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Phonetic complexity of words immediately following utterance-initial productions in children who stutter

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ABSTRACT

Purpose: The purpose of the present study was to analyze phonetic complexity in the speech of children who stutter in a manner distinct from previous research with specific emphasis on three methodological considerations: (1) analysis of the word immediately following the initial word in the utterance; (2) accounting for other additional linguistic and lexical factors; and (3) discrimination of disfluency types produced.
Methods: Parent–child conversations were transcribed for 14 children who stutter (mean age = 3 years, 7 months; SD = 11.20 months) and coded for phonetic complexity using the Word Complexity Measure (WCM). Phonetic complexity of words immediately following the initial fluent or stuttered words of an utterance were included within binomial regression analyses, along with additional linguistic and lexical factors.
Results: Analyses indicate that the phonetic complexity of the second word of an utterance was not a significant contributor to the likelihood of whole- or part-word repetitions on the preceding initial word of the utterance.
Conclusion: Findings support previous data that suggest the phonetic complexity of speech, at least as measured by the WCM, does not distinctly influence stuttered speech in preschool-age children.

1. Introduction

Phonetic complexity is defined by the number of late-developing sounds, sound sequences, and prosodic features required to accurately produce a target word (e.g., Howell, 2004, 2011; Howell & Dworzynski, 2005). The contribution of phonetic complexity to stuttered speech is central to Howell and colleagues' EXPLAN model of stuttering (EX: execution, PLAN: planning). Researchers have explored the phonetic complexity of stuttered words in children and adults using a variety of assessment tools (e.g., Al-Timimi, Khamaiseh, & Howell, 2013; Coalson, Byrd, & Davis, 2012; Dworzynski & Howell, 2004; Howell & Au-Yeung, 1995, 2007; Howell, Au-Yeung, Yaruss, & Eldridge, 2006; Throneburg, Yairi, & Paden, 1994). Across these studies, a relationship between phonetic complexity and stuttering has been observed in older children and adults, but not in children younger than 6 years of age.

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Howell and colleagues (e.g., Howell, 2011; Howell & Au-Yeung, 2002) describe the frequency and type of disfluencies within the context of a phonological word. A phonological word is defined as a speech planning unit comprised of a content word preceded by a function word (Howell & Dworzynski, 2005, pp. 347–350). The EXPLAN model predicts that the phonetic complexity of the content word within a phonological word determines whether stuttering will occur, as well as the type of disfluency produced. According to Howell (2011, pp. 268–269), the presence of a phonetically complex content word requires additional time to prepare. Increased phonetic complexity of the second word may result in two distinct types of stuttered speech: (1) "stalling disfluencies," such as whole-word repetition of the initial, monosyllabic function word, or (2) "advancing disfluencies," such as sound-syllable repetitions, if the speaker prematurely attempts to produce the second, more complex content word. Studies by Howell and colleagues support that the phonetic complexity of the stuttered content words is higher than the phonetic complexity of the fluent content words produced by adults and older children (e.g., Dworzynski & Howell, 2004; Howell & Au-Yeung, 2007; Howell et al., 2006). If increased phonetic complexity provokes stuttered speech, as suggested by the EXPLAN model, one would expect younger children to be particularly vulnerable, as their speech production systems are less mature. Upon review of the theoretical tenets of the EXPLAN model, the reports of non-significant findings in younger children may be related to three methodological limitations.

First, previous studies investigating the predictions of the EXPLAN model in younger children examined the fluency of a word relative to its *own* phonetic complexity (Coalson et al., 2012; Dworzynski & Howell, 2004). However, the EXPLAN model predicts that the presence or absence of stuttering is contingent on the complexity of the upcoming (content) word. Second, when the upcoming word was considered during analysis (e.g., Howell & Au-Yeung, 1995; Throneburg et al., 1994), relevant factors known or suspected to influence speech fluency were not taken into consideration (e.g., word frequency, phonotactic properties, neighborhood density or frequency, utterance length and syntactic complexity). Finally, none of the previous studies considered which types of disfluencies are predicted to occur relative to the phonetically complex word. If stalling and advancing disfluencies occur as predicted by the EXPLAN model, increased phonetic complexity of the word immediately following the stuttered word should predict only the whole-word repetition of the previous word (Howell & Au-Yeung, 1995; Throneburg et al., 1994), while increased phonetic complexity of the word currently in production should predict only the frequency of part-word disfluencies (Coalson et al., 2012; Dworzynski & Howell, 2004). However, across all studies completed to date, no distinction has been made among disfluency types produced. Thus, the purpose of the present study is to analyze phonetic complexity in the speech output of children who stutter in a manner distinct from previous research with specific emphasis on the following methodological considerations: (1) analysis of the word that immediately follows the initial word in the utterance; (2) accounting for other linguistic variables; and (3) distinction of disfluency types produced. In addition, to isolate the most common loci of stuttering during production (e.g., Buhr & Zebrowski, 2009; Richels, Buhr, Conture, & Ntourou, 2010), words in the initial position and immediately following the initial position of utterances were selected.

1.1. Phonetic complexity of the stuttered word

Dworzynski and Howell (2004) explored the phonetic complexity of the stuttered word using the Index of Phonetic Complexity (IPC), a tool developed by Jakielski (2000) to describe the nature of early acquisition patterns in young children's sound inventories. The IPC is an additive index of phonological complexity based on analysis of spontaneous speech. A numerical value is assigned to types of sounds and structures produced by young children in the following areas: (1) consonant place, (2) consonant manner, (3) vowel types, (4) word shapes, (5) word length, (6) consonant reduplication versus variegation, (7) singletons versus clusters, and (8) cluster types (see Table 1 for IPC scoring rubric). IPC points reflect relatively later age of acquisition of associated phonetic constructs. As such, higher IPC scores per word would be expected with age given the similarity of the IPC to typical developmental phonetic milestones (e.g., late-emerging sounds; multisyllabic words, consonant clusters). There are data that suggest children produce increasingly higher mean IPC scores per word across the period of 1–3 years of age (Jakielski, 2002; Jakielski, Matyasse, & Doyle, 2006). These findings support phonetic inventory diversification for sounds and sequences as a reflection of the broadening capacities of the production system.

As previously noted, results from the studies that have employed the IPC indicate that phonetic complexity is associated with stuttered words in older children and adults but similar findings of significance have not been reported in children (Al-Tamimi et al., 2013: 6–11 years of age; Dworzynski & Howell, 2004: beyond 6 years of age; Howell et al., 2006: 11–18 years of age; Howell & Au-Yeung, 2007: beyond 6 years of age). Given that the IPC is based on infant–toddler speech development patterns, these findings are surprising as the fluent speech of younger speakers should presumably be more vulnerable to phonetic difficulty than older speakers. Coalson et al. (2012) argued that these unexpected findings might be attributed to limitations with respect to the use of the IPC and/or other linguistic factors that may have contributed to the observed effects of phonetic complexity with development.

