PHONOLOGICAL COMPLEXITY AND SPEECH DISFLUENCY IN YOUNG CHILDREN

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Recent theories suggest that speech disfluencies result from a disruption in the time-dependent processes of phonological and phonetic encoding (Howell & Au-Yeung, 2002; Karniol, 1995; Perkins, Kent, & Curlee, 1991; Postma & Kolk, 1993; Wingate, 1988). The purpose of this study was to examine the relationship between phonological complexity and disfluencies in the speech of preschool-age children. It was predicted that speech disfluencies would be more likely to occur in utterances with a higher degree of phonological complexity than in utterances with a lower degree of phonological complexity.

Participants in this study were 12 monolingual English-speaking preschool-age children who stutter. Other than the diagnosis of stuttering, all 12 children exhibited normal speech, language, and hearing function. Each child was videotaped with a parent or guardian while engaged in a 30 minute free-play conversational interaction. Each of the participant's utterances was examined to identify the presence of speech disfluencies. The presence of word-initial late-emerging consonants and consonant strings (LEC_i/CS_i; Howell, Au-Yeung, & Sackin, 2000; Shriberg, 1993; Throneburg, Yairi, & Paden, 1994) and the Index of Phonetic Complexity (IPC; Jakielski, 2000) were utilized as metrics to identify a relationship between speech disfluencies and phonological complexity.

Logistic regression was employed to determine the relationship between phonological complexity and disfluency for each child individually and to determine if a similar relationship existed for the group as a whole. While the results of initial analyses suggested that an utterance

with a higher phonological complexity score was more likely to be disfluent than an utterance with a lower phonological complexity score, post-hoc analyses did not support this initial conclusion. The results of post-hoc analyses suggested that the initial results were confounded by the effect of utterance length. The best fit to the logistic regression model was achieved by utterance length (in number of words). The addition of phonological complexity did not add significantly to the regression model.

The results of this study do not offer support to the contention that speech disfluency in young children is influenced by the phonological complexity of the utterance being produced (Howell et al., 2000; Weiss & Jakielski, 2001).

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1. Overview

Several current models of stuttering suggest that the occurrence of speech disfluencies may be related, at least in part, to the process of planning or formulating language (Howell & Au-Yeung, 2002; Karniol, 1995; Perkins, Kent, & Curlee, 1991; Postma & Kolk, 1993; Wingate, 1988). For example, Wingate hypothesized that the production of disfluencies were associated with errors in phonological encoding. He proposed that syllable onsets are retrieved in a timely manner, but that the syllable rimes are not. This delay results in the speaker not being able to move beyond the syllable onset. Perkins et al. suggested that disfluencies are the result of a dyssynchrony between the linguistic and paralinguistic system. The authors proposed a model adapted from Shattuck-Hufnagel's (1979) slot/filler framework in which they suggested that disfluencies occur when there is a dyssynchrony in timing of the arrival of the syllable frame which carries suprasegmental or paralinguistic information (i.e., the slot) and the frame that carries segmental information (i.e., the phonological filler). In Karniol's suprasegmental sentence plan alignment (SPA) model, she suggests that moments of disfluency arise because speakers often have to realign the original suprasegmental plan with a revised plan subsequent to online revision of the message. These three models of stuttering suggest that there is a disruption in a timed process that is necessary for fluent speech to occur.

Postma and Kolk's Covert Repair Hypothesis (CRH; 1993, 1997) posits that speech disfluencies are secondary to the speaker's attempt to repair an error in phonological encoding. Once a speaker has selected a syntactic word (or lemma), the appropriate articulatory gestures for the selected word in its appropriate prosodic context, must be prepared. Phonological encoding is the process that translates the abstract lemma into a syllabified phonological word which serves as input for the process of phonetic encoding where this abstract representation is translated into an articulatory gesture. According to the CRH, a disfluency is the result of the attempt to repair an error in phonological encoding, not the error itself. Postma and Kolk suggest that this error occurs at the level of the segmental spellout. They propose that slow activation rates result in an incorrect phoneme being selected for association in the phonological frame. In their EXPLAN theory, Howell and Au-Yeung (2002) suggest that fluency failures arise because of a delay in the completion of the phonological plan for an utterance being spoken. According to EXPLAN, the generation of a phonological plan is independent of articulation but takes place in parallel. The authors hypothesize that one word is being executed while the subsequent word is being planned. If a complete plan is not available in a timely manner, execution is stalled. According to the authors, this phenomenon is more likely to occur when a phonologically difficult target (often a content word) follows a phonologically simple target (i.e., a function word). Like the models above, the developers of both the CRH and EXPLAN models suggest the time dependent process of speech planning and production is disrupted. Postma and Kolk hypothesize that this disruption takes place during the process of phonological encoding. Howell and Au-Yeung suggest that disfluency is related to a disturbance in the planning process, but do not identify at which level (i.e., phonological encoding or phonetic encoding) the delay occurs.

