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The influence of phonetic complexity on stuttered speech

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Abstract
The primary purpose of this study was to re-examine the influence of phonetic complexity on stuttering in young children through the use of the Word Complexity Measure (WCM). Parent–child conversations were transcribed for 14 children who stutter (mean age = 3 years, 7 months; SD = 11.20 months). Lexical and linguistic factors were accounted for during the analysis. Results indicate that phonetic complexity, as measured by WCM, did not exhibit a significant influence on the likelihood of stuttering. Findings support previous data that suggest stuttering in preschool-age children does not appear significantly related to phonetic complexity of the production.

Keywords: *stuttering*, *children*, *Word Complexity Measure*, *spontaneous speech*

Introduction

Phonetic complexity has been suggested as a contributing factor to moments of stuttering. A series of recent studies suggest that the influence of phonetic complexity on stuttering may be more apparent in older children and adults (Dworzynski & Howell, 2004: beyond 6 years of age; Howell & Au-Yeung, 2007: beyond 6 years of age; Howell, Au-Yeung, Yaruss, & Eldridge, 2006: 11–18 years of age). To date, phonetic complexity has not been revealed as a significant contributing factor to stuttering in preschool-age children (Howell & Au-Yeung, 1995; Throneburg, Yairi, & Paden, 1994). These findings are unexpected as younger speakers should presumably be more vulnerable to phonetic difficulty than older speakers. The purpose of this study is to re-examine the effects of phonetic complexity on stuttered speech in preschool-age children using the Word Complexity Measure (WCM; Stoel-Gammon, 2010), a recently published tool developed based on speech samples of children within the age range of stuttering onset. Furthermore, as noted by Bloodstein and Bernstein Ratner (2008), it is difficult to separate phonetic factors from linguistic factors during spontaneous output. Thus, in this study we will also consider the influence of co-occurring linguistic factors in our analysis of phonetic complexity on stuttered speech.

The role of phonetic complexity is central to the EXPLAN model of stuttering (EX: execution, PLAN: planning; Howell, 2011). According to the EXPLAN model (Howell, 2004; Howell & Dworzynski, 2005), phonetic properties are considered a component of the speech plan, rather

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than its execution. The EXPLAN model predicts that stuttering occurs due to increased phonetic complexity, which delays efficient planning of speech. Howell (2004, p. 128) acknowledged that other properties of speech production may independently affect planning of speech segments, such as grammatical class, word frequency and linguistic stress, and suggested future studies also assess the influence of each individual factor. Thus, this study will attempt to account for these and other relevant factors while re-examining the relative contribution of phonetic complexity on stuttered speech. Furthermore, we will consider these factors within preschool-age children, for whom stuttering is more prevalent and speech is more prone to planning and/or execution breakdowns.

Previous studies have not found a predictable association between phonetic complexity and stuttering in younger children. Throneburg et al. (1994) and Howell and Au-Yeung (1995) found that stuttered words of children 2–6 years of age were not significantly correlated with more complex phonetic constructs, such as consonant clusters, late-emerging sounds and multisyllabic words. Howell and colleagues examined the influence of phonetic complexity on stuttered speech in children within the context of grammatical class using the index of phonetic complexity (IPC; Jakielski, 1998). The IPC is an additive index of phonological complexity based on analysis of spontaneous speech. A numerical value is assigned to sounds and structures 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. Using the IPC, Dworzynski and Howell (2004) reported findings similar to Throneburg et al. and Howell and Au-Yeung. That is, words with higher phonetic complexity, as indicated by higher IPC score, were not more likely to be stuttered in preschool-age children.

The IPC is an unpublished measurement tool adapted from a longitudinal index of pre-linguistic babbling (five infants, 7–36 months). As noted by Ratner (2005; cf. Howell & Dworzynski, 2005), several phonetic constructs included in the IPC are mastered at ages before stuttering typically emerges, such as consonant reduplication and closed syllable words. However, Stoel-Gammon (2010) recently developed and published the WCM, an IPC that was based on speech samples of seven children similar to the age of stuttering onset (17–48 months; see Table I for comparative scoring rubric). Unlike the IPC, the WCM does not award points for (a) place variegation of consonants within words or clusters or (b) inter-syllabic clusters. Thus, the WCM does not include

Table I. Comparative scoring rubric for the IPC and WCM.