Specifically, Coalson et al. (2012) examined the role of phonetic complexity during stuttered speech in two critical ways that differed from past research. First, they employed Stoel-Gammon's Word Complexity Measure (WCM, 2010). The WCM is a measure of phonetic complexity with constructs similar, but not identical, to the IPC (see Table 1 for comparative scoring rubric). For example, the WCM does not award points for (a) place variegation of consonants within words or clusters, or (b) inter-syllabic clusters. Another key difference from the IPC is that the WCM awards points for (a) voiced fricatives and affricates, and (b) non-initial word stress pattern. Stoel-Gammon also developed the WCM using speech samples of seven children whose age range (17–48 months) was closer to the age of onset of stuttering than the age range of the children

Table 1
Comparative scoring rubric for the Index of Phonetic Complexity (IPC), the Word Complexity Measure (WCM), and Throneburg et al. (1994).

Points	IPC	Points	WCM	Points	Throneburg[a] categories
1	Dorsals	1	Velars/dorsals		N/A
1	Fricatives	1	Fricatives	1	Fricatives
	N/A	1	Voiced fricatives		Voiced fricatives
1	Affricates	1	Affricates		Affricates
	N/A	1	Voiced affricates		Voiced affricates
1	Liquids	1	Liquids/syllabic Liquids		Liquids/syllabic Liquids
1	Rhotics	1	Rhotics		Rhotics
1	Place variegations of consonants within word		N/A		N/A
1	Word-final consonant	1	Word-final consonant		N/A
1	>2 syllables	1	>2 syllables		N/A
	N/A		N/A	1	>1 syllable
1	Consonant clusters (intra-syllabic)	1	Consonant clusters (intra-syllabic)	1	Consonant clusters (intra-syllabic)
1	Consonant clusters (inter-syllabic)		N/A		Consonant clusters (inter-syllabic)
1	Place variegations within clusters		N/A		N/A
	N/A	1	Non-initial stress		N/A

Note: IPC – Index of Phonetic Complexity (Jakielski, 2000); WCM – Word Complexity Measure (Stoel-Gammon, 2010).

[a] Categories from Throneburg et al. (1994).

for whom the IPC was developed (12–36 months). In addition to use of the WCM, Coalson and colleagues also employed logistic regression to account for the following linguistic factors known or suspected to influence speech production or speech fluency: phonotactic probability, phonological neighborhood properties, word frequency, grammatical classification, utterance position, utterance length and syntactic complexity. They reported that when accounting for these factors, phonetic complexity as measured by the WCM, did not uniquely predict the likelihood of stuttering, but three utterance level factors did: (1) length of utterance, (2) syntactic complexity of utterance, and (3) utterance-initial position. Results from Coalson and colleagues were similar to preschool data reported in Dworzynski and Howell (2004) and consistent with the notion that, in young children, a stuttered word is not predicted by its own phonetic complexity. However, the findings reported by Coalson et al. and Dworzynski and Howell are limited in their applicability to the EXPLAN model because neither study examined the complexity of the word that immediately followed the stuttered word.

1.2. *Phonetic complexity of the adjacent word*

If increased phonetic complexity of the second word, or rather the word that is produced after the stuttered word, uniquely compromises the fluency of the initial word, one would expect the phonetic complexity of words *after* the stuttered word to be high, or at least higher than the preceding word. To date, two studies have explored this possibility. Throneburg et al. (1994) devised an eight-category hierarchy of phonetic complexity based on the presence or absence of three core constructs: consonant clusters, multisyllabic words, and late-emergent sounds (see Table 1 for comparative rubric with IPC and WCM). Stuttered and fluent words were collected from connected speech samples of 24 children who stutter (age range: 2 years, 4 months to 4 years, 9 months). Researchers compared the expected versus actual ratio of stuttered words and words immediately following stuttered words in each category. Results indicated that proportions of both the initial stuttered word, and the second word, did not significantly differ across categories of increasing complexity.

Howell and Au-Yeung (1995) examined stuttered and fluent words extracted from six children (age range: 2 years, 7 months to 6 years, 0 months) as well as older children and adults. These authors used the same categorical classification as Throneburg et al. (1994) while also including four covariates based on Brown's (1945) criteria: grammatical classification, consonant difficulty, sentence position, and word length. Similar to Throneburg and colleagues, results indicated no significant difference in phonetic complexity between fluent and stuttered words as well as no significant difference in the phonetic complexity of the stuttered word and the following word. Together, these studies suggest the phonetic complexity of the stuttered word, as well as the following word, is not a factor that distinctly influences the fluency of young children who stutter.

Howell and Au-Yeung (1995) and Throneburg et al. (1994) address one of the core characteristics of the EXPLAN model through their examination of stuttered words relative to the properties of the word produced immediately after the stuttered word. However, similar to Dworzynski and Howell (2004) and Coalson et al. (2012), they define stuttered speech in a manner inconsistent with the predictions of the EXPLAN model. According to Howell and Dworzynski (2005), children are more likely to repeat monosyllabic words immediately prior to complex words, and more likely to produce part-word repetitions or blocks on the upcoming, complex word. Thus, increased phonetic complexity of the second word should predict the presence of whole-word repetitions and interjections on the preceding words, but not part-word repetitions, prolongations or blocks. Researchers across all four studies that examined phonetic complexity in the speech output of preschool-aged children considered a word to be stuttered if it was produced with a sound-syllable repetition, whole-word repetition, prolongation, and/or block (Coalson et al., 2012; Dworzynski & Howell, 2004; Howell & Au-Yeung, 1995; Throneburg et al., 1994). The combination of these four disfluency types, one of which is predicted to occur only on the preceding word (i.e., whole-word repetitions) rather than the complex word itself, may have compromised the ability to accurately distinguish the influence of phonetic complexity on stuttered versus non-stuttered words.

Another critical consideration is that the studies completed thus far have extracted individual words from connected speech samples, but few have considered the linguistic factors that may also contribute to the difficulties individuals who stutter have establishing fluent speech. Moreover, if linguistic factors were included during analyses, examination of phonetic complexity was restricted to the stuttered word rather than the word produced immediately after the stuttered word. Recent investigations of the role of phonetic complexity in older children and adults who stutter suggest linguistic factors such as low neighborhood density, in addition to phonetic complexity, may increase the likelihood of stuttered speech (LaSalle & Wolk, 2011; Wolk & LaSalle, 2015, cf. Coalson et al., 2012). With particular relevance to the EXPLAN model, certain lexical properties have been found to delay speech planning of a target word in individuals who stutter when measured in conjunction with phonetic complexity. For example, Byrd, Coalson, Yang, and Moriarty (in press) reported that phonetic complexity alone was not a unique predictor of speed, accuracy, or fluency of production in adults who stutter during a confrontational naming task. However, if additional word-level factors such as low neighborhood density, low neighborhood frequency, and low word frequency were present in addition to increased phonetic complexity, speech reaction time was significantly slower for adults who stutter, but not typically fluent adults. If this is also the case in children, consideration of these factors in addition to phonetic complexity when examining the properties of the word following the stuttered word would lend additional support to the assumption that stuttered speech occurs due to delayed planning of the word yet to be produced.