An association between linguistic factors and the production of disfluencies by adults who stutter is well established. The seminal researchers in this area suggested that a speech disfluency is more likely to occur on longer words, content words, words beginning with a consonant, and words occurring at the beginning of an utterance (Brown, 1937, 1938a, 1938b, 1945; Brown & Moren, 1942; Johnson & Brown, 1935). A number of follow-up studies, utilizing both adults and older children as participants, supported the conclusion that linguistic factors are associated with the occurrence of speech disfluencies (Danzger & Halpern, 1973; Hahn, 1942; Quarrington, 1965; Quarrington, Conway, & Siegel, 1962; Palen & Peterson, 1982;

Ronson, 1976; Soderberg, 1962; Taylor, 1966a; Wingate, 1967, 1979). Schlesinger, Melkman, and Levy (1966) investigated the relationship among these same factors in children as young as 8 years old, and reported similar results. These early researchers suggested that as the linguistic complexity of a word increases, the likelihood that older children and adults will produce that word disfluently also increases.

It should be noted, that while Brown and his contemporaries viewed the four factors mentioned above as representing linguistic complexity, our current understanding of speech planning and execution suggests a more complicated picture. These four factors represent both the area of planning and production. The grammatical factors of (a) content versus function word, and (b) word position, are linguistic factors. The two remaining factors however, (c) word length, and (d) words beginning with a consonant, represent both linguistic (i.e., planning) and articulatory (i.e., production) complexity. While Throneburg, Yairi, and Paden (1994) argued that longer words are associated with increased phonological complexity, an increase in a words length also results in an increased level of articulatory complexity (Jakielski, 2000). Howell and colleagues have suggested that word-initial late-emerging consonants represent increased phonological complexity (Howell, Au-Yeung, and Sackin, 2000). These same eight consonants are also hypothesized to represent increased articulatory difficulty, because their production requires a greater degree of control over independent articulators than vowels and consonants that emerge earlier in child's development (Jakielski, 2000).

The role that these factors play in the speech of younger children near the age of stuttering onset is less clear. Bloodstein and Gantwerk (1967) examined the speech of preschool-age children to ascertain whether the same factors associated with disfluency in adults also played a role in the occurrence of a disfluency in younger children. In contrast to the studies with older children and adults, disfluencies in this population appeared to be distributed randomly with respect to the grammatical factor of content versus function word. Bloodstein and Gantwerk attributed this phenomenon to the fact that in children, disfluencies tend to occur on the first word of a syntactic unit, which is typically a function word. Bloodstein (1974, 1995) concluded that stuttering in young children represents a fragmentation of the syntactic unit and is related primarily to the syntactic complexity of the utterance, not the grammatical complexity of the disfluent word.

The results of two studies by Silverman and colleagues contradicted those of Bloodstein and Gantwerk's 1967 study (Silverman, 1974; Williams, Silverman, & Kools, 1969). Silverman and colleagues examined the speech of preschool- and school-age children, some who stuttered and some who did not. The results of these three studies suggested that the same factors related to the occurrence of a disfluency in adults and older children also play a role in determining the likelihood of a speech disfluency in younger children.

A number of later studies offered support for Bloodstein and Gantwerk's (1967) conclusion that normal disfluency and/or stuttering in younger children is related to syntactic complexity (Bernstein, 1981; Bernstein Ratner & Costa-Sih, 1987; Bloodstein & Grossman, 1981; Gaines, Runyan, & Meyers, 1991; Logan & Conture, 1995, 1997; McLaughlin & Cullinan, 1989; Melnick & Conture, 2000; Pearl & Bernthal, 1980; Yaruss, 1999). While these researchers have demonstrated a significant relationship between increased syntactic complexity and stuttering for participants using group data, Yaruss demonstrated that this single linguistic factor was only significant for a small number of the individual children in his study. Syntactic complexity is not the only linguistic factor related to the production of speech disfluencies in young children.

