention. Indeed, there is some evidence to suggest that attentional focus is different in some children who stutter (Anderson et al., 2003; Anderson & Wagovich, 2010; Embrechts et al., 2000; Karrass et al., 2006). If attentional focus is different in children who stutter, then that difference could have contributed to differences in nonword performance. Presumably, attentional control would influence both tasks equally, yet differences were only found for nonword repetition and not digit naming. This does not rule out the influence of differences in attentional focus, but it does suggest that attentional factors cannot fully account for the results obtained in the current study.

Finally, this is a relatively small study. Data from more children were collected during the course of this study than were reported in this study due to the implementation of careful controls and nearly identical pairing of participants based on general language measures (i.e., 29 participants were recruited, while data from only 22 perfectly matched participants were used).

Additional research with more specific tasks and stimuli across different ages will provide further insight into the relationship of phonological memory and children who stutter. The findings suggest that any differences may be subtle; therefore, tasks must be sensitive enough to detect potential differences and groups must be sufficiently well-matched so that important differences are not washed out due to predictable variability.

## 5.0 *Conclusions*

A unique characteristic of the current study was the use of paired samples to control for potentially confounding factors that are known to influence phonological memory (general language abilities, sex, SES). Any participants who scored outside of typical limits on the matching measure were excluded. Careful matching of this kind may be necessary when attempting to reveal subtle phonological processing differences (Pelczarski & Yaruss, 2014). This fact may help to explain why some studies have failed to find differences (or reported a smaller difference) in nonword repetition between those who stutter and those who do not. This study contributes to the existing literature on phonological memory in children who stutter through use of nonword repetition tasks, and demonstrates that differences in phonological memory abilities between children who do and do not stutter are relatively subtle. Children who stutter perform less well than children who do not stutter, even though their performance is within the range of what is considered to be typical.

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Table 1. Demographic data for the stuttering (S) and nonstuttering (NS) groups.

| Pair Number | Participant Group | Age | Language Matching Score | Sex | Maternal Education Level | Stuttering Severity Instrument-3 (S only) |
|---|---|---|---|---|---|---|
| Pair 1 | S | 5.2 | 9.5 | Male | Graduate | Moderate- |
| | NS | 5.9 | 9.5 | Male | Degree | Severe |
| Pair 2 | S | 5.5 | 10.5 | Male | Graduate | Mild |
| | NS | 5.0 | 10.5 | Male | Degree | |
| Pair 3 | S | 4.9 | 11.0 | Male | Graduate | Mild |
| | NS | 5.5 | 11.0 | Male | Degree | |
| Pair 4 | S | 5.5 | 11.5 | Male | Graduate | Moderate |
| | NS | 6.3 | 11.5 | Male | Degree | |
| Pair 5 | S | 6.0 | 12.0 | Male | Graduate | Moderate- |
| | NS | 5.4 | 12.0 | Male | Degree | Severe |
| Pair 6 | S | 5.6 | 13.0 | Male | Graduate | Mild |
| | NS | 5.3 | 13.5 | Male | Degree | |
| Pair 7 | S | 5.5 | 13.5 | Male | Graduate | Moderate- |
| | NS | 6.8 | 14.0 | Male | Degree | Severe |
| Pair 8 | S | 5.9 | 9.5 | Female | Graduate | Mild |
| | NS | 6.5 | 9.5 | Female | Degree | |
| Pair 9 | S | 5.2 | 11.0 | Female | Graduate | Moderate- |
| | NS | 5.5 | 10.0 | Female | Degree | Severe |
| Pair 10 | S | 5.0 | 12.0 | Female | Graduate | Mild |
| | NS | 6.5 | 11.0 | Female | Degree | |
| Pair 11 | S | 5.1 | 12.5 | Female | Graduate | Mild |
| | NS | 5.9 | 13.5 | Female | Degree | |

Table 2. Phonological memory. Means (*M*), standard deviation (*SD*), Wilcoxon Signed-Ranks Test (*Z*) and *p*-value (*p*) for *Language Matching Score, Expressive Vocabulary Test, Peabody Picture Vocabulary Test –III, Goldman Fristoe Test of Articulation -2,* and the phonological memory subtests from the *Comprehensive Test of Phonological Processing*.