IPC points	IPC	WCM points	WCM
1	Dorsals	1	Velars/dorsals
1	Fricatives	1	Fricatives
	X	1	Voiced fricatives
1	Affricates	1	Affricates
	X	1	Voiced affricates
1	Liquids	1	Liquids/syllabic liquids
1	Place variegations of consonants within word		X
1	Rhotics	1	Rhotics
1	Word-final consonant	1	Word-final consonant
1	>2 syllables	1	>2 syllables
1	Consonant clusters (intra-syllabic)	1	Consonant clusters (intra-syllabic)
1	Consonant clusters (inter-syllabic)		X
1	Place variegations within clusters		X
	X	1	Non-initial stress

Notes: IPC (Jakielski, 1998) and WCM (Stoel-Gammon, 2010).

certain phonetic constructs that are thought to have already been mastered in preschool children. In addition and also unlike the IPC, the WCM awards points for later developing constructs such as voiced fricatives and affricates. The WCM also awards points for a particular construct that has been suggested to influence speech production in children who stutter: non-initial stress patterns (Hakim & Ratner, 2004; cf. Natke, Sandrieser, Van Ark, Pietrowski, & Kalveram, 2004). For these reasons, the WCM, a tool previously unavailable to researchers, may be more reflective of phonetic complexity and stuttered speech in preschool children.

As noted by Howell (2004) and Ratner (2005), linguistic factors should also be considered when analyzing words extracted from spontaneous samples of speech. Howell, Au-Yeung, and Sackin (2000) found that children are more likely to stutter on words that begin with both consonant clusters and late-emerging consonants within content words, but not function words. However, the age range was broader than previous studies (3–11 years). Logan and Conture (1997) examined the effect of syllable structure on moments of stuttering in the spontaneous speech of young children (3–5½ years of age). In their initial analysis, stuttered utterances contained more intra-syllabic clusters than fluent utterances, but not when utterances were matched in length. Taken together, the relative influence of phonetic complexity may be more apparent when linguistic factors, such as utterance length and grammatical classification, are considered during analysis.

Ratner (2005) discussed these and other co-occurring linguistic variables that are likely to confound any reported influence of phonetic complexity on stuttering during spontaneous speech samples. Factors such as length and syntactic complexity of utterances (Brundage & Ratner, 1989; Logan & Conture, 1997; Ratner & Sih, 1987; Yaruss, 1999; Zackheim & Conture, 2003), word frequency (Palen & Peterson, 1982; Prins, Main, & Wampler, 1997; Anderson, 2007; cf. Newman & Bernstein Ratner, 2007; Ratner, Newman, & Strekas, 2009) and phonological neighborhood properties (Anderson, 2007; Anderson & Byrd, 2008; Arnold, Conture, & Ohde, 2005) are potential contributors during moments of stuttering. Grammatical classification, as well as utterance position, also need consideration during analysis due to frequent co-occurrence of phonetically simple function words in initial position (Bell, Brenier, Gregory, Girand, & Jurafsky, 2009; Segalowitz & Lane, 2000) and known association with stuttering (Buhr & Zebrowski, 2009; Richels, Buhr, Conture, & Ntourou, 2010). In this study, these factors will be considered to better isolate the influence of phonetic complexity.

In summary, the existing data suggest that phonetic complexity does not influence stuttered speech in preschool children. This study will re-examine previous findings using the recently developed WCM, which may reveal subtle differences not previously detected. In addition, and also unlike previous studies, we plan to examine the influence of phonetic complexity on moments of stuttering while considering co-occurring factors of speech production. This information will further our understanding as to whether the phonetic complexity of words uniquely influences the fluency of speech production in the preschool population.

Methods

Participants

Participants were 14 native, monolingual English-speaking children who stutter (8 boys, 6 girls; mean age = 3 years, 8 months; standard deviation (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 II 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.

Table II. Participant characteristics for standardized speech-language measures and stuttering measures.