Another variable that has received a significant amount of attention in the literature is utterance length. As Bernstein Ratner and Costa-Sih (1987) noted, utterances that are syntactically more complex are often longer than a comparison group of less syntactically complex utterances. In an effort to separate the effects of syntactic complexity and utterance length, Bernstein Ratner and Costa-Sih administered an elicitation task to 8 normally fluent children and 8 children who stutter. All of the children were between the ages of 3 years, 11 months and 6 years, 4 months at that time of testing. The authors suggested that length was less predictive of fluency characteristic for the elicited output than was syntactic complexity. Because the variables were not varied independently of each other (i.e., the more complex utterances were longer), it is difficult to separate the effect of the individual variables.

A number of studies utilized spontaneous speech samples in an effort to better understand the effect of utterance length and complexity in the conversational speech of preschool-age children (Gaines et al., 1991; Logan & Conture, 1995, 1997; McLaughlin & Cullinan, 1989; Weiss & Zebrowski, 1992, Yaruss, 1999). Across these studies, syntactic complexity was determined in a number of different manners. The majority of these studies determined the complexity using Lee's (1974) Developmental Sentence Scoring (DSS) procedures (Gaines et al., 1991; Logan & Conture, 1995; McLaughlin & Cullinan, 1989; Weiss & Zebrowski, 1992). Logan and Conture (1997) determined the number of clausal constituents in each utterance to assess the syntactic complexity. Yaruss (1999) examined several aspects of syntactic complexity simultaneously in an attempt to better understand which factors were related to an increased likelihood that an utterance would be produced disfluently. A common finding in all of these studies was that disfluent utterances were more likely to be longer and more complex than fluent utterances.

For those studies that attempted to separate the individual contribution of utterance length from syntactic complexity, the results were unclear. McLaughlin and Cullinan (1989) suggested that increased syntactic complexity had a greater impact on whether an utterance would be produced disfluently, than did length of utterance. Logan and Conture (1995) and Yaruss (1999), on the other hand, argued that utterance length was more predictive than was syntactic complexity.

Yaruss (1999) found however, that the variable with the best predictive value in his study (i.e., utterance length) was only able to reliably predict which utterances would be stuttered for 50% of the participants in his study. Syntactic complexity (measured in terms of several measures of sentence structure, clause structure, and phrase structure) added little to the regression model's ability to predict a stuttered utterance. This suggests that these aspects of complexity are not the only factors related to stuttering in the speech of young children. Other factors then, not yet identified, must play a role in determining the location of stuttering in the speech of these preschool-age children.

In an effort to explain why longer utterances were often times more complex, Logan and Conture (1995) suggested that it might be reasonable to consider utterance length a macrovariable that encompasses other speech production variables. In another paper, these same authors hypothesized that the relationship between increased utterance length and stuttering may reflect the effect of increased phonological processing demands (Logan & Conture, 1997). These authors speculated that stuttered utterances might contain more syllables with complex syllable structures. That is, they hypothesized that stuttered utterances would contain more syllables containing filled onsets and codas; and more of the onsets and codas would be filled with consonants and consonant clusters. While the results of their study did not support the idea that stuttered and perceptibly fluent utterances differ in regards to the number or type of filled onsets and codas, Logan and Conture (1997) suggested that it might be worthwhile to examine the relationship between speech fluency and the types of consonants within an utterance.

Recently, the relationship between phonological complexity (as represented by consonant type) and disfluency in younger children has been examined (Howell & Au-Yeung, 1995; Howell, Au-Yeung, & Sackin, 2000; Howell, Au-Yeung, Yaruss, & Eldridge, in press; Throneburg, Yairi, & Paden, 1994; Weiss & Jakielski, 2001). While the findings of Howell and colleagues (1995) and Throneburg et al. appeared to offer support to the conclusion of Bloodstein and colleagues (1967, 1974, 1981), Howell et al. (2000) recently have argued that this conclusion was reached in error. They suggested that their own earlier study (Howell & Au-Yeung) and that of Throneburg et al. were limited in that no distinction was made regarding the position of phonologically demanding sounds. Howell et al. reported that the youngest children in their study (ages 3-11) were significantly more likely to stutter on words that began with a late-emerging consonant (LEC) or consonant string (CS) compared to words that did not begin with an LEC or CS. LECs and CSs are thought to represent greater phonological difficulty (Howell et al., 2000; Throneburg et al.).