1.3. Summary and purpose of the present study

In the present study we examined the relationship between phonetic complexity of the second word in the utterance on two different types of disfluencies – whole-word repetitions and sound-syllable repetitions – produced on the initial word. Nine additional word- and utterance-level factors were considered during analyses to isolate the contribution of phonetic complexity within the context of the EXPLAN model. In accordance with the EXPLAN model, we predicted that increased phonetic complexity of the word produced after the stuttered word would uniquely predict whole-word disfluencies, but not part-word disfluencies, on the preceding word.

2. Methods

Participants, classification, inclusion criteria, data collection, transcription protocol and coding procedure in this study were similar to that of Coalson et al. (2012) and are provided for ease of understanding and replication. However, two major distinctions from this previous study exist: (a) accounting for utterance position by restriction of data set, rather than as an independent predictor variable, and (b) analysis of the second word in the utterance relative to the fluency of the preceding word, rather than each stuttered word in isolation to assess the specific predictions of the EXPLAN model.

2.1. Participants

Participants were 14 native, monolingual English-speaking children who stutter (8 boys, 6 girls; mean age = 3 years, 8 months; SD = 11.20 months; range = 2 years, 7 months to 5 years, 9 months) who had been diagnosed with stuttering by a certified speech-language pathologist. The reported mean time since onset of stuttering was 8.5 months (SD = 9.1 months; range = 0.5 months to 2 years, 7 months). See Table 2 for participant description. All participants presented with normal hearing, language and speech skills, with the exception of stuttering, as reported by parents and observed during a formal speech and language evaluation.

2.2. Classification and inclusion criteria

2.2.1. Speech, language and hearing measures

Participants passed a bilateral pure tone hearing screening at 20 dbHL for 1000, 2000 and 4000 Hz (ASHA, 1997). All 14 participants performed within normal limits (i.e., no less than 1 standard deviation below the mean) on the *Peabody Picture Vocabulary Test-III* (PPVT-III; Dunn & Dunn, 1981), the *Expressive Vocabulary Test* (EVT; Williams, 1997), and the *Goldman-Fristoe Test of Articulation-II* (GFTA-2; Goldman & Fristoe, 2000). All participants scored within two standard deviations of the group mean on measures of vocabulary (EVT *z-score* range: −1.77 to 1.63; PPVT-III *z-score* range: −1.44 to 1.93) and lexical diversity (TTR *z-score* range: −1.71 to 1.54). All participants also presented with a mean length of utterance (MLU range: 2.21–4.87) and articulation skills (GFTA-2 range: 91–127) that were within normal limits. See Table 2 for a review of participant performance on across measures.

Table 2
Participant characteristics for standardized speech-language measures, stuttering measures, and distribution of word pair tokens.

Participant	Gender	Age (m)	PPVT-III	EVT	GFTA-2	TSO (m)	%SLD	SSI-3	MLU	TTR	SSR	WWR	Total word pairs
1	M	31	131	N/A[a]	127	2	21.3	27	2.91	0.47	1	1	16
2	M	33	108	110	111	8	4.33	18	3.38	0.35	1	4	63
3	F	35	95	104	93	3	5	18	2.21	0.32	1	1	53
4	F	35	119	114	117	3	13	24	4.03	0.31	1	0	65
5	F	38	89	109	109	2	3.22	18	3.08	0.27	0	1	85
6	M	38	102	99	91	0.5	3.5	15	3.82	0.37	6	0	36
7	F	40	108	102	97	5	5	14	3.25	0.45	2	2	29
8	M	46	94	95	120	3	7.7	19	3.81	0.39	1	2	43
9	M	46	105	114	107	16	3	8	3.31	0.31	2	3	87
10	F	47	102	108	103	15	12.67	24	3.19	0.44	5	2	32
11	M	49	113	108	115	1	11.66	26	3.52	0.48	2	6	25
12	F	52	112	93	99	9	5.33	22	3.19	0.37	1	0	49
13	M	63	133	119	114	21	3	11	4.87	0.41	0	1	61
14	M	69	99	110	99	31	3.6	14	3.79	0.39	0	4	102
M		44.43	107.86	106.54	107.29	8.5	7.31	18.43	3.45	0.38			
SD		11.20	13.02	7.64	10.73	9.1	5.42	5.69	0.61	0.06	*N* = 23	*N* = 27	*N* = 746

Note: M = mean; SD = standard deviation; Age (m) = age in months; PPVT-III: Peabody Picture Vocabulary Test-Third Edition (standard score); EVT = Expressive Vocabulary Test (standard score); GFTA-2 = Goldman-Fristoe Test of Articulation-2 (standard score); TSO = parent-reported time since initial onset of stuttering (months); %SLD = mean frequency of stuttering-like disfluencies (percent) per 100 words; SSI-3 = Stuttering Severity Instrument-3 (total score); MLU = mean length of utterance (in morphemes); TTR = type-token ratio (in total utterances); WWR = whole-word repetitions; SSR = sound-syllable repetitions.

[a] N/A = formal testing unavailable at time of testing. Total word pairs calculated after removal of content-content word pairs (*n* = 74).

2.2.2. *Criteria for diagnosis of stuttering*

To be considered a child who stutters and, thus, qualify for participation in the present study, each child had to meet the following criteria: (a) present with greater than three instances of stuttering-like disfluencies (i.e., monosyllabic-word repetitions, sound/syllable repetitions, and/or audible and inaudible sound prolongations) per 100 words on three consecutive 100 word conversational samples (Yairi & Ambrose, 2005), (b) parent report of concerns about the child's fluency, and (c) diagnosis of stuttering by a certified speech-language pathologist. See Table 2 for descriptive statistics for each participant related to measures of stuttering.

2.3. *Procedures*

During analysis, the dependent variable was the stuttering classification of each initial word, or rather whether the word was produced with or without a stuttering-like disfluency (SLD). There were nine independent lexical and linguistic predictor variables, including: phonetic complexity as measured by the WCM, segmental phonotactic probability, biphone phonotactic probability, length of utterance, syntactic complexity of utterance, word frequency, neighborhood density, neighborhood frequency, and grammatical classification. In addition to these linguistic and lexical control factors, two additional non-linguistic factors were entered into the analyses: (a) age, to account for the variance in skills due to maturation, and (b) individual participants, to account for the unequal contributions of stuttered words cross participants to the data. Procedures of measurement for each variable are discussed in following sections.

2.3.1. *Data collection*

After the child completed the formal testing and it was confirmed that the participant met the aforementioned criteria, the parent and child were instructed to complete a conversational interaction in a therapy room. They were told to talk to each other 'as they would at home.' Each interaction lasted approximately 20 min and was video-taped.

2.3.2. *Transcription analysis*

The conversational interactions between parents and their children were transcribed offline by four undergraduate research assistants with each assistant completing one to four of the 14 samples. These assistants were trained in phonetic transcription, identification of utterance boundaries, specification of stuttering type and determination of intelligibility.