Participant	Gender	Age (m)	PPVT-III	EVT	GFTA-II	TSO (m)	%SLD	SSI-3	MLU	TTR
1	M	31	131	N/A	127	2	21.3	27	2.91	0.47
2	M	33	108	110	111	8	4.33	18	3.38	0.35
3	F	35	95	104	93	3	5	18	2.21	0.32
4	F	35	119	114	117	3	13	24	4.03	0.31
5	F	38	89	109	109	2	3.22	18	3.08	0.27
6	M	38	102	99	91	0.5	3.5	15	3.82	0.37
7	F	40	108	102	97	5	5	14	3.25	0.45
8	M	46	94	95	120	3	7.7	19	3.81	0.39
9	M	46	105	114	107	16	3	8	3.31	0.31
10	F	47	102	108	103	15	12.67	24	3.19	0.44
11	M	49	113	108	115	1	11.66	26	3.52	0.48
12	F	52	112	93	99	9	5.33	22	3.19	0.37
13	M	63	133	119	114	21	3	11	4.87	0.41
14	M	69	99	110	99	31	3.6	14	3.79	0.39
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

Notes: 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-II, Goldman–Fristoe test of articulation-II (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). N/A, formal testing unavailable at time of testing.

The study was approved by the Institutional Review Board at The University of Texas at Austin and informed consent was obtained for each participant.

Classification and inclusion criteria

Speech, language and hearing measures. Participants passed a bilateral pure tone hearing screening at 20 dbHL for 1000, 2000 and 4000 Hz (American Speech-Language-Hearing Association, 1997). All 14 participants performed within normal limits (i.e. no less than 1 SD below the mean) on the *Peabody picture vocabulary test – III* (PPVT-III; Dunn & Dunn, 1981) and the *Expressive vocabulary test* (EVT; Williams, 1997) and the *Goldman–Fristoe test of articulation – II* (GFTA-II; Goldman & Fristoe, 2000). All participants presented with a mean length of utterance (MLU; range: 2.21–4.87) and type-token ratio (TTR; range: 0.27–0.48) that were within normal limits. See Table II for a review of participant performance on each of these measures.

Criteria for diagnosis of stuttering. To be considered a child who stutters and, thus, qualify for participation in this 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) individuals in the child's daily environment had to have reported concerns about the child's fluency and (c) receive a diagnosis of stuttering by a certified speech-language pathologist. See Table II for descriptive statistics for each participant related to measures of stuttering.

Procedures

During analysis, the dependent variable was the stuttering classification of each word: produced with a stuttering-like disfluency (SLD) or not. There were 10 independent 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, grammatical classification and utterance position. Procedures of measurement for each variable are discussed in following sections.

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 simply talk to each other "as they would at home". Each interaction lasted approximately 20 min and was video-taped.

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 were coded as having been produced with an SLD or not based on definitions provided by Yairi and Ambrose (2005). 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 and unintelligible words were not included in the data analysis or calculation of utterance length (Miller & Iglesias, 2006). Interrupted, abandoned or imitative utterances were not included in the analysis (Johnston, 2001; Sawyer, Chon, & Ambrose, 2008). One-word utterances were also excluded from the final data analysis similar to Logan and Conture.

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

To ensure reliability of the transcribed samples, five additional research assistants were again trained in the language and stuttering analysis procedures and completed reviews 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 three authors.

Using these criteria, after the initial and subsequent review, 4096 words (of a total 5109 words; 3882 produced without an SLD, 214 produced with an SLD) were included resulting in a final data corpus that only included 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, grammatical classification and utterance position.

Phonetic complexity. Words were analyzed for phonetic complexity using the WCM (Stoel-Gammon, 2010). WCM scores were calculated for each produced word within an utterance. During word-level analysis, phonetic complexity scores were not controlled for length of word because of length-sensitive factors included within the WCM rubric. Specifically, the WCM awards points for number of syllables in a word and clusters, both of which increase the length of a word (see Table I). Thus, raw WCM scores were calculated for each word.

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 (mean frequency of the same individual phoneme in the same position in all words) and biphone probability (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 SDs established by Storkel and Hoover.

Utterance length. Length of the utterance was calculated by counting the number of syllables within each utterance (Brundage & Ratner, 1989; Logan & Conture, 1997; Logan & LaSalle, 1999). Utterance length values were considered raw values of number of syllables for each utterance.