Using the Index of Phonetic Complexity (IPC) developed by Jakielski (2000), Weiss and Jakielski (2001) examined the relationship between phonetic complexity (i.e., motoric complexity) and disfluency in young children ranging in age from 6 to 11 years old. The authors reported that while the relationship did not reach statistical significance in their study (possibly secondary to small sample size), the speech of the youngest children in their study appeared to be more influenced by phonetic complexity than that of the older children. While the eight indices of the IPC were derived from the research of MacNeilage and Davis (1990) and represent production constraints, the IPC has recently been utilized as a metric for phonological (i.e., planning) complexity (Howell et al., in press). Increased IPC scores may be indicative of both increased difficulty for planning and production of words.

The results of the Howell et al. (2000) and Weiss and Jakielski (2001) studies suggest that phonological complexity may be an important factor for determining the occurrence of a disfluency in the speech of young children near the onset age of stuttering. It is important to note, however, that the speech samples for the 3 youngest children in the Howell et al. study contained a small number of utterances, and that Weiss and Jakielski had only 2 participants under the age of 7. Neither of these two recent studies analyzed a sufficient number of young children near the age of the onset of stuttering to address the question of whether stuttering is related to phonological complexity with sufficient statistical power. Thus, the role that phonological complexity plays in the speech of preschool-age children near the onset of stuttering remains unclear. Improved understanding of the relationship between phonological complexity and disfluency in preschool-aged children, especially as it relates to models of speech planning and production, may provide information essential to our understanding of theories of stuttering onset.

The purpose of this study was to examine the relationship between phonological complexity and the occurrence of speech disfluencies in the speech of a larger group of young children near the onset age of stuttering. Because preschool-age children still are gaining control over their speech sound repertoires, phonologically complex sounds and sound sequences may pose a planning challenge to these children (Weiss & Jakielski, 2001). It was hypothesized that disfluencies would be more likely to occur in an utterance with higher phonological complexity than an utterance with lower phonological complexity. This study utilized two metrics to quantify phonological complexity; word-initial LECs and CSs (LEC_i/CS_i; Howell et al., 2000) and the Index of Phonetic Complexity (IPC; Jakielski, 2000). The LEC_i/CS_i measure was used to examine the influence of the phonological complexity of the word-initial sounds, while the IPC was used to assess whole-word phonological complexity.

2. Literature Review

2.1. Early Studies of Linguistic Complexity

The review that follows is divided into two main sections: (a) early studies of linguistic complexity, and (b) more recent studies of phonological complexity and stuttering in children. Because the seminal studies of the effects of linguistic complexity were completed on adults and older children who stutter, the first section of this literature review examines findings from these two age groups.

The second section is focused on more recent studies addressing a single aspect of linguistic complexity; phonological complexity. This section is also only concerned with the relationship between phonological complexity and disfluency in children, especially those near the age of stuttering onset. These more recent studies are interpreted in light of recent models of speech planning and production, in particular, the Word-form Encoding by Activation and VERification (WEAVER++ computer simulation, drawn from Levelt, Roelofs, and Meyer's 1999 model of speech planning and production (Roelofs, 1997). The WEAVER++ model was chosen for this discussion because it proposes distinct processes of phonological and phonetic encoding in which an abstract syntactic representation (i.e., the lemma) is incrementally translated into the articulatory gestures which serve as input for articulation. The role of phonological complexity in the planning of fluent speech is explored in this experiment. It is hypothesized by the author of the present study that increased phonological complexity will interfere with the time-dependent phonological process(es) of phonological and/or phonetic encoding. This delay will result in a delay of the completion of the articulatory plan, which will be realized as a speech disfluency.

2.1.1. A Note on Terminology

As the literature for this study was reviewed, it became apparent that the word *stuttering* as used in one paper did not necessarily mean the same thing as the word *stuttering* as used in another. In some articles, the authors identified moments of stuttering, but provided no definition of stuttering (Bloodstein & Gantwerk, 1967; Soderberg, 1962; Taylor, 1966a, 1966b; Weiss & Jakielski, 2001). In other studies, the definition of stuttering included the term "word-repetitions," but there was no clarification if these words were mono- or multi-syllabic (Au-Yeung, Howell, & Pilgrim, 1998; Howell et al., 2000). This is an important distinction because while the repetition of monosyllabic words is sometimes judged as stuttering and sometimes as a normal disfluency, the repetition of multisyllabic words is not commonly considered to be a stuttered disfluency (Conture, 2000; Guitar, 2005; Yairi, 1997; Yairi, Watkins, Ambrose, & Paden, 2001). In still other articles, the definition of stuttering included initiators such as interjections (Kadi-Hanifi & Howell, 1992), or was interpreted differently for each participant (Brown 1937, 1938a, 1938b, 1945; Brown & Moren, 1942). In the review that follows, if the author(s) either provided no definition of stuttering or included in their definition any disfluency types that are typically judged by listeners to be normal disfluencies, this will be stated explicitly. It is hoped that this will highlight potential differences in terminology, without making the review unnecessarily complicated.