Words produced by the participants in the initial corpus were coded for fluency based on definitions provided by Yairi and Ambrose (2005: whole-word repetitions, sound-syllable repetitions, prolongations and/or blocks). An utterance was defined in the same way it has been in previous studies (e.g., Logan, 2001; Logan & Conture, 1997; Logan & LaSalle, 1999; Meyers & Freeman, 1985; Yaruss, 1999). Specifically, to be considered an utterance it had to (a) be set apart by a pause, (b) communicate information, and (c) be bound by one intonational contour. Nonspeech words, interjections, unintelligible words, and inaudible words were not included in the data analysis or calculation of utterance length (Miller & Iglesias, 2006). Interrupted, abandoned or imitative utterances were also excluded (Johnston, 2001; Sawyer, Chon, & Ambrose, 2008). In addition, one-word utterances were excluded from the final data analysis similar to methods described by Logan and Conture.

2.3.3. *Reliability of transcribed samples*

Uncertainties regarding phonetic judgment, stuttering type, utterance boundaries, or intelligibility were resolved through review and discussion with at least one of the two authors. Reliability for phonetic judgment, stuttering type, utterance boundaries, and intelligibility on 100% of the transcribed data was achieved by 100% consensus between the authors and the four trained research assistants.

To further ensure reliability of the transcribed samples, five additional research assistants were again trained in the language and stuttering analysis procedures. Each of these research assistants completed a second review of one to three of the 14 transcribed samples. Similar to the original transcription process, any uncertainties, which were significantly few given the processing of the original transcripts, were again discussed with at least one of the two authors.

Using these criteria, after the initial and subsequent review, the usable data corpus included 4096 words (of a total 5109 words; 3882 produced without an SLD, 214 produced with an SLD). The usable data corpus was comprised of words that were fully intelligible (Eisenberg, Fersko, & Lundgren, 2001; Logan & Conture, 1995; Melnick & Conture, 2000; Miller & Chapman, 1981) and did not have any remaining discrepancies relative to coding of stuttering or utterance boundary identification.

Each word within each utterance was then coded for segmental and biphone phonotactic probability, word frequency, neighborhood density and neighborhood frequency by the same five research assistants who completed the re-analysis of the initial glosses of the 14 conversational samples. These research assistants also coded for length of utterance and syntactic complexity. Five additional research assistants coded the same words for phonetic complexity as measured by the WCM, and grammatical classification.

In contrast to Coalson et al. (2012), which examined all words within spoken utterances ($n = 4096$), the data corpus for the present study was restricted to the first two words of each utterance. It is well known that utterance-initial words are most frequently stuttered during spontaneous speech in children (e.g., Buhr & Zebrowski, 2009; Richels et al., 2010). Rather than include utterance position as an independent predictor variable, only the first and second word of each utterance was included in the final data corpus to control for the influence of utterance position. Thus, the data set was reduced to 924 initial words and 924 second words (1848 words total). The comprehensive transcription procedures applied to the original corpus ($n = 5109$, 100% of words with any discrepancies resolved) also applies to the current corpus as it is a subset of that original corpus.

The EXPLAN model provides predictions specific to individual types of disfluencies at the single word level (e.g., whole-word repetitions, single-sound repetitions, prolongations, blocks, interjections, and phrase repetitions), but does not address disfluency clusters or revisions. Thus, initial words that were produced as part of a cluster of disfluencies (e.g., "[C* C* Caaaan] Can he. . ."; $n = 39$) and/or revision (e.g., "[Can the] Can he. . ."; $n = 11$) were removed from the final corpus. In addition, initial words produced as part of a phrase repetition (e.g., [Can he] can he. . ."; $n = 11$) were removed from the final data corpus, as the nature of these disfluencies would require fluent repetition of the initial two words and potentially reflect difficulties beyond the portion of the utterance examined in the present study. Unfortunately, too few sound prolongations or blocks were produced to provide meaningful analysis ($n = 10$) and were also removed. Finally, words produced with an interjection were removed ($n = 33$) to ensure the stalling and advancing disfluencies included in the study were considered "stuttering-like" in nature (e.g., Yairi & Ambrose, 2005). Thus, the final corpus prior to model-fitting procedures resulted in 820 usable word pairs, including 770 fluent words in initial position, 23 produced with sound-syllable repetitions, and 27 produced with whole-word repetitions. The mean frequency of SLDs within the final corpus (sound-syllable repetitions + whole-word repetitions = 50, total words = 820; 6.10%) was similar to the mean frequency of stuttering observed across participants during intake procedures (7.31%, see Table 2) and considered representative of typical stuttering frequency across the 14 participants.

2.3.4. *Phonetic complexity*

Words were analyzed for phonetic complexity using the WCM (Stoel-Gammon, 2010). WCM scores were calculated for each of the initial two words of an utterance. During word-level analysis, phonetic complexity scores were not controlled for length of word because length-sensitive factors were included within the WCM rubric. Specifically, the WCM awards points for number of syllables in a word and consonant clusters, both of which increase the length of a word. Thus, raw WCM scores were calculated for each word. Phonetic complexity was the primary factor of interest. Additional factors were included to control for their potential relationship to fluent and stuttered speech production (segmental phonotactic probability, biphone phonotactic probability, utterance length, syntactic complexity, word frequency, neighborhood density, neighborhood frequency, grammatical classification).

2.3.5. *Phonotactic probability*

Values for phonotactic probability were obtained for each word from an online database established by Storkel and Hoover (2010: Child Mental Lexicon [CML]; available from http://www2.ku.edu/~wrdlrng/), which consists of combined corpora of word produced by children in kindergarten and first-grade. Each word was scored for segmental position probability (i.e., mean frequency of the same individual phoneme in the same position in all words) and biphone probability (i.e., mean frequency of the same pair of phonemes in the same word position in all words). When coding individual words, length of word (number of phonemes in the word) was controlled by converting phonotactic probability scores for each word into *z-scores* using length-dependent and age-appropriate means and standard deviations established by Storkel and Hoover.

2.3.6. Utterance length

Length of the utterance was calculated by counting the number of syllables within each utterance (e.g., Brundage & Bernstein Ratner, 1989; Logan & Conture, 1997; Logan & LaSalle, 1999). To account for differences in typical utterance length produced across ages, as well as the potential effect on fluency as utterances exceed the child's average length (e.g., Zackheim & Conture, 2003), raw values were transformed to *z-score*s. This transformation provided consideration as to whether each utterance was above or below that child's mean number of syllables per utterance.

2.3.7. Syntactic complexity

Similar to Logan (2001), utterance complexity was defined as number of clauses per utterance, and clauses were defined as containing a noun and a predicate. Raw number of clauses were also transformed to *z-score*s based on the child's mean number of clauses to account for the complexity of the utterance relative to the child's typical syntactic output.

2.3.8. Word frequency, neighborhood density and neighborhood frequency

A described in Coalson et al. (2012), values for word frequency, neighborhood frequency and neighborhood density were obtained for each word from the same online database (CML; Storkel & Hoover, 2010) used to obtain phonotactic probability. Word frequency was defined as log frequency of the word in the database. Neighborhood frequency was defined as the mean log frequency of associated neighbors (sum of word frequency of neighbors divided by the total number of neighbors). Neighborhood density was defined as the number of words that differ from the target word by the substitution, addition or deletion of one phoneme. If words were not found in the CML, values were obtained from the Hoosier Mental Lexicon (HML) adult database (see Luce & Pisoni, 1998; Luce, Pisoni, & Goldfinger, 1990; available at http://128.252.27.56/neighborhood/Home.asp).

