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Disfluencies and phonological revisions in a nonword repetition task in school-age children who stutter

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ABSTRACT

Phonological encoding and associated functions, including monitoring of covert and overt speech, have been attributed relevant roles in stuttering. The aim of this study was to investigate these processes by testing the effects of nonword length in syllables (3-, 4-, 6-syllable), phonotactics, and phonemic/phonetic complexity on disfluencies and phonological revisions in 26 school-age children who stutter (CWS, $n = 13$) and matched fluent controls (CWNS). Participants repeated nonwords in two sessions separated by an hour. Within-group comparisons of percentage disfluencies using nonparametric tests resulted in significantly more disfluencies for the 6- compared to the 3-syllable nonwords and suggested that nonword length influences disfluencies in the CWS. The groups were comparable in the percentage of disfluencies at all levels of nonword length. The findings failed to provide conclusive evidence that phonological complexity and phonotactic manipulations have a greater effect on disfluencies in CWS compared to CWNS. The findings of significantly fewer phonological revisions and the lack of a significant correlation between disfluencies and revisions in the CWS in Session 1 compared to the CWNS are interpreted to suggest reduced external auditory monitoring. Demands on incremental phonological encoding with increasing task complexity (the *Covert Repair Hypothesis*, Postma & Kolk, 1993) and reduced external auditory monitoring of stuttered speech can account for the disfluencies, speech errors, and revisions in the speech of school-age CWS.

1. Introduction

The influence of phonological variables on speech disfluencies is a debated topic. Previous studies have suggested that such effects are influenced by higher-order lexical variables (*e.g.*, Brundage & Bernstein Ratner, 1989; Howell, Au-Yeung, & Sackin, 2000; LaSalle & Wolk, 2011). The purpose of this study was to investigate the extent to which phonological variables – length in syllables, phonotactics (defined by the probability of occurrence of sound and sound combinations in a language), and phonological complexity (defined by systematic variations in intra-syllabic phonemic/phonetic properties), influence disfluencies in children who stutter (CWS) and age- and sex-matched fluent controls (CWNS) in a nonword repetition task. Due to the long-standing tradition of associating disfluencies and speech repairs (errors and revisions) with speech monitoring in the psycholinguistic (Levelt, Roeloffs, & Meyer, 1999), child language (Rispoli, 2003), and stuttering literatures (Bernstein Ratner & Wijnen, 2007; Vasić & Wijnen, 2005), we also investigated the use of phonological revisions in the nonword repetition (NWR) task.

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1.1. Influence of phonological variables on disfluencies: theoretical relevance

Developmental theories of language production (the *Child Talk Model*, Strand, 1992; the *Leading-Edge Hypothesis*, Rispoli & Hadley, 2003) attribute a role for linguistic stressors in fluency disruption. All types of disfluencies, stuttering and non-stuttering, are included within such theories. Non-stuttering disfluencies include phrase repetitions, revisions, and interjections, while stuttering disfluencies include monosyllabic whole-word repetitions, part-word repetitions involving sounds or syllables, prolongations, blocks, tense pauses and fragmented speech (Ambrose & Yairi, 1999). In the stuttering literature (hereafter the terms “disfluency” and “stuttering” are used interchangeably to refer to part- or whole-word repetitions, prolongations, and blocks), multifactorial models identify stressors at the linguistic, cognitive, and emotional domains as contributing factors to speech motor production and disfluencies (Smith & Weber, 2017; Walden et al., 2012). Several theoretical accounts have identified a role for phonological processes in stuttering. Howell (the EXPLAN model, 2004) postulated that temporal asynchrony between components of planning (PLAN) and speech motor execution (EX) of subsequent syllables in an utterance can result in stuttering; phonological encoding, the process of encoding individual phonemic segments and syllabic stress, occurs at the final stages of speech planning leading up to articulation (Levelt et al., 1999). Postma and Kolk (the Covert Repair Hypothesis [CRH], 1993) postulated that the speech plan of individuals who stutter is error-prone due to prolonged activation of competing phonological segments during speech planning. The CRH identified stuttering disfluencies as overt compensations for covert error corrections to the phonological code. Furthermore, Vasić and Wijnen (the Vicious Circle Hypothesis [VCH], 2005) postulated hypervigilant external auditory monitoring as the default mode for speech in stuttering without associated deficits in phonological encoding. Levelt (1989, 1999) hypothesized that speech monitoring involves the comprehension system. Nozari, Dell, and Schwartz (2011) proposed a central domain general monitoring mechanism located in the Anterior Cingulate Cortex (ACC) that utilizes response conflict as a signal for speech monitoring and error detection and is applicable to both covert and overt speech monitoring. Within the monitoring models, speech repairs have been attributed to both covert and overt error detection (to varying extent) and the subsequent correction of such errors. The study of disfluencies and speech repairs can inform the theories of phonological encoding and monitoring in stuttering.

1.2. Influence of phonological variables on disfluencies: research findings

The influence of phonological variables on disfluencies is a well-researched topic in the stuttering literature. In the following sections, we discuss phonological variables that have been studied for their effects on disfluencies in persons who stutter.

1.2.1. Word length and disfluencies

Several studies have identified length of speech production units, in syllables, words, or utterances, as a contributing factor to stuttering. Schlesinger, Melkman, and Levy (1966) reported an increase in disfluencies from one- to three-syllable words in CWS between 8 and 16 years (also refer to Soderberg, 1971, and Wingate, 1967, for similar results in adults [AWS]). Subsequently, studies using imitation or conversation tasks in younger CWS between 2 and 7 years have reported an increase in disfluencies with unit length (*e.g.*, Brundage & Bernstein Ratner, 1989; Logan & Conture, 1995; Logan & LaSalle, 1999; Sawyer, Chon, & Ambrose, 2008; Weiss & Zebrowski, 1992). Contrary findings attributing a limited role for length of production units on disfluencies have also been reported. Based on five studies in fluent speakers, CWS, and AWS, Silverman (1972) reported that reading longer words, defined by the number of letters, resulted in more disfluencies. However, persons who stutter were more disfluent in shorter words compared to fluent peers while a reverse effect was observed for the longer words. Silverman interpreted the findings to suggest that word length does not influence the loci of disfluencies in persons who stutter. Bernstein Ratner and Sih (1987) reported that utterance complexity was a better predictor of disfluencies than utterance length in sentence imitation in CWS between 3;11 (years;months) and 6;4. Logan and Conture (1995) reported significant differences between stuttered and fluent utterances from play-based conversation samples in CWS between 3;0 and 5;6 only for sentences higher in both syntactic complexity (measured using Developmental Sentence Scoring, Lee, 1974) and length in syllables. Yaruss (1999) tested conversational samples of CWS between 3;4 and 6;0 and found that, compared to fluent productions, stuttered productions were longer in number of words, syllables, morphemes, and utterances. However, individual data failed to show a consistent length effect on disfluencies. Zackheim and Conture (2003) reviewed studies that have reported on either the individual contributions or the combined influences of length and complexity on disfluencies (*e.g.*, Gaines, Runyan, & Meyers, 1991; Logan & Conture, 1997; Melnick & Conture, 2000; Yaruss, 1999; Zackheim & Conture, 2003).

While a few studies in the stuttering literature have used nonwords as stimuli, the focus of such studies has been on evaluating the effects of nonword length on speech errors or disfluencies, and the findings have been mixed (Anderson, Wagovich, & Hall, 2006; Bakhtiar, Ali, & Sadegh, 2007; Hakim & Bernstein Ratner, 2004; Ludlow, Siren, & Zikria, 1997; Oyoun, El Dessouky, Sahar, & Fawzy, 2010; Sasisekaran & Byrd, 2013; Sasisekaran, 2013; Smith, Goffman, Sasisekaran, & Weber-Fox, 2012). Both Anderson et al. (2006) and Hakim and Bernstein Ratner (2004) did not find a systematic effect of nonword length on disfluencies in CWS between 3 and 8 years. Smith et al. (2012) reported very few disfluencies in a NWR task in CWS between 4 and 5 years. Even if the limited number of nonwords (one at each nonword length spanning one to four syllables) could be attributed to the lack of length effects on disfluencies in Smith et al. (2012), the same argument is not applicable to the findings from the other studies that have utilized several nonwords at each syllable length. While Bakhtiar et al. (2007); Oyoun et al. (2010), and Sasisekaran and Byrd (2013) tested school-age CWS on nonwords varying in syllable length, they did not report data on disfluencies. Thus, there is a distinct lack of similar studies on the influence of nonword length on disfluencies in school-age CWS. While it can be hypothesized that the inherent variables contributing to disfluencies should be present in all age groups and for all stimuli types, this has not been confirmed.