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. Syntactic complexity values were considered raw values of number of clauses for each utterance.

Word frequency, neighborhood density and neighborhood frequency. 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 target word by the substitution, addition or deletion of one phoneme. 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. If words were not found in the CML, values were obtained from the Hoosier mental lexicon (HML) adult database (see Luce, Pisoni, & Goldfinger, 1990; Luce & Pisoni, 1998; available from http://128.252.27.56/neighborhood/Home.asp).

If words were not found in the CML or HML, word frequency values were removed from the database after coding and prior to analysis (139 of 4235 intelligible words; 133 produced without an SLD, 6 produced with an SLD). Neighborhood densities of words with no phonological neighbors received a score of zero (165 of 4096 words). Likewise, neighborhood frequencies of words within the database with no phonological neighbors received a score of zero (165 of 4096 words).

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. While 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.

Grammatical classification. Words within the utterance were defined as either function or content words using criteria identical to Howell's studies (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.

Utterance position. Similar to previous studies (Buhr & Zebrowski, 2009; Richels et al., 2010), words were considered as either "initial" or "non-initial". That is, only words that were produced as the first word of the utterance received "initial" categorization. All other words were considered "non-initial". Unusable starter words such as interjections (e.g. "uh", "um") were excluded prior to analysis during transcription.

Reliability of word coding procedures. Prior to completing analysis of the final data corpus, two different research assistants and the first author re-calculated all coded values on 20% of the words ($n = 821$) randomly extracted from the usable data corpus (i.e. WCM, grammatical classification, utterance position, 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 Kappa coefficients, respectively, for the 10 aforementioned factors. Results were as follows: WCM: 90%, 0.95; segmental phonotactic probability, 94%, 0.90; biphone phonotactic probability: 96%, 0.95; length of utterance: 93%, 0.97; syntactic complexity: 90%, 0.81; word frequency: 97%, 0.90; neighborhood density: 98%, 0.99; neighborhood frequency: 96%, 0.96; grammatical classification: 90%, 0.79; and utterance position: 98%, 0.96.

Statistical analysis

Main effects of phonetic complexity. The main purpose of the current study was to examine the isolated contributions of phonetic complexity, as measured by either the WCM, on words produced with SLDs in preschool children during spontaneous speech, when controlling for phonotactic probability, word frequency, neighborhood frequency, neighborhood density, grammatical classification, utterance position, length of utterance and syntactic complexity of utterance. To determine if these predictors (continuous and categorical independent variables) provided unique information in predicting the fluency of a spoken word (categorical dependent variable), a binomial logistic regression analysis was completed.

Multicollinearity of predictor variables. Previous studies suggest possible inter-correlation between the effects of phonotactic probability, word frequency, neighborhood density and neighborhood frequency (Anderson, 2007; Storkel, 2004; Storkel, Maekawa, & Hoover, 2010). In addition, increased syntactic complexity is commonly associated with increased utterance length. For these reasons, prior to completing the analyses, tests of multicollinearity were conducted to determine the degree of inter-relatedness of all predictor variables (i.e. WCM, segmental and biphone phonotactic probability, word frequency, neighborhood density, neighborhood frequency, grammatical classification, utterance position, length of utterance and syntactic complexity). All variables had acceptable variance inflation factor (VIF) and tolerance values (VIF = 1.084–2.126, tolerance = 0.470–0.923). 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). These results suggest that inter-correlation was not significant. Thus, all predictors were included in the final binomial logistic regression analysis.

Results

The research question posed examined the differential effects of phonetic complexity, as measured by the WCM, on words produced with an SLD in young participants when accounting for other linguistic variables known to impact stuttering. A binomial logistic regression model was used to analyze the unique contribution of the aforementioned variables. Due to the clustered nature of the data (words nested within participants), the analysis was controlled for non-independence using a generalized estimating equations model with the Proc GenMod procedure in SAS 9.2. This approach modifies binomial logistic regression to account for multiple observations within participants (McCullagh & Nelder, 1989; Sheu, 2000).

Results of regression analysis were described in terms of odds ratio (OR) and confidence intervals (CIs). See Table III for lists of ORs and significance, and Figure 1 for graphs of regression.