During coding of individual words, raw values for word frequency, neighborhood density and neighborhood frequency were obtained. As stated in Storkel (2004), length of word as measured by the number of phonemes has been shown to correlate with neighborhood density. However, *z-score* values of neighborhood density have shown a non-significant correlation with word length. By comparison, other value transformations have been shown to significantly correlate with word length (i.e., median transformations), length-dependent and age-appropriate data have not been collected in current literature (Storkel & Hoover, 2010). Thus, raw values of neighborhood density were used during coding and subsequent analysis.

2.3.9. Grammatical classification

Words within the utterance were defined as either function or content words using criteria identical to Howell's studies (i.e., Dworzynski & Howell, 2004; Howell & Au-Yeung, 2007; Howell et al., 2006) per description by Hartmann and Stork (1972) and Quirk, Greenbaum, Leech, and Svartvik (1985). Function words were considered pronouns, articles, prepositions, conjunctions, copula verbs, and auxiliary verbs. Content words were considered nouns, main verbs, adverbs, and adjectives.

Although strict interpretation of the EXPLAN model would predict that disfluencies would occur primarily during function content word pairs, in the present study, the initial and second words included in the corpus were not restricted to this grammatical pattern. Our rationale to examine all initial and second word pairs, regardless of grammatical composition, was to allow comparison to similar analyses conducted in previous studies by Howell and colleagues' (i.e., Dworzynski & Howell, 2004; Howell & Au-Yeung, 2007; Howell et al., 2006). Nonetheless, post hoc analyses were conducted using a smaller data set restricted to function-content word pairs to more directly assess the predictions of the EXPLAN model.

2.3.10. Age

The age in months of each child was included as an additional control factor to account for the diverse range of linguistic abilities, as well as the potential correlation with phonetic complexity (e.g., Jakielski, 2002; Jakielski et al., 2006).

2.3.11. Individual participant variability

Due to the clustered nature of the data (words nested within participants), and to account for the variance in stuttering severity between participants, the analysis was controlled for non-independence by including individual participants as an additional categorical predictor variable.

2.3.12. Reliability of word coding procedures

Prior to completing an analysis of the final data corpus, two different research assistants and the first author re-calculated all coded values on 20% of the 1828 words ($n = 370$) randomly extracted from the full, usable data corpus (i.e., WCM, grammatical classification, segmental phonotactic probability, biphone phonotactic probability, word frequency, neighborhood density, neighborhood frequency, length of utterance and complexity of utterance). Inter-rater reliability was determined using agreement indices (i.e., agreement divided by agreements plus disagreements, multiplied by 100) and intra-class correlation coefficients, respectively, for the aforementioned linguistic and phonetic factors. Results were as follows: WCM: 99.2%, 0.99; segmental phonotactic probability, 98.1%, 0.99; biphone phonotactic probability: 98.4%, 0.99; length of utterance: 94.1%, 0.89; syntactic complexity: 93.5%, 0.91; word frequency: 98.1%, 0.96; neighborhood density: 99.5%, 0.99; neighborhood frequency: 98.9%, 0.99; and grammatical classification: 93.2%, 0.91.

2.4. Statistical analysis

2.4.1. Phonetic complexity

The primary purpose of the current study was to examine the phonetic complexity of words that followed stuttered words (i.e., sound-syllable repetitions and whole-word repetitions), when accounting for phonotactic probability, word frequency, neighborhood frequency, neighborhood density, grammatical classification, length of utterance, syntactic complexity of utterance, age and participant variance. To determine if these predictors (continuous and categorical independent variables) provided unique information in predicting the fluency of a previously spoken word (categorical dependent variable), four binary logistic regression analyses were completed.

2.4.2. Absolute value of second word

According to one interpretation of the EXPLAN model, the presence of an upcoming word of sufficiently high phonetic complexity could trigger disfluency on the initial word, regardless of the complexity value of that initial word. Therefore, the first two binary logistic regression analyses were conducted using the *absolute* value of the second word for all predictor variables. Each disfluency type relative to fluent words served as the categorical dependent variable for each binary logistic regression model (i.e., sound-syllable repetition and fluent words, whole-word repetition and fluent words), with fluent words as the reference category in each analysis.

2.4.3. Difference values between initial and second words

The second two binary logistic regression analyses were conducted using the *difference* between the initial word and the second word, rather than the absolute value of the second word. Previous studies that have examined the upcoming word's phonetic complexity measured the absolute value of the following word (Howell & Au-Yeung, 1995; Throneburg et al., 1994). However, based on the theoretical framework described by Howell and colleagues (e.g., Howell, 2011; Howell & Au-Yeung, 2002; Howell & Dworzynski, 2005), it is equally possible that the difference in complexity between words, rather than the absolute value of the upcoming word may be more problematic, as shorter and 'less complex' words preceding a complex word would be theoretically more disruptive than two consecutive easy or complex words. Therefore, we also examined the relative difference in phonetic complexity between both words, in addition to the absolute value. To calculate difference values, the value of the second word was subtracted from the first word. As such, continuous variables could be positive or negative values.

2.4.4. Multicollinearity of predictor variables

Previous studies suggest possible inter-correlation between the effects of phonotactic probability, word frequency, neighborhood density neighborhood frequency, and grammatical classification (Anderson, 2007; Storkel, 2004; Storkel, Maekawa, & Hoover, 2010), as well as utterance-level factors such as length and syntactic complexity (e.g., Brundage & Bernstein Ratner, 1989; Logan & Conture, 1995), and age with overall linguistic, lexical, and phonetic abilities. Further, Howell and colleagues report the relationship between phonetic complexity and grammatical classification (e.g., Dworzynski & Howell, 2004; Howell et al., 2006). For these reasons, prior to completing the analyses, tests of multicollinearity were conducted to determine the degree of inter-relatedness of all nine lexical and linguistic predictor variables (i.e., phonetic complexity, segmental and biphone phonotactic probability, word frequency, neighborhood density, neighborhood frequency, grammatical classification, length of utterance, and syntactic complexity) as well as age and individual participant variance.

Multicollinearity was indicated by VIF values greater than 4, a level corresponding to a doubling of the standard error of the coefficient. In addition VIF values approaching 10 or greater suggest problematic degrees of multicollinearity (Cohen, Cohen, West, & Aiken, 2003). Tolerance close to 1.0 indicates a high degree of independence in the variance of a single factor from other predictor factors; tolerance values near .10 indicate redundancy and a high degree of variance (i.e., 90%) that is attributable to other predictors included in the equation.