1.2.2. Phonological complexity, phonotactics, and disfluencies

The study of the effects of phonological complexity on disfluencies involves varying phonemic (complexity of individual sounds and sound combinations), syllabic (syllable structure variations), or metric (*e.g.*, trochaic *vs*. iambic stress) attributes of words and investigating the extent to which such variations influence disfluency rates. Using such measures, studies from younger CWS between 3 and 12 years have reported negligible effects of phonological complexity on disfluencies (*e.g.*, Coalson, Byrd, & Davis, 2012; Howell & Au-Yeung, 1995; Logan & Conture, 1997; Weiss & Jakielski, 2001). Howell and Au-Yeung (1995) reported that the rate of disfluencies did not vary with age or stuttering severity in the different phonological categories studied in conversational utterances of CWS between 2;7 and 12;7. Logan and Conture (1997) did not find an influence of syllable structure measures, based on sonority, syllable onset and coda properties, and syllable shape, on disfluencies in the conversational samples of CWS between 3;0 and 5;6. Weiss and Jakielski (2001) analyzed conversational samples from 13 CWS between 6 and 11 years using the Index of Phonetic Complexity (IPC, Jakielski, 1998). The IPC is a measure that provides complexity scores for words based on the number of difficult syllable structures they contain. The researchers did not find a predictable pattern of interaction between disfluencies and IPC scores. Coalson et al. (2012) did not find an effect of phonetic complexity measured using the Word Complexity Measure (WCM, Stoel-Gammon, 2010), an index based on inter- and intra-syllabic phonemic/phonetic complexity, on stuttering disfluencies in parent-child conversation samples of preschool CWS between 2;7 and 5;9.

Contrary to the above findings, studies in older CWS and AWS have confirmed a role for phonological complexity (*e.g.*, Howell et al., 2000; Howell, Au-Yeung, Yaruss, & Eldridge, 2006; LaSalle & Wolk, 2011). Reanalyzing the data from Howell and Au-Yeung (1995); Howell et al. (2000) found significant effects of phonological complexity on disfluencies in the conversational samples of individuals who stutter between 3 and 18+ years. Howell et al. (2006) found that stuttered words had higher phonemic and phonetic complexity in older CWS (11–18 years) and AWS (18+ years) compared to younger CWS (6–11 years). LaSalle and Wolk (2011) found that compared to fluent words matched in number of syllables, phonemes, and word familiarity, stuttered words in conversation samples of school-age CWS were higher in phonological complexity and lower in neighborhood density (also see similar results from Wolk & LaSalle, 2015).

A few studies have also examined phonotactic properties of words (frequency of occurrence of phonemic segments and segment combinations in a language) for their effects on disfluencies. It has been hypothesized that phonological encoding deficits will result in more disfluencies on words of low phonotactic probability. Using conversation samples from CWS between 3;0 and 5;8, Anderson and Byrd (2008) reported that phonotactic probability was not a predictor of stuttering, although it was predictive of the type of stutter event (also see similar results from Anderson, 2007). Similar investigations of phonotactic properties of stimuli and their effects on disfluencies in school-age CWS are lacking, although the findings from some of the studies may have indirect relevance to this variable. For instance, the finding from LaSalle and Wolk (2011) of more disfluencies in words from lower neighborhood density may also suggest that the phonotactics properties of such words may have contributed to the observed effects. Coalson et al. (2012) reported that the phonetic complexity of words did not influence disfluencies in younger CWS when controlled for phonotactics. Such an effect may have been evident if the phonotactic properties of the words were taken into consideration.

In summary, word/nonword length, phonotactics, and phonemic/phonetic complexity, have all been studied for their influence on disfluencies. Except for the few studies in AWS (Schlesinger et al., 1966; Silverman, 1972), studies on length effects have been limited to younger CWS in the age range of 3 and 8 years and the findings have been equivocal. The confirmation of a syllable length effect in school-age CWS would identify the extent of contributions of such effects with the persistence of stuttering. The effect of phonological complexity on disfluencies remains unclear. Studies vary in the measures used to compute phonological complexity. Some of the studies have investigated the activation of speech sounds or sound sequences of individual words or words within a network (phonotactics; *e.g.*, Anderson, 2007; Anderson & Byrd, 2008; LaSalle & Wolk, 2011), thereby directly involving phonological level processes. Others have studied the effects of phonetic (speech motor) complexity or a combination of phonemic and phonetic complexity to varying extent (*e.g.*, Coalson et al., 2012; Howell & Au-Yeung, 1995; Howell et al., 2000, 2006; Logan & Conture, 1997; Weiss & Jakielski, 2001). A clear dichotomy between these levels may not be achievable, although the approach of varying phonotactic and phonemic/phonetic properties of stimuli is most likely to effectively evaluate the influence of phonological complexity on disfluencies. Furthermore, because most of the studies have used words and utterances as stimuli, disambiguating lexical or syntactic factors from phonological influences is a challenging endeavour. Although nonwords lack dictionary definition, their use to investigate such effects is ideal for several reasons. First, by varying nonword properties the individual effects of phonological variables on disfluencies can be investigated systematically. Second, using nonwords limits the influence of higher-order variables on disfluencies, thereby enabling to focus specifically at the phonological level.

1.3. Self-monitoring and its role in disfluencies

The process of speech monitoring has been closely associated with phonological processes, disfluencies, and speech repairs in both the psycholinguistic (Huettig & Hartsuiker, 2010; Levelt, 1989; Levelt et al., 1999) and stuttering theories (*e.g.*, Postma & Kolk, 1993). Speech monitoring is also considered an executive function skill involving attentional resources (1989, Levelt, 1983; MacDonald, Johnson, Forsythe, Plante, & Munhall, 2012). The study of speech monitoring in children has involved documenting overt speech errors followed by revisions (hereafter referred by the term “revisions”), a behavior identified as a type of disfluency. While revisions are not included in the disfluency types considered stuttering, their presence at the different levels of language production (phonemic, syntactic, semantic) has been interpreted as demonstration of linguistic sophistication through the effective use of external auditory monitoring (Rispoli, 2003; Rispoli, Hadley, & Holt, 2008).

Using a variety of methods several studies have provided evidence for monitoring deficits in persons who stutter (*e.g.*, Brocklehurst & Corley, 2011; Hollister, Van Horne, & Zebrowski, 2015; Logan & LaSalle, 1999; Postma & Kolk, 1992; Vasić & Wijnen, 2005; Wagovich, Hall, & Clifford, 2009). Postma and Kolk (1992) reported that AWS were comparable to fluent speakers in reporting errors in self-generated speech with and without auditory feedback, but detected fewer errors in the speech of others. Brocklehurst and Corley (2011) found that AWS self-reported higher rates of overt and covert speech errors during the production of tongue twisters. These findings suggest aberrant phonological encoding and altered external auditory monitoring of speech. The dual-task paradigm has been used to investigate monitoring abilities in AWS. Vasić and Wijnen (2005) found that when distracted with a secondary visual or speech monitoring task, AWS became more fluent thereby suggesting hypervigilant external auditory monitoring of speech by default. In children, the use of revisions at stuttering onset has been interpreted with relevance to speech monitoring. Logan and LaSalle (1999) reported that fewer disfluency clusters in CWS (*Mean* age = 52 months, *SD* = 9.0) were associated with revisions compared to age-matched CWNS and attributed the presence of complex disfluency clusters and revisions to difficulties in the planning and production of grammatical units. The findings from Logan and LaSalle (1999) might also suggest a trade-off between disfluencies and revisions in CWS. Wagovich et al. (2009) reported an increase in revisions with syntactic complexity over time in a group of CWS between 2;1 and 4;11 tested each month for 10 months. Hollister et al. (2015) reported that compared to 2 to 5-year-olds who later recovered from stuttering and CWNS, CWS who later persisted in stuttering demonstrated a higher revision rate with syntactic development based on testing at 0, 6, and 12 months post stuttering onset. The findings of higher rate of revisions in these studies have been interpreted to suggest a salient role for external auditory monitoring with the anticipation or expectation of stuttering. Furthermore, neuroimaging studies have reported reduced activation of the temporoparietal cortex and increased activation of the ACC during stuttered speech that have been attributed to altered speech and language monitoring (*e.g.*, Braun et al., 1997; Chang, Kenney, Loucks, & Ludlow, 2009; De Nil, Kroll, Kapur, & Houle, 2000; Fox et al., 2000; Salmelin et al., 1998).