Phonetic complexity

While controlling for the effects of phonotactic probability, word frequency, neighborhood density, neighborhood frequency, grammatical classification, utterance position length of utterance and syntactic complexity, phonetic complexity as measured by the WCM was not a significant predictor of greater odds of producing a word with an SLD (OR = 1.010, $p = 0.870$). Thus, as phonetic complexity increased as indicated by the WCM, the odds or likelihood that the word would be produced with an SLD did not change.

Significance of controlled variables

Three variables other than phonetic complexity exhibited significant predictive value of a word being produced with an SLD during binomial logistic regression analyses: utterance position, length of utterance and syntactic complexity of utterance.

Table III. Odds ratios and confidence intervals for fluent and disfluent words.

Predictor variable	B	OR	SE	Lower CI	Upper CI	*p*
Phonetic complexity – WCM	0.010	1.010	0.064	0.892	1.144	0.870
Phonotactic probability						
Segmental	−0.132	0.876	0.082	0.746	1.029	0.108
Biphone	0.003	1.003	0.127	0.781	1.287	0.983
Word frequency	0.184	1.202	0.131	0.929	1.553	0.161
Neighborhood density	0.012	1.012	0.011	0.990	1.034	0.281
Neighborhood frequency	0.025	1.026	0.064	0.905	1.163	0.692
Grammatical class – function	0.090	1.094	0.207	0.729	1.642	0.665
Utterance position – initial	1.198	3.313	0.163	2.405	4.563	0.000***
Length of utterance	0.067	1.070	0.030	1.008	1.134	0.025**
Syntactic complexity	−0.323	0.724	0.133	0.558	0.939	0.015**

Notes: B, coefficient; OR, odds ratios; SE, standard error; CI, confidence interval (95%); WCM, Word Complexity Measure (Stoel-Gammon, 2010); phonotactic probability scores (segmental and biphone) calculated using z-scores.
**Significant at 0.05.
***Significant at 0.01.