2.4.5. Model estimation

Initial assessment of logistic regression models revealed two necessary modifications. First, entry of age and individual participant variability as predictor variables lowered the tolerance level of each below acceptable criterion (0.10). That is, a large degree of variance (i.e., 94–95%) was shared by both age and individual participant variability, as indicated by low tolerance values (range: 0.085–0.086) and high VIF values (range: 11.55–11.75) across all four models. Removal of age as a factor resulted in a smaller difference in variance explained (as measured by R-squared) across the four models when compared to individual participant variability. Therefore, to maintain the unbiased estimates and standard errors during analyses, age was removed as a predictor variable prior to final analyses. Second, inflated standard error during analysis revealed a zero-count violation for content–content word pairs – that is, no variance was observed because all tokens were produced without disfluency (see Appendix A). Thus, content–content word pairs were removed ($n = 74$) to maintain the standard error for each categorical level and reliably compare remaining grammatical word pairs.

Upon removal of these elements, multicollinearity diagnostics indicated four robust logistic regression models for the remaining 746 word pairs (696 fluent, 23 sound-syllable repetitions, 27 whole word repetitions). For the logistic regression models comparing sound-syllable repetition and fluent words, VIF and tolerance values for the absolute value model were 1.023–1.889, and 0.529–0.977, respectively. VIF and tolerance values for the difference model were 1.048 and 1.996, and .501

Table 3
Odds ratios and confidence intervals for words following utterance-initial sound-syllable and whole-word repetitions.

Predictor variable	B (SSR/WWR)	OR (SSR/WWR)	SE (SSR/WWR)	Lower CI (SSR/WWR)	Upper CI (SSR/WWR)	p (SSR/WWR)
Phonetic complexity	0.154/0.055	1.166/1.057	0.201/0.178	0.786/0.746	1.729/1.497	.445/.756
Phonotactic probability						
Segmental	−0.075/0.390	0.928/1.477	0.344/0.329	0.473/0.776	1.822/2.814	.828/.235
Biphone	0.327/−0.158	1.387/0.854	0.308/0.309	0.759/0.467	2.535/1.564	.288/.610
Word frequency	0.423/−0.465	1.527/0.628	0.397/0.259	0.701/0.378	3.324/1.043	.286/.072
Neighborhood density	−0.048/−0.009	0.953/0.991	0.035/0.030	0.890/0.934	1.020/1.050	.167/.752
Neighborhood frequency	0.315/0.242	1.370/1.274	0.395/0.317	0.632/0.685	2.971/2.370	.425/.445
Grammatical class – content word	0.504/0.258	1.655/1.294	0.547/0.511	0.567/0.475	4.831/3.523	.357/.614
Length of utterance	0.456/0.027	1.577/1.027	0.229/0.231	1.007/0.653	2.469/1.616	**.046***/.908
Syntactic complexity	−0.186/0.543	0.830/1.722	0.270/0.278	0.489/0.746	1.408/2.967	.489/.050
Individual participant variability	1.921/0.357	6.827/1.429	0.794/0.608	1.439/0.434	32.387/4.702	**.016***/.557

Note: SSR: sound-syllable repetitions; WWR: whole-word repetitions; B: coefficient; OR: odds ratios; SE: standard error; CI: confidence interval (95%); phonotactic probability scores (segmental and biphone) calculated using *z-scores*; age measured in months; length of utterance and syntactic complexity calculated using *z-scores* based on participant mean and standard deviation.

* $p < .05$.

and .954, respectively. For logistic regression models comparing whole-word repetition and fluent words, VIF and tolerance values for the absolute value model were 1.019–1.817, and 0.550–0.982, respectively. VIF and tolerance for the difference value model were 1.044–1.950, and 0.513–0.957, respectively. These results indicate that although certain variables naturally correlate (e.g., utterance length and syntactic complexity), the inter-correlation between these and other variables was not significant. Thus, the 10 remaining predictors, excluding age, were included in the logistic regression analyses.

2.5. Goodness-of-fit

To assess the 'goodness-of-fit' of the four regression models, overall model significance and Hosmer and Lemeshow tests were conducted. Non-significant Hosmer and Lemeshow tests indicate a 'good-fitting' model. Across all four analyses, an adjusted threshold was determined for predicted probability of rare events (i.e., sound-syllable repetition = 27, whole-word repetition = 23) to maximize the sensitivity of classification. The optimal classification cutoff value of 0.05 was established using the Receiver Operating Characteristic procedure described by Chan (2004), with sensitivity = .739, specificity = .853. Finally, variance of stuttering explained within the models was assessed using Nagelkerke R-squared tests (range 0–100%).

2.5.1. Sound-syllable repetition models

For binary regression analysis with sound-syllable repetition and fluent words as dependent variables, the absolute value model was statistically significant, X^2 (22, $N = 719$) = 51.983, $p < .001$, indicating that the model was able to distinguish between sound-syllable repetition and fluent words in 85.1% of cases (85.5% fluent words, 73.9% sound-syllable repetitions). Further, Hosmer and Lemeshow test for the model was non-significant (X^2 (8) = 4.467, $p = .813$). Nagelkerke R-squared test indicated that as a whole the model explained 28.3% of the variance associated with stuttering. The difference value model was also statistically significant (X^2 (23, $N = 719$) = 51.083, $p < .001$; Hosmer and Lemeshow, X^2 (8) = 2.410, $p = .966$), indicating that the model was able to distinguish between sound-syllable repetition and fluent words, and correctly classified 85.0% of cases (85.2% fluent words, 78.3% sound-syllable repetitions). The difference value model as a whole explained 27.8% (Nagelkerke R-squared) of the variance of stuttering.

2.5.2. Whole-word repetition models

For binary regression analysis with whole-word repetition and fluent words as dependent variables, the absolute value model was statistically significant (X^2 (22, $N = 723$) = 42.451, $p = .006$; Hosmer and Lemeshow: X^2 (8) = 4.660, $p = .793$), indicating that the absolute value model was able to distinguish between whole-word repetition and fluent words in 76.9% of cases (77.2% fluent words, 70.4% whole-word repetitions). Nagelkerke R-squared tests indicated that as a whole the model explained 20.9% of the variance associated with stuttering. The difference value model was also statistically significant (X^2 (23, $N = 723$) = 42.990, $p = .007$; Hosmer and Lemeshow, X^2 (8) = 2.669, $p = .953$), indicating that the model was able to distinguish between whole-word repetition and fluent words, and correctly classified 78.0% of cases (78.0% fluent words, 77.8% whole-word repetitions). The difference value model as a whole explained 21.1% (Nagelkerke R-squared) of the variance of stuttering.

Table 4
Odds ratios and confidence intervals for the difference value between initial disfluency (sound-syllable and whole-word repetitions) and second word in the utterance.