1.4. Specific aims of this study

The present investigation contributes to the study of the influences of phonological variables on speech disfluencies in school-age CWS and CWNS in a NWR task. Based on the several theoretical accounts that have attributed a role for phonological processes in stuttering (the CRH, Postma & Kolk, 1993; the EXPLAN model, Howell, 2004) and the supporting data (see introduction), the first aim of the study was to investigate the effects of three variables—length in syllables, phonotactics, and phonemic/phonetic complexity—on disfluencies in CWS. Increase in nonword length, low phonotactics, and increase in phonemic/phonetic complexity are all likely to constrain phonological encoding and subsequent speech motor processes, thereby resulting in more disfluencies. The second aim was to investigate the use of phonological revisions in both groups. The finding of higher rate of revisions in younger CWS has been interpreted to suggest heightened external auditory monitoring at the onset of stuttering (for a similar hypothesis see, Yaruss & Conture, 1996, p. 361). The nonword task focuses specifically at the phonological level and requires participants to rely on external auditory monitoring to learn and produce the nonwords accurately, the study of disfluencies, errors, and revisions in this task can therefore offer insights into the roles of phonemic encoding and external auditory monitoring in regulating disfluent speech in school-age CWS.

Two contradictory hypotheses on the effects of phonological variables on disfluencies can be considered in older CWS. Based on the CRH (Postma & Kolk, 1993), a deficit in phonological encoding in CWS will result in more disfluencies with increase in task demands at the phonological level to compensate for covert error corrections to the speech plan. Additionally, with such error corrections, the CWS may be comparable in errors or may even demonstrate fewer errors than the CWNS. However, a higher error rate is also compatible with the predictions of the CRH. To the contrary, the VCH attributes hypermonitoring rather than phonological encoding as the central variable in stuttering (the VCH; Vasić & Wijnen, 2005). Because it does not identify phonological encoding deficits, a discernable pattern between disfluencies and speech errors is not predictable from the VCH. Furthermore, neither the CRH nor the VCH postulate a potential trade-off between stuttering and other disfluencies. In particular, a higher rate of revisions in younger CWS closer to stuttering onset reported in the previous studies has been attributed to heightened external auditory monitoring (Hollister et al., 2015; Wagovich et al., 2009). Based on such findings, we hypothesize that the CWS will demonstrate more revisions than the CWNS due to active external monitoring of speech.

To test these hypotheses, the following research questions were addressed in this study:

1 Do school-age CWS and CWNS show individual effects of nonword length, phonotactics, and phonemic/phonetic complexity on disfluencies in a NWR task, and are such effects comparable between the groups?
2 Do school-age CWS and CWNS differ in the use of phonological revisions in the NWR task?

2. Methods

2.1. Participants

Participants were 13 CWS (10 males, 3 females) in the age range of 8 to 15 years. Each participant in the CWS group was matched in sex and age within 1 year, except for one participant who was matched within 1.5 years, to a participant in the control group. All participants were monolingual native speakers of American English. The participants in the CWNS group were recruited from a pre-existing database maintained at the Speech Fluency lab and through flyers posted around the University of Minnesota campus. Participants in the CWS group were all recruited through the Julia M. Davis Speech-Language-Hearing Center in the Department of Speech-Language-Hearing Sciences at the University of Minnesota. The experimental protocol was approved by the Institutional

Review Board, University of Minnesota.

2.1.1. Initial screening

A total of 16 CWS (12 males, 4 females) and 16 CWNS were initially recruited to participate in the study. Participants in both the groups responded to a screening form to rule out language, hearing, reading, and/or co-occurring neurological deficits, and to obtain information on usage of medications likely to affect the outcome of the experiment (*e.g.* ADHD, motor weakness). Data from three participants in the CWS group were excluded from the final dataset because they failed to meet the initial screening criteria for the absence of language/hearing/reading impairments and neurological deficits. Data from one CWS on ADHD medication was within 1 standard deviation (*SD*) of the CWS group averages on the dependent measures in the final analysis, therefore this participant's data were included in the final data set. The remaining participants did not report language, speech, hearing, and/or co-occurring neurological deficits other than stuttering in the CWS group. After excluding the three participants, data from 13 participants in the CWS group (3 females, *Mean Age* = 12.33, *SD* = 2.4) and the corresponding age- and sex-matched participants from the control group (3 females, *Mean Age* = 12.35, *SD* = 2.2) were included in the final analysis. An independent *t*-test showed that the groups were comparable in the *Mean* age of the participants, $t(24) = -0.02$, $p = 0.48$.

All participants passed a binaural hearing screening at 25 dB HL at .5, 1, 2, 4, and 8 kHz; the threshold was set at 25 dB to accommodate the absence of a sound booth. All participants in the CWS group had a history of treatment for stuttering.

2.2. Stuttering assessment

All CWS participants had a stuttering diagnosis from a speech-language pathologist either at the Julia M. Davis Speech, Language, Hearing center, University of Minnesota, or a Minnesota public school district prior to participation in the study. Stuttering severity ratings were obtained from the accompanying parent for all the CWS participants on the day of testing to confirm stuttering. The parents were asked to rate stuttering severity on a 7-point scale (1-mild, 7-severe). Three participants received a rating of 1, four participants in the range of 1–2 (only for one participant, the parent did not provide a severity rating and a rating of 1 was provided based on severity computation from the Stuttering Severity Instrument-3, Riley, 1994), three participants in the severity range of 2–4, and three participants in the severity range of 4-5.

2.3. Standardized tests and other assessments

Reading and conversational samples were obtained from all participants to rule out articulation errors and systematic phonological deviations. A series of tests were administered to evaluate baseline language and cognitive abilities in both the groups. Expressive vocabulary was tested using the Expressive Vocabulary Test (EVT, Williams, 1997). Short-term and working memory were tested using the forward and backward digit span subtests of the Weschler's Intelligence Test (Wechsler, 1997). Participants in both the groups were also tested using the Nonword Repetition Test (NRT; Dollaghan & Campbell, 1998). The nonwords from the NRT vary in phonological and phonetic complexity from the nonwords used in this study. Data from two participants (one CWS and one CWNS) from the NRT were lost due to technical issues and the missing values were replaced by group *Means*.

Due to the age range of participants tested (8–15 years), participants in both the groups were subdivided into younger (8;9–12;1, $n = 6$) and older (13;8–15;8 years, $n = 7$) age groups. The groups (CWS, CWNS) and age groups (8–12 years, 13–15 years) were compared in the baseline measures using four factorial analysis of variance (ANOVA) tests with the *p* values corrected for the four different outcome variables (p [0.05/4] = 0.012). Table 1 shows the *F*, *df*, and *p* values for the main and interaction effects from the factorial ANOVAs. The analyses did not result in significant group differences.

Table 1
Results of factorial ANOVAs comparing CWS and CWNS in Expressive Vocabulary Test Standard Scores (EVT SS), Forward and Backward Digit Span (%), and Nonword Repetition Test (NRT).