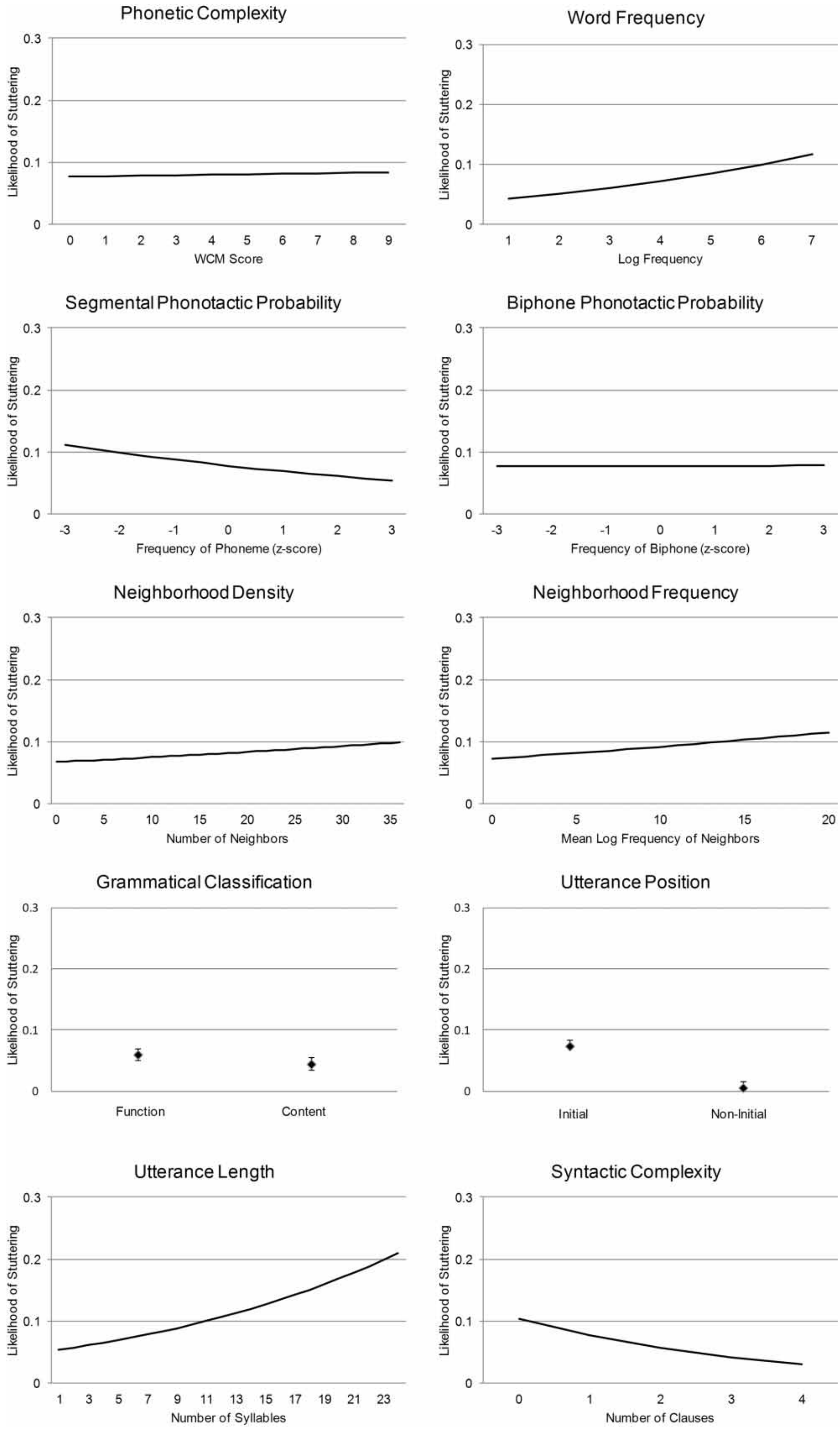

Figure 1. Likelihood of stuttering based on phonetic complexity (WCM) values and controlled linguistic variables (i.e. word frequency, grammatical classification, utterance position, phonotactic probability, neighborhood density and frequency, length and syntactic complexity of utterance).

Utterance position. Utterance position contributed significantly to the likelihood of a word being produced with an SLD (OR = 3.313, $p < 0.000$). That is, when accounting for all other mentioned variables, the odds of a word being produced with an SLD were 3.313 times greater for the initial word of an utterance.

Length of utterance. Length of utterance contributed significantly to the likelihood of a word being produced with an SLD (OR = 1.070, $p = 0.025$). That is, when accounting for all other mentioned variables, the odds of a word being produced with an SLD were 1.070 times greater as the length of the utterance increased by one syllable.

Syntactic complexity. Syntactic complexity contributed significantly to the likelihood of a word being produced with an SLD (OR = 0.724, $p = 0.015$). That is, when accounting for all other mentioned variables, the odds of a word being produced without an SLD were 1.381 (i.e. 1/0.724) times greater as the number of clauses increased by one.

Discussion

Past research has suggested that phonetic complexity may lead to difficulties establishing and/or maintaining fluent speech production. The purpose of this study was to re-examine the effects of phonetic complexity on the speech fluency of preschool participants using the recently developed WCM with consideration of co-occurring lexical and linguistic factors.

Phonetic complexity effects

Findings regarding phonetic complexity and stuttering were consistent with previous reports that phonetic complexity does not appear to increase the likelihood of stuttering in young children (Howell & Au-Yeung, 1995; Throneburg et al., 1994). Findings are also similar to those reported for preschool-age children in Dworzynski and Howell (2004) using the IPC. In sum, when confounding factors were considered and an age-appropriate measure for young children was applied, phonetically complex words were no more likely to be produced with an SLD than phonetically simple words.

Inclusion of multiple variables was important with regard to interpretation. In *post-hoc* analysis, a binomial logistic regression with phonetic complexity as the only predictor variable revealed that words with higher WCM scores were significantly more likely to be produced with an SLD, (OR = 0.874, $p = 0.012$). That is, without accounting for the lexical and linguistic factors, phonetic complexity as measured by the WCM would have appeared to be a significant predictor of a word being produced with an SLD in preschool children. However, when additional factors were considered within a binomial logistic regression, the significance of phonetic complexity was no longer present. Thus, findings from this study suggest more complex speech-motor patterns does not uniquely influence the production of SLDs in preschool children, at least not when complexity is measured using the WCM.