Predictor variable	B (SSR/WWR)	OR (SSR/WWR)	SE (SSR/WWR)	Lower CI (SSR/WWR)	Upper CI (SSR/WWR)	*p* (SSR/WWR)
Phonetic complexity	−0.102/−0.082	0.903/0.921	0.153/0.127	0.669/0.718	1.218/1.182	.503/.520
Phonotactic probability						
Segmental	−0.075/−0.150	0.928/0.861	0.245/0.235	0.575/0.543	1.498/1.365	.760/.523
Biphone	0.254/0.116	1.289/1.123	0.242/0.228	0.801/0.718	2.073/1.756	.296/.611
Word frequency	−0.100/0.130	0.905/1.139	0.240/0.198	0.565/0.772	1.449/1.679	.676/.513
Neighborhood density	0.000/0.007	1.000/1.007	0.025/0.021	0.951/0.966	1.051/1.050	1.000/.742
Neighborhood frequency	−0.384/0.171	0.681/1.186	0.285/0.238	0.390/0.744	1.190/1.890	.177/.473
Grammatical class						
Function–function[a]						
Content–function	−0.787/−0.846	0.455/0.429	0.701/0.838	0.115/0.083	1.799/2.217	.262/.313
Function–content	0.151/0.025	1.163/1.026	0.569/0.521	0.381/0.369	3.547/2.849	.791/.961
Length of utterance	0.493/0.054	1.637/1.056	0.232/0.238	1.040/0.663	2.578/1.682	**.033**[*]/.819
Syntactic complexity	−0.223/0.517	0.800/1.678	0.264/0.294	0.477/0.942	1.342/2.988	.398/.079
Individual participant variability	2.068/0.362	7.905/1.437	0.813/0.606	1.606/0.438	38.906/4.713	**.011**[*]/.550

Note: SSR: sound-syllable repetition; WWR: whole-word repetition; B: coefficient; OR: odds ratios; SE: standard error; CI: confidence interval (95%); phonotactic probability scores (segmental and biphone) calculated using *z-scores*; age measured in months; length of utterance and syntactic complexity calculated using *z-scores* based on participant mean and standard deviation.

[a] Reference category.

[*] $p < .05$.

3. Results

Outcomes of each regression analysis for individual disfluency types were described in terms of odds ratio (i.e., *OR*) and confidence intervals (i.e., *CI*). See Tables 3 and 4 for lists of odds ratios and significance for results of absolute value and difference value analyses, respectively.

3.1. Phonetic complexity

While accounting for the effects of phonotactic probability, word frequency, neighborhood density, neighborhood frequency, grammatical classification, length of utterance, syntactic complexity, and individual participant variability, the absolute value of phonetic complexity of the following word was not a significant predictor of greater odds of producing sound-syllable repetitions ($OR = 1.166$, $p = .445$) or whole-word repetitions ($OR = 1.057$, $p = .756$). Similarly, when accounting for the same factors, the difference between phonetic complexity of target and the following word was not a significant predictor of greater odds of producing sound-syllable repetitions ($OR = 0.903$, $p = .503$) or whole-word repetitions ($OR = 0.921$, $p = .520$). Thus, as phonetic complexity between first and second words fluctuated, the odds or likelihood that the target word would be produced with either stuttering-like disfluency did not change.

3.2. Significance of controlled variables

When measuring absolute and difference values, only length of utterance exhibited significant predictive value of a target word being produced with a sound-syllable repetition during both analyses (absolute value: $OR = 1.577$, $p = .046$; difference value: $OR = 1.637$, $p = .033$). That is, when accounting for all other mentioned variables, the odds of an utterance-initial word being produced with a sound-syllable repetition increased by 597.7–63.7% as the length of the utterance increased by one standard deviation above the speaker's own mean number of syllables per utterance.

Syntactic complexity approached but did not reach significance as a predictive factor for whole-word repetitions in the absolute value analysis ($OR = 1.722$, $p = .050$) or the difference value analysis ($OR = 1.678$, $p = .079$). Finally, individual participant variability was a significant predictor of sound-syllable repetitions (absolute value: $OR = 6.827$, $p = .016$; difference value: $OR = 7.905$, $p = .011$), but not whole-word repetitions (absolute values: $OR = 1.429$, $p = .557$; difference value: $OR = 1.437$, $p = .550$) across both regression models.

3.3. Grammatical class

According to the EXPLAN model, whole-word repetitions would be most frequent for function words followed by a complex content word. To test this prediction, post hoc analyses were conducted using a data set restricted to function-content word pairs ($n = 148$). Absolute and difference value logistic regression analyses were conducted, while also accounting for all remaining factors (excluding grammatical classification). Phonetic complexity of the following content word was not a significant predictor of whole-word repetition within either model (absolute value: $OR = 2.735$, $p = .173$; difference value: $OR = 0.703$, $p = .348$).

4. Discussion

The purpose of this study was to examine the potential contribution of phonetic complexity to stuttered speech in preschool age children. Three methodological considerations were taken into account to examine the predictions of the EXPLAN model (Howell, 2011). First, the phonetic complexity of the second word in the utterance relative to the fluency of the initial word was assessed. Second, we distinguished between disfluencies predicted to occur prior to complex words (i.e., whole-word repetitions) and disfluencies not predicted to occur on words preceding phonetically complex words (i.e., sound-syllable repetitions). Third, we accounted for nine additional factors to control for linguistic and lexical variables known to impact the speed, accuracy, and fluency of production. Findings suggest that phonetic complexity of the second word produced within an utterance is not a significant predictor of any disfluency type produced on the initial word.

The EXPLAN model does not specify whether the raw phonetic complexity of the word yet to be produced creates an elevated "threshold" of phonetic difficulty that prompts stuttering, or whether the relative difference between the word being produced and the word to follow creates temporal planning disruptions that result in stuttered speech. Therefore, each interpretation was assessed independently by examining both the absolute phonetic complexity (i.e., WCM value) of the upcoming or second word as well as the difference value between the initial and second word. In both analyses, phonetic complexity was not a significant predictor of stuttering frequency in children and provide further support that complexity of a word is not associated with fluent production of the previous word, irrespective of interpretation of the EXPLAN model.

4.1. Methodological considerations

Comparable stuttering frequency regardless of the phonetic complexity of the next word support previous findings that fluency does not fluctuate due to the phonetic complexity of upcoming words in preschool-aged children who stutter (Howell & Au-Yeung, 1995; Throneburg et al., 1994). However, interpretations across previous research should be made with caution given the methodological differences between studies. For example, unlike previous research (e.g., Dworzynski & Howell, 2004; Howell & Au-Yeung, 1995; Howell et al., 2006), the present study limited analyses to the first two words of the utterance, and analyses excluded disfluent words produced within a cluster. In addition, and also unlike previous studies, the present study did not conduct separate analyses for function and content words (e.g., Dworzynski & Howell, 2004). Instead, the regression analyses were designed to assess the contribution of grammatical class by including it as one of several predictors while also examining phonetic complexity in children who stutter. These methodological differences may limit direct comparisons to previous research, but also allow greater sensitivity to isolate the contribution of factors which often co-occur with grammatical class (e.g., word frequency, phonetic complexity, utterance position).