Test	Effect	*df*	*F*	*p*	*partial-eta-squared*
EVT SS	Group	1,22	3.91	0.061	0.15
	Age group	1,22	0.11	0.747	0.00
	Group x Age Group	1,22	0.38	0.542	0.02
Forward span (%)	Group	1,22	0.22	0.646	0.01
	Age group	1,22	2.39	0.136	0.10
	Group x Age Group	1,22	2.30	0.144	0.09
Backward span (%)	Group	1,22	0.31	0.584	0.01
	Age group	1,22	5.08	0.034	0.19
	Group x Age Group	1,22	4.15	0.054	0.16
NRT (%)	Group	1,22	3.61	0.070	0.14
	Age group	1,22	2.75	0.111	0.11
	Group x Age Group	1,22	6.50	0.017	0.22

Note. p values corrected to 0.012 due to four baseline measures.

Table 2
Nonword stimuli varying in syllable length, phonotactics, and phonological complexity.

Nonword	Length (in syllables)	Complexity	PC/NPC	Phonemic composition
/mæb/ /bɪ/ /tiem/	3	Simple	PC	Early 8 consonants
/mæb/ /beiz/ /tʃab/		Complex	PC	Early, middle, late 8 consonants
/mæb/ /spoʊ/ /kwi/ /feɪb/	4	Simple	PC	Middle, late 8 consonants, 2 consonant clusters
/mæb/ /skri/ /spl(sp)ɔɪ/ /strub/		Complex	PC	Middle, late 8 consonants, 3 consonant clusters
/mæb/ /tɑi/ /bɑ/ /po/ /ti/ /bɑ/	6	Simple	PC	Early and middle 8 consonants, 0 consonant clusters
/mæb/ /grɑ/ /ʃro/ /plʊ/ /kri/ /bɑ/		Complex	PC	Middle, late 8 consonants, 4 consonant clusters
/mæb/ /θwaip/ /fkrob/	3	Simple	NPC	Early, middle, late 8 consonants, 2 consonant clusters
/mæb/ /ʃfuʤ/ /tʃloib/		Complex	NPC	Early, middle, late 8 consonants, 2 consonant clusters

2.4. Stimuli

The nonwords for the study were adapted from Sasisekaran and Weisberg (2014) and varied systematically in three variables. The first variable, nonword length, was defined based on number of syllables (3-, 4-, 6-syllables). The second variable, phonotactics (defined by the probability of occurrence of sound and sound combinations in a language), was varied as a binary concept with nonwords consisting of permissible combinations (PC) in English or not (NPC). Considering the difficulty that adults experienced with this manipulation (Sasisekaran & Weisberg, 2014), testing this variable was limited to the 3-syllable level (3-PC *vs.* 3-NPC). The third variable, complexity, was manipulated at each level of nonword length by including both a simple and a complex nonword. Complexity was defined primarily by phonemic composition based on age of acquisition: early *vs*. middle, late consonants (Shriberg, Austin, Lewis, McSweeny, & Wilson, 1997), and consonant clusters (for a description of stimuli, see Table 2). All nonwords carried an alternating trochaic (strong–weak) stress pattern and consisted of a mix of CV, CVC, and CC(C)VC syllables. The nonwords contained /mæb/ as the first syllable and the bilabial /b/ or /m/ in the final syllable to enable kinematic data collection (kinematic data are not reported in this manuscript). These manipulations resulted in a total of eight nonwords (3-PC, 4-syllable, 6-syllable, 3-NPC x 2 complexity). Cluster reduction of /splɔɪ/ to /spɔɪ/ was noticed frequently during testing and, since such reductions have been identified to occur in children in the age range tested, both productions were considered correct (Stoel-Gammon, 2010). No other simplifications or reductions were noted.

2.5. Procedure

Fig. 1 illustrates the entire study protocol. Each data collection session took about three hours and was divided into two sessions (Sessions 1 and 2) separated by an hour. Data collection was undertaken by the principal investigator (PI) and a trained research assistant. During both sessions, the nonwords, pre-recorded from a female native English speaker, were presented over loudspeakers at comfortable loudness and participants were provided one opportunity to repeat each nonword accurately. Participant productions were recorded and analyzed offline to obtain disfluencies, phonological revisions, speech accuracy, and kinematic data for the different nonword categories from Sessions 1 and 2. We report primarily on disfluencies and phonological revisions in this manuscript.

The experimental protocol involved four steps. First, participants underwent familiarization with the nonwords during which they received each nonword five times both in auditory and written formats and were required to produce the nonwords correctly at least twice. The nonwords were pronounced with a trochaic stress pattern and the stressed syllables were underlined in the written format (*e.g.*, /mæb/ /tɑi/ /ba/ /po/ /ti/ /bɑ/). For the 3-NPC nonwords only, additional trials were presented to elicit at least one correct production with assistance. Second, Session 1 was conducted immediately after familiarization, requiring participants to learn the nonwords through practice. Each participant was presented 18 sets of nonwords with each set consisting of the eight nonwords presented in random order. Thus, each participant received a total of 144 trials (18 sets x 8 trial per set). The number of sets and trials were chosen based on previous studies that have demonstrated practice effects on accuracy (*e.g.*, Sasisekaran, Smith, Sadagopan, & Weber-Fox, 2010) and movement variability (Smith et al., 2012) in NWR. Participants were instructed to repeat the nonwords at

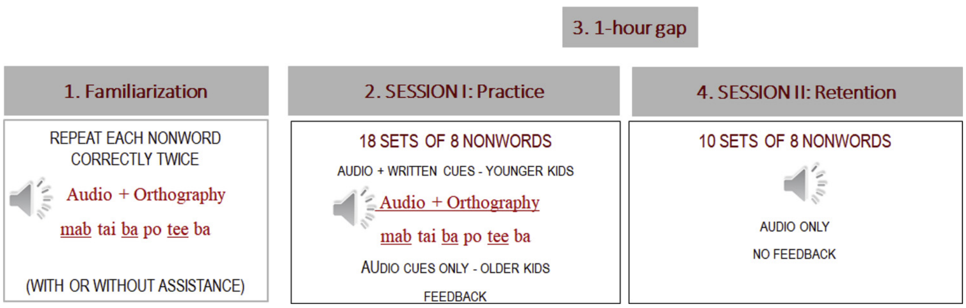

Fig. 1. Experimental protocol.

comfortable loudness and to aim for accuracy. Both knowledge of results (incorrect/correct nonword production) and knowledge of performance (auditory discrimination, articulatory placement cues) were provided if incorrect productions occurred on three or more consecutive trials throughout testing in Session 1. Third, after completing Session 1, participants were provided an hour's break involving 30 min of standardized testing and 30 min of no activity relating to the experimental protocol. Fourth, Session 2 was conducted after the break and consisted of 10 sets of nonwords (80 trials). Each set was presented in random order and required participants to repeat the nonwords accurately, without feedback on performance.

2.5.1. Procedural variations in younger vs. older children

Two age-appropriate modifications to testing were implemented to facilitate nonword learning. First, to elicit optimal performance, the younger children (< 12 years) in both groups were presented multimodal cues (auditory and orthographic presentation of nonwords) during the initial sets and later transitioned to auditory tokens. The older children in both groups received only the audio tokens. Age-matched pairs from both groups were also matched in the use of cues. Second, because eight participants (four in each group) in the older age range were tested previously with adults in a similar protocol (data from the adult participants are reported in Sasisekaran & Weisberg, 2014, data from the 8 children are reported in this manuscript), these participants produced the nonwords embedded in a carrier phrase ("say ______ again"). Use of the carrier phrase was excluded in the younger participants. These age-appropriate modifications were implemented because initial testing demonstrated that the younger participants were unable to repeat the nonwords with just the audio tokens and inconsistent in using the carrier phrase.

2.6. Data coding and reliability

During the experiment, the PI and the research assistant coded participants' productions for speech accuracy. All productions were also recorded using a digital Marantz recorder. Post-experiment, the second author and two trained research assistants independently coded all productions from both sessions for disfluencies and errors. Disfluencies were operationally defined using the categories identified in the stuttering literature, including repetitions (sound, monosyllabic, and multisyllabic), prolongations, blocks, and perceptually tense pauses. Considering the complex nature of the stimuli, disfluencies were expected in both the CWS and the CWNS. The raters were provided detailed instructions on coding the disfluencies. Each nonword production received a coding of "1″ or "0″ to indicate the presence or absence of one or more disfluencies. Multiple disfluencies within the same nonword were counted as one stutter event (Yaruss, 1998). Cohen's kappa used to obtain interrater agreement resulted in "substantial" (CWS, 0.74) and "almost perfect" (CWNS, 0.90) levels of rater agreement on disfluencies (Cohen, 1960; values greater than 0.81 are considered "almost perfect"). The disagreements were revisited by the first author to either be resolved or excluded from data analysis. A total of 14 and 12 trials from the CWNS (total 3050 trials) and the CWS (total 2915 trials), respectively, were excluded due to disagreements.