Current data are similar to Dworzynski and Howell's (2004) preschool participants and consistent with the notion that, in children, a word produced with an SLD is not predicted by its phonetic complexity. Data do not provide support for the EXPLAN model as it relates to children (Howell, 2004, 2011). This study does, however, provide support that co-occurring linguistic factors do need to be considered when measuring phonetic properties of words taken from spontaneous speech. As noted by Howell (2004, 2011) and Ratner (2005), the EXPLAN hypothesis is not immune to other factors that influence planning and execution, particularly as syntactic skills mature (e.g. increased production of longer and more complex utterances). For example, while phonetic complexity and grammatical classification did not predict the likelihood of stuttering in this study, utterance length and syntactic complexity exhibited considerable predictive value. To fully support the interactive nature of these factors in children or adults, future studies will need to consider phonetic complexity and stuttering while also considering related linguistic factors.

WCM and childhood stuttering

One benefit of using the WCM as a measure of phonetic complexity was the exclusion of less age-appropriate factors included in previous measurement tools, such as singleton and cluster place variegation. However, exclusion of these factors from the WCM did not result in phonetic complexity being a significant contributor to stuttering. One unique aspect of the WCM, non-initial stress, was posited to be a meaningful contributor to moments of stuttering. Greater frequency of words with non-initial stress, indicated in part by higher WCM score, did not predict the production of SLDs in words. Null findings are in accordance with Natke et al. (2004), who found that short stressed syllables in initial position were stuttered more than unstressed syllables in young children during spontaneous speech. Hakim and Ratner (2004) found that children who stutter repeated nonwords with atypical, non-initial stress patterns with greater phonemic and stress-placement errors than fluent peers. However, uncommon stress patterns did not result in increased stuttering. In this regard, present findings are supported. It is possible that phonetic factors that contribute to speech errors do not necessarily contribute to moments of stuttering.

At present, comparison of the current findings in preschool-age children and those of older children and adults who stutter from previous studies would be speculative, as ages do not overlap (Howell & Au-Yeung, 2007; Howell et al., 2006). However, extension of this current analysis protocol in older speakers would be worthwhile. The present analyses can be applied to older speakers to further investigate any unique influence of phonetic complexity and corroborate past research that suggest the influence on stuttering increases with age. Selection of an adult measurement tool should be made with caution. To these authors' knowledge, no measure of phonetic complexity for adults currently exists. While acknowledging its limitations, the paucity of appropriate measures may support the WCM as the most relevant and available measurement tool for older speakers. To determine if this is the case, studies using the WCM in older population in a similar methodological manner would be warranted.

Implications for future studies

In this study, we attempted to isolate lexical and linguistic factors from phonetic factors in conversational speech. It is possible that experimental measures may be more appropriate to detect any subtle influences of phonetic factors. A few studies of this nature have been performed in adults who stutter using phonetic constructs measured in this study. For example, during a nonword repetition task, Smith, Sadagopan, Walsh, and Weber-Fox (2010) found adults who stutter to exhibit increased speech motor variability on words with increasing phonetic complexity (i.e. increased syllables, clusters and late-emerging consonants) compared to peers, while fluency and accuracy of production remained unaffected. In a similar study, Sasisekaran, Smith, Sadagopan, and Weber-Fox (2010) found speech motor control of fluent children to be highly variable even during accurate, but less complex, nonword repetition. If similar studies were extended to children who stutter, perhaps fluctuations in phonetic complexity will reveal that motor stability is disrupted to a greater degree, even during accurate and fluent speech production. However, because motor instability has been exhibited in adults who stutter due to other linguistic factors (syntactic complexity: Kleinow & Smith, 2000), confounding variables should be considered similar to this study.

Conclusion

In sum, careful replication and extension of previous findings suggest that phonetic complexity as measured by the WCM is not a significant predictor of stuttering in preschool-age children. These findings extend past research in two key ways. First, the measurement tool was based on an age-appropriate cohort. Second, consideration of linguistic factors at the word level further isolated the role phonetic complexity. Authors recommend future studies employ such methods to further enhance our understanding of the role, if any, of phonetic complexity on stuttered speech in older populations using the WCM or an age-appropriate tool if one becomes available.

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