| | Children Who Stutter | Children Who Do Not Stutter | Test Statistics |
|---|---|---|---|
| Language Matching Score | *M* = 11.5<br>*SD* = 1.3<br>Range = 9.5 - 13.5 | *M* = 11.5<br>*SD* = 1.6<br>Range = 9.5 – 14.0 | *Z* = -.138<br>*p* = .890 |
| Expressive Vocabulary Test | *M* = 103.5<br>*SD* = 11.0<br>Range = 85 - 117 | *M* = 106.1<br>*SD* = 12.4<br>Range = 85 - 125 | *Z* = -.979<br>*p* = .328 |
| Peabody Picture Vocabulary Test -III | *M* = 112.6<br>*SD* = 12.8<br>Range = 97 - 143 | *M* = 111.9<br>*SD* = 10.2<br>Range = 99 - 131 | *Z* = -.445<br>*p* = .656 |
| Goldman Fristoe Test of Articulation -2 | *M* = 103.3<br>*SD* = 9.2<br>Range = 89 - 116 | *M* = 104.6<br>*SD* = 8.3<br>Range = 89 - 114 | *Z* = -.222<br>*p* = .824 |
| Nonword Repetition | *M* = 7.73<br>*SD* = 1.4<br>Range = 6 - 10 | *M* = 10.0<br>*SD* = 1.3<br>Range = 7 -12 | *Z* = -2.825<br>*p* = .005** |
| Memory for Digits | *M* = 9.27<br>*SD* = 2.6<br>Range = 6 - 15 | *M* = 10.6<br>*SD* = 1.6<br>Range = 8 - 14 | *Z* = -1.799<br>*p* = .072 |

***p* value: <0.01

Table 3. Correlations for children who stutter. Spearman's Rho ($r_s$), *p*-value (*p*) and number of participants (11) for *Language Matching Score, Expressive Vocabulary Test, Peabody Picture Vocabulary Test –III, Goldman Fristoe Test of Articulation -2,* and the phonological memory subtests from the *Comprehensive Test of Phonological Processing*.

| | Expressive Vocabulary Test | Peabody Picture Vocabulary Test -III | Goldman Fristoe Test of Artic. -2 | Nonword Repetition | Memory for Digits |
|---|---|---|---|---|---|
| Language Matching Score | $r_s$ = .622*<br>*p* = .041<br>N = 11 | $r_s$ = .399<br>*p* = .224<br>N = 11 | $r_s$ = .335<br>*p* = .314<br>N = 11 | $r_s$ = .447<br>*p* = .168<br>N = 11 | $r_s$ = .480<br>*p* = .135<br>N = 11 |
| Expressive Vocabulary Test | - | $r_s$ = .575<br>*p* = .064<br>N = 11 | $r_s$ = .648*<br>*p* = .031<br>N = 11 | $r_s$ = .438<br>*p* = .178<br>N = 11 | $r_s$ = .157<br>*p* = .645<br>N = 11 |
| Peabody Picture Vocabulary Test –III | - | - | $r_s$ = .534<br>*p* = .090<br>N = 11 | $r_s$ = .566<br>*p* = .069<br>N = 11 | $r_s$ = -.058<br>*p* = .866<br>N = 11 |
| Goldman Fristoe Test of Articulation-2 | - | - | - | $r_s$ = .622*<br>*p* = .041<br>N = 11 | $r_s$ = -.152<br>*p* = .655<br>N = 11 |
| Nonword Repetition | - | - | - | - | $r_s$ = .225<br>*p* = .506<br>N = 11 |

**p* value: <0.05
***p* value: <0.01

Table 4. Correlations for children who do not stutter. Spearman's Rho ($r_s$), *p*-value (*p*) and number of participants (11) for *Language Matching Score*, *Expressive Vocabulary Test*, *Peabody Picture Vocabulary Test –III, Goldman Fristoe Test of Articulation -2*, and the phonological memory subtests from the *Comprehensive Test of Phonological Processing*.

| | Expressive Vocabulary Test | Peabody Picture Vocabulary Test -III | Goldman Fristoe Test of Artic. -2 | Nonword Repetition | Memory for Digits |
|---|---|---|---|---|---|
| Language Matching Score | $r_s$ = .869**<br>$p$ = .001<br>N = 11 | $r_s$ = .798**<br>$p$ = .003<br>N = 11 | $r_s$ = .920**<br>$p$ = < .001<br>N = 11 | $r_s$ = .678*<br>$p$ = .022<br>N = 11 | $r_s$ = .652*<br>$p$ = .030<br>N = 11 |
| Expressive Vocabulary Test | - | $r_s$ = .737**<br>$p$ = .010<br>N = 11 | $r_s$ = .888**<br>$p$ = < .001<br>N = 11 | $r_s$ = .568<br>$p$ = .069<br>N = 11 | $r_s$ = .641*<br>$p$ = .034<br>N = 11 |
| Peabody Picture Vocabulary Test –III | - | - | $r_s$ = .769**<br>$p$ = .006<br>N = 11 | $r_s$ = .566<br>$p$ = .069<br>N = 11 | $r_s$ = .675*<br>$p$ = .023<br>N = 11 |
| Goldman Fristoe Test of Articulation-2 | - | - | - | $r_s$ = .569<br>$p$ = .068<br>N = 11 | $r_s$ = .642*<br>$p$ = .033<br>N = 11 |
| Nonword Repetition | - | - | - | - | $r_s$ = -.012<br>$p$ = .972<br>N = 11 |

*$p$ value: <0.05
**$p$ value: <0.01