In addition to disfluencies, phonological revisions that occurred within an utterance in the absence of external prompts from the experimenters were coded. These occurred at the sound, syllable, or multisyllabic levels (*e.g.*, /mæv/ [error] - /mæb/ [revision] /bɪ/ /tiem/; /mæb/ /bo/ /ba/ [error] - /mæb/ /tɑi/ /ba/ /po/ [revision] /ti/ /bɑ/). The first and second authors coded all productions from both sessions for such revisions. Disfluencies and revisions were considered mutually exclusive. Although the presence of a disfluency was not mandatory for a trial to be identified as a revision, if disfluencies were present in a trial identified as a revision then the trial was coded as both a disfluency and a revision. Cohen's kappa used to obtain interrater reliability resulted in almost perfect levels of rater agreement (CWS, 0.84; CWNS, 0.87). The disagreements were revisited by the first author to either be resolved or excluded from the data analysis. A total of 17 and 5 trials from the CWNS and the CWS, respectively, were excluded due to rater disagreements. Percent disfluencies, revisions (computed using the formula, "*number of* disfluencies or revisions per nonword / total number of trials of each nonword per session * 100") were obtained for each nonword by complexity and session.

2.7. Statistical analysis

2.7.1. Preliminary analysis

Correlations computed between the percentage of disfluencies at each nonword length and participant age did not show significant effects in either of the groups, hence age of participants was not included in the analyses. Kolmogorov-Smirnov and Lilliefors tests revealed normal data distribution for all levels of the different variables except for the 3-syllable nonwords in Session 1. Therefore, nonparametric tests with asymptotic p values (adjusted for the number of a priori comparisons) and Dunn-Bonferroni planned comparisons were used to analyzed the differences in the percentage of disfluencies within- (Friedman's test) and between-groups (Mann-Whitney U test) to investigate the effects of nonword length, phonotactics, and complexity on disfluencies. Similarly, a priori comparisons were conducted on the use of phonological revisions both within- and between-groups using nonparametric statistics. Effect size (r) estimates for the Friedman's test results were computed using the formula $X^2/N(k\text{-}1)$ where X^2 is the test statistic, N is the sample size, and k is the number of measurements per participant. Effect size (r) estimates for Mann-Whitney U test results were computed using the formula Z/sq.rt. of n, where Z is the standardized test score and n is the number of observations (Tomczak & Tomczak, 2014). Finally, considering the theoretical and empirical support for a link between disfluencies and revisions, correlations were computed between these variables at those levels where the groups demonstrated the most differences in the percentage of disfluencies.

Table 3
Percent disfluencies (*Mean* and *SD*) by group, session, and nonword properties.

Group		3-PC		4-syllable		6-syllable		3-NPC	
		Simple	Complex	Simple	Complex	Simple	Complex	Simple	Complex
	Session 1								
CWS	*Mean*	1.9	0.4	5.6	6.2	9.7	22.1	15.0	12.4
	SD	3.3	1.5	4.7	9.2	10.4	27.2	16.3	13.2
	Session 2								
	Mean	3.1	5.4	7.7	10.0	13.3	23.8	11.0	14.6
	SD	6.3	12.0	10.9	17.3	15.2	20.2	13.6	17.6
Group		3-PC		4-syllable		6-syllable		3-NPC	
		Simple	Complex	Simple	Complex	Simple	Complex	Simple	Complex
	Session 1								
CWNS	*Mean*	1.6	3.6	6.9	6.0	9.5	12.5	9.9	14.3
	SD	2.4	7.2	8.2	10.1	10.4	15.6	15.5	18.9
	Session 2								
	Mean	3.6	4.5	3.5	7.3	5.5	11.7	5.4	13.9
	SD	6.7	9.3	6.3	12.7	10.4	12.4	6.8	14.6

3. Results

3.1. Disfluency analysis

3.1.1. Nonword length effects

Table 3 reports the *Mean, Median,* and *SD* values for the percentage disfluencies from both the groups by nonword length, complexity, and session. For the non-parametric statistical comparisons, the disfluency values were averaged across the two levels of complexity and session. Two comparisons were conducted subsequently (within- and between-groups) to test the effects of nonword length.

Friedman's test of within-group comparisons (Fig. 2) conducted to determine differences in disfluencies between the three levels of nonword length (3-PC, 4-, 6-syllable) was significant in the CWS, $X^2(2) = 21.2$, $p < 0.0001$, $r = 0.81$. Bonferroni-corrected planned comparisons ($p[0.05/3] = 0.016$) showed that the CWS demonstrated significantly more disfluencies for the 6-syllable (*Mean Rank* = 2.85, *Mean* = 17.5, *SD* = 13.2, $p < 0.0001$), and descriptively more disfluencies for the 4-syllable (*Mean Rank* = 2.08, *Mean* = 6.37, *SD* = 6.64, $p = 0.032$), compared to the 3-PC nonwords (*Mean Rank* = 1.08, *Mean* = 1.71, *SD* = 2.06). Similar within-group comparisons in the CWNS demonstrated a significant main effect with a smaller effect size and none of the comparisons showed significance at post-hoc testing, $X^2(2) = 8.1$, $p = 0.017$, $r = 0.31$. A strong trend for a difference in the percentage of disfluencies between the 6-syllable (*Mean Rank* = 2.54, *Mean* = 10.3, *SD* = 11.3) and 3-PC nonwords (*Mean Rank* = 1.46, *Mean* = 4.2, *SD* = 6.5; $p = 0.018$) was observed. Mann-Whitney U test comparing the two groups at the different levels of nonword

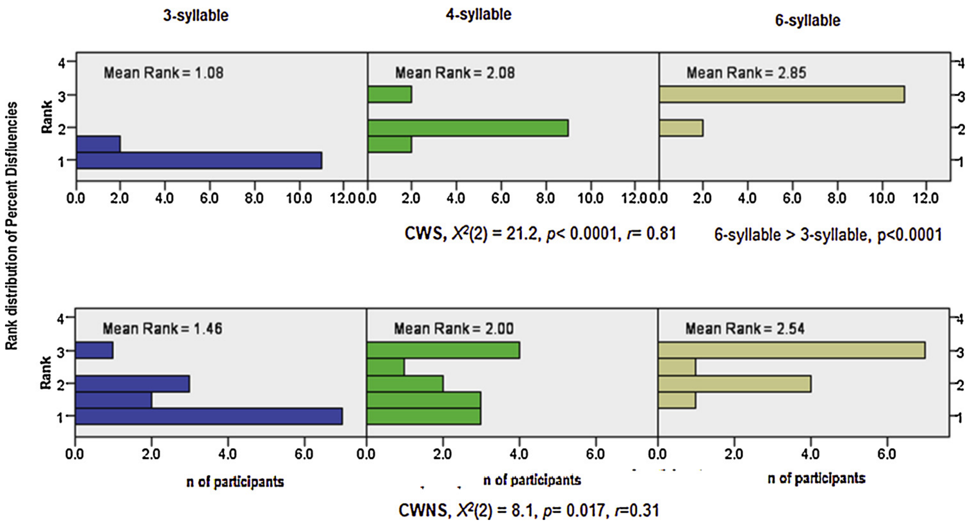

Fig. 2. Rank distribution of percent disfluencies by nonword length and group.

length did not show significant differences even though the CWS demonstrated nearly twice the disfluencies at the 6-syllable level compared to the CWNS.

In summary, both the CWS and the CWNS demonstrated a within-group increase in disfluencies with nonword length. However, compared to the CWNS, the effect size of such within-group differences in disfluencies was larger in the CWS and yielded statistically significant differences at post-hoc testing. Statistically significant between-group differences in disfluencies was not observed.