When accounting for these co-occurring factors, grammatical class of the following word was not a significant contributor to stuttering in the present study. However, strict interpretation of Howell's (2011) EXPLAN model indicate that whole-word repetitions would occur primarily on monosyllabic, function words that precede high complexity content words. To more directly address this specific prediction, post hoc regression analyses were conducted for function-content word pairs alone in accordance with the EXPLAN model. Although data were reduced relative to the original analyses, results indicated that the phonetic complexity of the content word was not significantly associated with the fluency of the preceding word. In addition, whole-word repetitions were also observed on content-function pairs and in greater number for function–function pairs – grammatical combinations that would not be predicted to produce whole-word repetitions within the EXPLAN model (see Appendix A). These data, although limited, do not support that whole-word repetitions were exclusively linked to function-content word pairs as predicted by the EXPLAN model. However, as proposed by Buhr and Zebrowski (2009), data support the notion that moments of stuttering during early development – particularly at the utterance-initial position – appear to be more closely associated with planning utterance-level factors, such as utterance length, as opposed to word-level factors, such as grammatical class or phonetic complexity. Future studies are required to examine the role of these same utterance- and word-level factors over time, and at ages that more closely match the cohorts for which phonetic complexity (and grammatical classification) have been linked to overt moments of stuttering (e.g., Al-Timimi et al., 2013; Dworzynski & Howell, 2004; Howell & Au-Yeung, 2007; Howell et al., 2006).

4.2. Influence of additional variables

Another critical difference from many studies of phonetic complexity and stuttered speech was consideration of utterance-based factors such as length and syntactic complexity during analyses. Although these were not the factors of interest in the present study, increased length of utterance was uniquely associated with sound-syllable repetitions, and increased syntactic complexity approached a significant association that was unique to whole-word disfluencies. These combined findings may inform previous studies which suggest a role of both length and syntactic complexity in stuttered speech (e.g., Buhr & Zebrowski, 2009; Logan & Conture, 1995, 1997; Melnick & Conture, 2000; Sawyer et al., 2008; Yaruss, 1999; Zackheim & Conture, 2003), but did not distinguish between distinct types of disfluencies during analyses. It is beyond the scope of this study to discuss the potential underlying reasons for this unique outcome. Nevertheless, these findings merit additional research and reiterate the importance of accounting for utterance-level factors in future studies examining connected speech samples.

Similar to the present study, Coalson et al. (2012) found that when accounting for multiple lexical and linguistic factors, stuttered speech is not predicted by its own phonetic complexity in preschool-aged children. Perhaps, phonetic complexity does not serve as a *unique* predictor of stuttered speech. As noted by Bernstein Ratner (2005), increased phonetic complexity alone has not been shown to disrupt speech fluency or delay speech reaction time in non-stuttering individuals. However, there are data from older children and adults who stutter that suggest phonetic complexity may *contribute* to stuttered speech and/or delayed speech planning relative to fluent peers when examined in the presence or absence of other, non-phonetic factors (e.g., word frequency, neighborhood density, neighborhood frequency; Byrd et al., in press; LaSalle & Wolk, 2011; Wolk & LaSalle, 2015). Further examination of the interaction between each of these factors, while also considering the potential contribution of the upcoming word upon words currently in production, will further validate or invalidate the predictions of the EXPLAN model.

Finally, the phonetic, linguistic, and lexical factors considered in the present study accounted for only 20–30% of the variance observed in moments of stuttering (as measured by Nagelkerke *R*-squared values). As evidenced in the present study, participant characteristics unaccounted for by the selected speech and language factors were a strong predictor of sound-syllable repetitions in children. Therefore, it is important to acknowledge that a considerable amount of variance remains attributable to factors not included in the model. It is also critical to clarify that the WCM assesses the complexity of the movements required to produce sounds within the specified developmental parameters, but this tool was not developed to be and should not be interpreted as a measurement of speech motor control. Thus, present as well as past null findings suggest that the complexity of the phonetic output, at least as measured by the indices employed, does not appear to be a significant predictor of stuttering in children. However, these null findings do not discount the potential contribution of speech motor planning and execution to stuttered speech (e.g., Namasivayam & van Lieshout, 2011; Smith, 1999).

4.3. Future studies

The present study was designed to investigate the frequency of stuttered speech that occurred prior to a phonetically complex word, in accordance with the first prediction of the EXPLAN model (Howell, 2011). Analyses do not support this prediction after controlling for linguistic and lexical variables also known to influence speech production. The present study did *not* examine stuttered speech which may have occurred on the following, complex word. It is possible that, in accordance with the EXPLAN model, increased part-word disfluencies (e.g., sound-syllable repetitions) were present as the child attempted to produce the second, phonetically complex word. Research to date does not support that younger children are more likely to stutter on a phonetically complex word (e.g., Coalson et al., 2012; Dworzynski & Howell, 2004). However, unlike the present analyses, these studies defined stuttering using disfluency types predicted to occur *prior to complex words* (i.e., whole-word repetitions) and *on complex words* (i.e., part-word disfluencies). Thus, the null findings of previous studies may have been compromised by the inclusion of disfluency types expected to occur prior to the complex word (i.e., whole-word repetitions). To more directly assess the second prediction of the EXPLAN model, future studies investigating the likelihood of a word to be stuttered relative to its own phonetic complexity should include only the stuttering-like disfluencies predicted to occur on phonetically complex words (i.e., part-word disfluencies) and exclude disfluencies predicted to occur prior to the complex word (i.e., whole-word repetitions). Differentiation between disfluency types, as completed in the present study, will provide more direct support of the predictions of the EXPLAN model and inform the overall contribution of phonetic complexity to stuttered speech in younger and older populations.

Although no association between fluency and phonetic complexity was observed in the present study regardless of grammatical configuration, additional predictions of the EXPLAN model remain to be examined. For example, one critical difference that governs whether a speaker will produce either type of disfluency when encountering a word of increased complexity (i.e., a word that requires greater planning time) is the speakers' gradual shift from 'stalling' disfluency (e.g., whole-word repetition) to a less-adaptive 'advancing' disfluency (e.g., sound-syllable repetition). It is possible the children sampled in the present study relied on the advancing strategy, and produced more sound-syllable repetitions when the adjacent, high complexity words were encountered. If so, production of whole-word repetitions on preceding words may not occur in high frequency. To better address this consideration, future studies should compare whole-word repetitions and complexity of the following word in children who stutter relative to children who do not stutter, on the presumption that the non-stuttering cohort will be less likely to adopt an advancing strategy (for further description, see Howell & Au-Yeung, 2002, p. 81).

5. Conclusion

Present findings indicate that phonetic complexity of the second word is not significantly associated with disfluencies that occur on the previous initial word. These findings extend past research in three key ways. First, unlike previous studies that have examined the relationship between phonetic complexity and stuttered speech, the present study considered properties of the word following the stuttered word, rather than the stuttered word itself, using an age-appropriate index of phonetic complexity. Second, the contribution of phonetic complexity was examined with consideration of additional lexical and linguistic factors associated with fluent speech production. Third, analyses distinguished between the advancing and stalling disfluencies in accordance with the predictions of the EXPLAN model. Results confirm previous findings that phonetic complexity does not uniquely compromise the fluency of the speech output in preschool children who stutter.

Future studies should continue to examine the fluency of the initial word relative to its own phonetic complexity, as well as the complexity of the second word as defined by the EXPLAN model, while *also* distinguishing between disfluency types and accounting for additional linguistic properties, to provide support for its unique predictive value on stuttered speech.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jfludis.2015.10.002.

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