3.1.2. Phonotactics

Comparison of the 3-PC *vs.* 3-NPC nonwords based on complexity did not result in significant differences in disfluencies in either of the groups, therefore the values were averaged across complexity. Friedman's within-group comparison of the 3-PC *vs.* 3-NPC nonwords by session showed a significant main effect in the CWS, $X^2(3) = 14.2$, $p = 0.003$, $r = 0.36$. Bonferroni-corrected planned comparisons ($p[0.05/2] = 0.025$) resulted in a trend for more disfluencies in the 3-NPC (*Mean Rank* = 3.12, *Mean* = 13.70, *SD* = 13.6) compared to the 3-PC (*Mean Rank* = 1.77, *Mean* = 1.14, *SD* = 1.68) nonwords only in Session 1 ($p = 0.032$). Similar within-group comparisons in the CWNS resulted in a significant effect, $X^2(3) = 17.1$, $p = 0.001$, $r = 0.43$, with significantly more disfluencies in the 3-NPC (*Mean Rank* = 3.0, *Mean* = 12.1, *SD* = 14.3) compared the 3-PC nonwords in Session 1 (*Mean Rank* = 1.62, *Mean* = 2.6, *SD* = 4.6; $p = 0.024$). Significant differences were not observed between the groups for this comparison.

In summary, phonotactics influenced the rate of disfluencies in both groups with the CWNS demonstrating larger differences in disfluencies between the 3-NPC *vs*. 3-PC nonwords. The between-group differences in the percentage of disfluencies for these nonword categories were not significant.

3.1.3. Complexity effects

Within-group comparisons on the percentage disfluencies were conducted using Friedman's test with complexity (2) and session (2) as the two factors at each nonword length. A significant main effect was obtained in the CWS at the 6-syllable level, $X^2(3) = 10.5$, $p = 0.014$, $r = 0.26$. Bonferroni-corrected planned comparisons ($p[0.05/2] = 0.025$) demonstrated descriptive differences between the 6-syllable simple *vs*. complex nonwords in Session 1 (Simple, *Mean Rank* = 1.85, *Mean* = 9.7%, *SD* = 10.3; Complex, *Mean Rank* = 2.85, *Mean* = 22.1, *SD* = 27.4, $p = 0.08$), and a similar trend was also noted in Session 2 (Simple, *Mean Rank* = 2.08, *Mean* = 12.7, *SD* = 13.5; Complex, *Mean Rank* = 3.23, *Mean* = 25.4, SD = 18.8, $p = 0.04$). In the CWNS, significant differences in disfluency rates between the complex *vs.* simple nonwords were not evident for any of the nonword lengths. Based on these results, between-group comparisons in the percentage of disfluencies were conducted for the 6-syllable complex nonword at Session 1 *vs.* 2. Neither of the comparisons were significant, although the CWS demonstrated more disfluencies for the complex nonwords in both sessions with a weak trend for significant differences in Session 2 (CWS, *Mean Rank* = 16.3, *Mean* = 22.1, *SD* = 27.2; CWNS, *Mean Rank* = 10.6, *Mean* = 12.5, *SD* = 15.5, $p = 0.057$). Comparison of the 3-PC *vs.* 3-NPC nonwords based on complexity did not result in significant differences in either groups.

In summary, complexity comparison at each nonword length did not reveal significant within- or between-group differences between the simple *vs*. complex nonwords.

3.2. Phonological revisions

Since overt error productions are relevant to overt errors followed by revisions, percentage speech accuracy in the NWR task was coded, arcsine transformed, and analyzed in a repeated measures mixed ANOVA. The results indicated a weak trend for group differences ($p = 0.071$) in speech accuracy with the CWS demonstrating descriptively more speech errors than the CWNS (for further details, see Sasisekaran, Basu, & Weathers, In press).

Table 4 presents the *Mean, Median*, and *SD* values for the percentage phonological revisions from the NWR task. A priori comparisons were conducted based on the within-group differences in disfluencies (Fig. 3). Friedman's test used to analyze within-group differences in the percentage of phonological revisions at the three nonword lengths – 3-PC, 4-, 6-syllable (averaged by session and complexity) demonstrated a significant effect in the CWS, $X^2(2) = 14.5$, $p = 0.001$, $r = 0.55$. Pairwise comparisons showed that the CWS used significantly more revisions in the 6-syllable (*Mean Rank* = 2.54, *Mean* = 3.52, *SD* = 3.18) compared to the 3-PC nonwords (*Mean Rank* = 1.27, *Mean* = 0.10, *SD* = 0.36; $p = 0.001$). Significant differences were not observed between the 4- *vs.* 6-syllable nonwords. A similar analysis in the CWNS also yielded a significant effect, $X^2(2) = 10.0$, $p = 0.007$, $r = 0.38$. Pairwise

Table 4
Mean, Median, and *SD* values for percent phonological revisions by nonword and group.

Group		3-PC	4-syllable	6-syllable	3-NPC
CWS	*Mean*	0.20	4.45	7.03	4.92
	Median	0.20	4.72	5.50	2.63
	SD	0.72	3.82	6.37	6.62
CWNS	*Mean*	2.42	7.31	15.75	15.05
	Median	1.46	8.18	10.58	15.53
	SD	4.02	6.53	15.90	13.83

PC – nonwords that follow English phonotactics.
NPC – nonwords that do not follow English phonotactics.

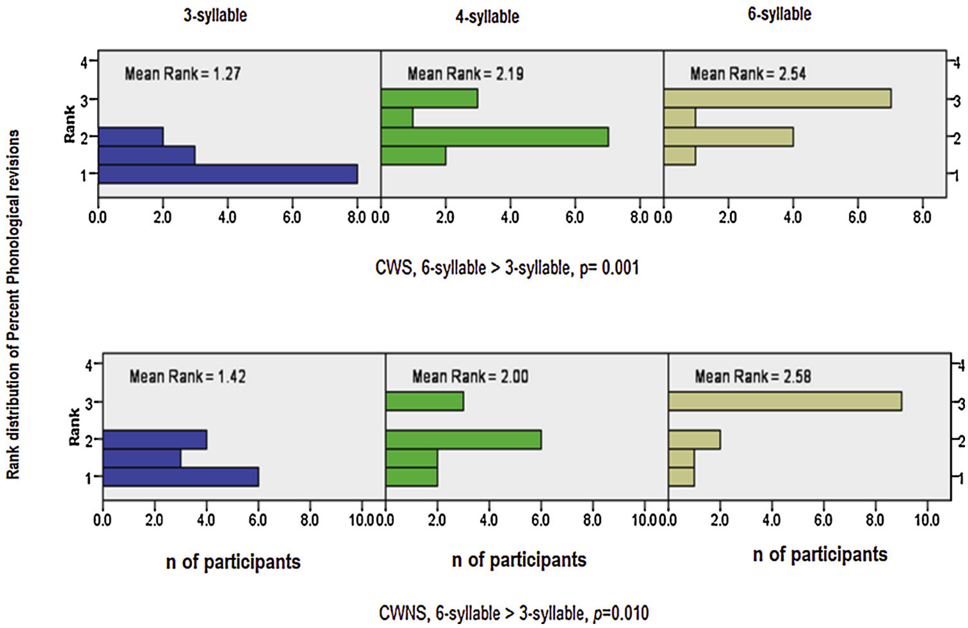

Fig. 3. Rank distribution of percent phonological revisions by nonword length and group.

comparisons showed that the CWNS also made significantly more phonological revisions to the 6- compared to the 3-PC nonwords ($p = 0.010$).

Mann-Whitney U test comparing the two groups in the percentage of phonological revisions at all levels of nonword length (3-PC, 4-, 6-syllable) and session (1, 2) was significant at the 6-syllable level. The CWNS (*Mean Rank* = 16.92, *Mean* = 8.4, *SD* = 8.5) demonstrated significantly more revisions than the CWS (*Mean Rank* = 10.08, *Mean* = 2.0, *SD* = 3.0) in Session 1, $U(26) = 2.3$, $p = 0.018$, $r = 0.45$.

Within-group comparisons in the use of revisions between the 3-NPC *vs.* 3-PC nonwords by session demonstrated significant differences in both the groups, although none of the Bonferroni-corrected planned comparisons were significant in the CWS. The CWNS demonstrated significantly more phonological revisions in the 3-NPC nonwords (*Mean Rank* = 3.31, *Mean* = 9.63, *SD* = 9.65) compared to the 3-PC nonwords (*Mean Rank* = 2.12, *Mean* = 1.66, *SD* = 3.92) in Session 1, $X^2(3) = 16.5$, $p = 0.001$, $r = 0.45$. Mann-Whitney U test showed significantly more phonological revisions in the CWNS (*Mean Rank* = 16.8, *Mean* = 9.6, *SD* = 9.6) compared to the CWS (*Mean Rank* = 10.12, *Mean* = 2.1, *SD* = 3.7) in Session 1, $U(26) = 2.4$, $p = 0.016$, $r = 0.47$.

Pearson correlations were computed between the percentage disfluencies and phonological revisions at the 6-syllable level, where the groups demonstrated the most differences in disfluencies to investigate the extent to which these variables were interrelated (the p value was adjusted for 2 correlations per group by session, $p = 0.025$). In Session 1, the CWS did not demonstrate a significant correlation while the CWNS demonstrated a high positive correlation (Session 1, CWS $r = 0.20$; CWNS $r = 0.76$, $p = 0.002$). Similar computations from Session 2 yielded a significant positive correlation in the CWS group and a weak trend towards significant positive correlation for the CWNS group (Session 2, CWS $r = 0.76$, p = 0.002; CWNS $r = 0.55$, $p = 0.048$).

In summary, both groups demonstrated significantly more revisions with increase in nonword length, and such within-group differences were statistically significant in the 6- compared to the 3-PC nonwords. Compared to the CWS, the CWNS also demonstrated significantly more revisions with increase in nonword length (*e.g.*, 6- *vs.* 3-PC) and complexity (*e.g.*, 3-NPC *vs.* 3-PC) in Session 1.

4. Discussion

We investigated the effects of systematic variations in nonword length, phonotactics, and phonemic/phonetic complexity, on disfluencies and phonological revisions in a NWR task in school-age CWS and age- and sex-matched CWNS. The findings confirmed an effect of syllable length on disfluencies in both the groups with a slightly larger effect size for such differences in the CWS. The within-group increase in disfluencies with syllable length in the CWS was accompanied by an increase in revisions, although the CWS group demonstrated significantly fewer revisions than the CWNS. Phonotactics influenced both disfluencies and revisions. However, compared to the CWS, the CWNS demonstrated more disfluencies and significantly more revisions for nonwords that did not follow English phonotactics. Finally, the developmentally-based complexity manipulation used in this study did not offer conclusive evidence for the influence of phonemic/phonetic complexity on disfluencies or revisions in school-age CWS. The findings and their implications for speech production processes and psycholinguistic theories of stuttering are discussed.

4.1. Phonological variables and disfluencies

4.1.1. Nonword length

Two findings were obtained on the effects of nonword length on disfluencies: (a) more disfluencies at the 6-syllable compared to the 3-syllable level in the CWS only; and (b) comparable rates of disfluencies between the 3- and 4-syllable nonwords in both the groups. While our findings did not yield statistically significant between-group differences for disfluencies at the different nonword lengths, the finding of a larger effect size for the within-group comparisons in the CWS and nearly twice the percentage of disfluencies at the 6-syllable level in the CWS compared to the CWNS are interpreted to support a role for nonword length on disfluencies in school-age CWS. The finding of comparable disfluencies at the 3- *vs.* 4-syllable levels confirmed previous findings of the lack of systematic effects of nonword length on disfluencies at these lengths reported in younger CWS (Anderson et al., 2006; Hakim & Bernstein Ratner, 2004; Smith et al., 2012). However, the nonword length at which maximal within-group difference in disfluencies was noted in this study (6-syllable) was not tested in the previous studies. At this nonword length, in addition to phonological encoding, greater demands on working memory and speech motor coordination may also be contributing to the observed differences. Therefore, the findings from this study using nonwords in school-age CWS confirmed previous reports on the influence of longer planning and production units on disfluencies in CWS (*e.g.*, Logan & Conture, 1995; Logan & LaSalle, 1999; Sawyer et al., 2008; Weiss & Zebrowski, 1992). These findings also suggest that the effects of syllable length on disfluencies is evident not just in younger CWS between 3 and 8 years of age, although the extent of such effects in older school-age CWS may vary due to habituation or treatment.

We also noted that while the CWS exhibited a range of disfluency types, including syllable repetitions (SR, 7.6%), multiple disfluencies involving multiple syllables (˜2.2%), prolongations, blocks, and pauses (˜2.2%), SR was the most frequent disfluency type in both the groups. Hence, the changes in disfluencies with nonword length evident in the CWS were mostly due to disproportionate increase in (syllable-level) repetitions rather than prolongations and blocks. Kelly and Conture (1992) and Zebrowski (1991) established that both CWS and CWNS produced the same types of disfluencies in varying proportions, and the present data confirmed such findings.

4.1.1.1. Theoretical implications. Based on the CRH (Postma & Kolk, 1993), we hypothesized that a deficit in phonological encoding will result in more disfluencies to compensate for covert error corrections while also resulting in comparable or fewer overt speech errors. In this study, the highly variable performance in speech accuracy at the 6-syllable level in both the groups (CWS, *Mean* = 39%, *SD* = 26.5; CWNS, *Mean* = 45.4%, *SD* = 23.4) suggested that the number of trials may not have been sufficient for either of the groups to consistently produce the nonwords accurately. Therefore, the significant within-group increase in disfluencies with nonword length observed in the CWS confirmed predictions from the CRH. These findings are interpreted to suggest reduced efficiency of phonemic selection, encoding, and subsequent correction of errors in the speech plan as potential contributing factors to disfluencies (Postma & Kolk, 1993). Cascading of such an effect with increase in syllable length can have implications for incremental encoding and speech production, hence more disfluencies at the 6-syllable level. The finding of descriptive differences in disfluencies between the 6- *vs.* 3-syllable nonwords in the CWNS is also in agreement with the CRH. Several paradigms are used to test phonological encoding in fluent speakers (*e.g.*, tongue twisters), and the findings from this study suggested that the nonwords may have constrained phonemic encoding and subsequent processes in both the CWS and CWNS, although to a greater extent in the CWS.

While the finding of more disfluencies with increased nonword length is compatible with the predictions of the VCH that hypermonitoring results in more disfluencies, this interpretation is less viable for two reasons. First, the nonword task used in this study was not manipulated to increase or decrease external auditory monitoring, although the nonword properties were varied to increase demands on phonological encoding. Second, the VCH cannot account for hypermonitoring resulting in more speech errors, and while we did not find significant group differences in overt speech errors in this study previous studies in younger CWS and AWS have reported more speech errors in nonword tasks (*e.g.*, Byrd, Vallely, Anderson, & Sussman, 2015; Sasisekaran & Weisberg, 2014).

4.1.2. Phonotactics

Studies in fluent speakers have reported the effects of phonotatics on perceptual and production processes (*e.g.*, Brown & Hildum, 1956; Eukel, 1980). With the exception of LaSalle and Wolk (2011), studies on the influence of phonotactics on disfluencies have been limited to younger CWS (Anderson & Byrd, 2008; Anderson, 2007). Our findings indicated that phonotactics did have an effect on disfluencies in school-age children, although such differences were significant only in the CWNS. Storkel and Morrisette (2002) stated that the probability that a sequence occurs more frequently in a language is reflective of higher resting threshold and connection strength of the phonemic representation in the sequence, thus enabling faster decoding and encoding in the recognition and production of such sequences. Based on this argument and the postulation of impaired phonological encoding (the CRH, Postma & Kolk, 1993), we hypothesized that the phonotactic manipulation (PC *vs.* NPC) will exert a greater effect on disfluencies in the CWS group. Lower threshold and prolonged competing activation threshold for unfamiliar compared to familiar sequences should have resulted in significantly fewer disfluencies in the PC compared to the NPC nonwords, and significant group differences in disfluencies for the 3-NPC nonwords. While the findings failed to confirm these effects, the conclusion awaits further confirmation due to the higher variability in performance that was evident in both the CWS and the CWNS groups. Ceiling and floor level performances in the PC and NPC categories, respectively, may have contributed to the lack of a clear group effect. Studies testing this variable have benefited from considering other methods that have reported natural variations in phonotactics of the stuttered and neighboring words in conversational samples. For instance, Tsai (2018) reported higher stuttering rates for words from low density neighborhoods based on conversation samples from AWS.

4.1.3. Phonological complexity

The developmentally-based complexity manipulation used in this study offered the opportunity to investigate phonological complexity effects on disfluencies with limited lexical and syntactic influences. Previous studies on preschool-age CWS have reported mixed findings on the effects of complexity *vs.* length of utterances on disfluencies (*e.g.*, Bernstein Ratner & Sih, 1987; Coalson et al., 2012; Logan & Conture, 1997; Weiss & Jakielski, 2001; Yaruss, 1999). However, several studies comparing school-age CWS and CWNS have reported that disfluent productions are phonologically complex than fluent productions (*e.g.*, Howell et al., 2000, 2006; LaSalle & Wolk, 2011). Considering that the complexity-based disfluency analysis in this study did not demonstrate differences at the 3-, 4-, or 6-syllable levels in both the groups, we interpret the finding of more disfluencies in the 6-syllable nonwords (averaged by complexity) compared to the 3-syllabe nonwords in the CWS to suggest that nonword length rather than complexity is a stronger predictor of disfluencies in school-age CWS. However, it is likely that more trials may have elicited complexity-based group differences in disfluencies and/or speech errors at the higher levels of length (*e.g.*, 6-syllable, simple *vs.* complex) or phonotactic variations (*e.g.*, 3-NPC *vs.* 3-PC). Therefore, contrary to the findings from the previous studies in older CWS, present findings do not offer conclusive evidence in support of the hypothesis based on the CRH for an effect of phonological complexity on disfluencies in school-age CWS. However, this is not to suggest that phonological complexity does not influence stuttering in older CWS. As stated previously, we used a developmentally-based approach to complexity manipulation that does not take into consideration the lexical and sublexical network properties, including phonological neighborhood frequency and density, directly into consideration. The latter variables are relevant to conversational speech and may demonstrate the previously reported effects of phonological complexity on disfluencies in school-age CWS (*e.g.*, Howell et al., 2000; Wolk & LaSalle, 2015).

4.2. Phonological revisions in CWS and CWNS

The current study is the first to report reduced use of revisions in school-age CWS compared to age-matched CWNS. The only other study to have reported reduced use of revisions found that younger CWS produced fewer revisions within disfluency clusters (Logan & LaSalle, 1999). In our study, both groups demonstrated increased use of revisions with nonword length thereby suggesting dependence on external auditory monitoring to achieve accurate nonword productions with increase in length of planning and production units. Despite this similarity, the groups demonstrated opposing patterns; the CWS showed significant increase in both disfluencies and revisions at the 6-syllable level and correlation between these variables was evident only in Session 2, while the CWNS demonstrated a significant increase in revisions only and significant correlation between disfluencies and revisions in Session 1. These findings while supporting psycholinguistic theories that have attributed shared underlying mechanisms to disfluencies and revisions (*e.g.*, Levelt, 1989), also suggest that the CWNS may be using revisions to effectively manage errors and disfluencies from the onset of practice. Furthermore, larger effect size for the increased use of revisions with nonword length in the CWS (*e.g.*, 6- *vs.* 3-PC: CWS, $r = 0.55$; CWNS, $r = 0.38$) seems to support other similar findings in younger CWS that have been interpreted as preliminary evidence for hypermonitoring of speech (*e.g.*, Hollister et al., 2015; Wagovich et al., 2009). However, the present study varies from these previous studies in two notable ways: First, previous studies investigated the use of revisions with varying syntactic complexity from conversational samples of younger CWS while this study used nonwords; second, not all previous studies used a comparison group of fluent speakers. In this study we found significantly fewer revisions for the 6-syllable and the 3-NPC nonwords in the CWS compared to the age-matched CWNS. Thus, our findings failed to confirm heightened use of revisions in school-age CWS when compared to a control group of fluent children and suggested to the contrary that CWS use fewer revisions with increase in task complexity.

4.2.1. Theoretical implications

Based on the postulation of the VCH (Vasić & Wijnen, 2005) of hypermonitoring and the finding of heightened use of revisions in CWS (*e.g.*, Hollister et al., 2015; Wagovich et al., 2009), we hypothesized that compared to the CWNS, the CWS will demonstrate more phonological revisions in the NWR task, because active external monitoring will result in heightened revisions of marginal and covert errors. However, our findings failed to support this hypothesis. Instead, three findings from this study suggested limited external auditory monitoring in the NWR task in the CWS: (1) fewer use of revisions with the longer and complex nonwords compared to the CWNS, (2) increase in both disfluencies and revisions with increase in nonword length, and (3) inconsistent correlation between disfluencies and revisions in Session 1. These findings agree most with the findings from neuroimaging studies that have attributed altered speech and language monitoring to reduced activation of the temporoparietal cortex and increased activation of the ACC during disfluent speech (*e.g.*, Braun et al., 1997; Chang et al., 2009; De Nil et al., 2000; Fox et al., 2000; Salmelin et al., 1998). Therefore, the present findings suggest an evolving role for external auditory monitoring in CWS, with reduced auditory monitoring in school-age CWS being attributable to the inability to sustain attention on disfluencies, errors, and revisions, or to treatment-related internal focus on speech proprioception than external auditory monitoring (Guitar, 2014). Further testing with tasks involving higher linguistic and cognitive demands is required to confirm the present findings. Additionally, based on the psycholinguistic theories that have identified a central domain-general monitoring mechanism (*e.g.*, Nozari et al., 2011), present findings suggest that both overt and covert speech monitoring may be altered in persons who stutter (for recent evidence in support of covert speech monitoring deficits, see, Howell & Ratner, 2018; Coalson, Byrd, & Kuylen, 2017).

4.3. Conclusions and future directions

We investigated the effects of phonological variables – length in syllables, phonotactics, and phonemic/phonetic complexity, on disfluencies in a NWR task in school-age CWS and CWNS. Our findings suggested that nonword lengths that place greater demands on phonological encoding, working memory, and speech motor demands, elicit more disfluencies in school-age CWS. The findings on the effects of phonotactics and phonological complexity on disfluencies were inconclusive and may have elicited significant group differences with more trials to learn the 6-syllable and 3-NPC nonwords. Although the finding of more disfluencies with nonword length supported both the CRH (Postma & Kolk, 1993) and the VCH (Vasić & Wijnen, 2005), the use of fewer phonological revisions and the lack of correlation between disfluencies and revisions in the CWS at the onset of practice suggested reduced external auditory monitoring of disfluent speech in the NWR task. The findings suggested that deficits in phonological encoding and reduced auditory monitoring of speech may co-exist and contribute to disfluencies, speech errors, and revisions observed in the speech of school-age CWS. The findings on phonological revisions in school-age CWS from this study and in younger CWS from other previous studies suggest an emerging role for external auditory monitoring in stuttering.

A few limitations should be considered in discussing the implications of the findings. First, while the homogenous group of CWS and age-matched CWNS is a strength of the study, the relatively small sample size necessitates further testing and confirmation. Second, although participants were not tested for an articulation disorder, an initial screening form and subsequent reading and conversation samples were used to evaluate articulation abilities in all participants. Finally, stuttering is foremost a multidimensional disorder with affective, behaviors, and cognitive consequences to the individual. While the present results have important implications for current theoretical views of stuttering, the findings are specific to the core behavioral features of stuttering, namely disfluencies.

CRediT authorship contribution statement

Jayanthi Sasisekaran: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing - original draft, Visualization, Project administration, Supervision. **Erin J. Weathers:** Investigation, Data curation, Writing - review & editing.

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