2.1.2. Loci of Disfluency in Adults and Older Children

While the location and frequency of stuttering may at first appear to be random, both the location and frequency of speech disfluencies in all speakers are influenced by linguistic factors (Ratner, 1997). In 1938, Brown began a series of studies examining the relationship between linguistic factors and stuttering in adults who stuttered (Brown, 1937, 1938a, 1938b, 1945;

Brown & Moren, 1942). The data studied in this series of experiments was the same as those utilized in an earlier study by Johnson and Brown (1935). In this earlier study, the authors reported that any interruption in the normal rhythm of the reading passage was considered to be a stuttering spasm. These interruptions included complete blocks, undue prolongations of a sound, repetitions of initial sounds or syllables, interjections, and cessation of speaking. These various interruptions were interpreted, "in the light of what was known about the type of stuttering characteristics of each stutterer." (Johnson & Brown, 1935, p. 484). Therefore, the definition of what constituted stuttering varied among the participants. The results of this series of studies suggested that adults were more likely to stutter on: (a) words beginning with a consonant, (b) content words as opposed to function words, (c) one of the first three words of a sentence, and (d) longer words of more than five orthographic letters in length. These results suggested that the occurrence of stuttering in adults was associated with phonological and/or phonetic factors related to consonant production and word length; as well as syntactic factors related to word type and word position. Brown concluded that these factors, "appear to be the most important determinants of the loci of stutterings, and may be the only important ones." (Brown, 1945, p. 192). A number of follow-up studies reported a similar relationship between these same factors and the occurrence of stuttering in older children and adults (Danzger & Halpern, 1973; Hahn, 1942; Quarrington, 1965; Quarrington et al., 1962; Soderberg, 1962; Taylor, 1966a; Wingate, 1967, 1979).

Brown (1945) later suggested that the loci of stuttering could not be accounted for merely by the presence or absence of these four factors. Instead, he claimed that the presence of these factors was associated with words of greater prominence or information load. More specifically, he suggested that the desire to not stutter on words of high information load (which he referred to as *propositionality*) results in the person who stutters reacting with caution, hesitancy, effort, and conflict, which lead to increased incidence of stuttering. He appeared to argue that the propositionality of the word was more important than the other factors he had previously identified as important for determining whether a sentence would contain a stuttered word. This more psychological view is understandable given the historical context of the times. In 1949, Bloodstein reviewed the literature concerned with the conditions under which stuttering was reduced or absent. The first three major sections of his article dealt with the effect of: (a) reduced communicative responsibility, (b) the behavior of the listener, and (c) the lack of urgency to make a favorable impression on a listener. Brown's contention that increased stuttering was related to fear and psychological conflict, rather than motoric or linguistic difficulty, is understandable given the psychological focus of much of the stuttering research at the time of his research. Nevertheless, recent multi-factorial models of stuttering have recognized the importance of psychological factors such as propositionality (Perkins et al., 1991; Smith & Kelly, 1997).

Quarrington et al. (1962) suggested that while increased stuttering in early sentence positions might be secondary to increased information load of early position words, it also could be related to a more general difficulty with the initiation of speech. Quarrington (1965) independently analyzed the effect of sentence position and the information value of words. While the results of his study confirmed the assertion that the likelihood of a word being stuttered is partially related to its information value, the prominence of a word was not solely responsible for this increase in stuttering. Sentence position also was related to stuttering when information value was held constant. These results suggested that stuttering could not be explained solely as a speaker's attempt to avoid saying a word because that word was particularly meaningful or prominent. Additional factors must play a role in this phenomenon, as well.

Taylor (1966b) argued that all four of the factors identified by Brown (1945) represented loci of great uncertainty. She suggested that while a normally fluent speaker may hesitate at loci of great uncertainty, the speech of a person who stutters is disrupted by the uncertainty (Goldman-Eisler, 1958; Taylor, 1966b). Taylor (1966a) reported that the largest effect in her study of the relationship of these four factors to stuttering came from the consonant-vowel difference, followed by the effect of word position in a sentence, and, last by the effect of word length. Taylor offered no definition of stuttering. She suggested that consonants were more difficult to produce because they involve a more complex articulatory mechanism than vowels. Taylor (1966a) also argued that because there are 24 consonants and only 5 vowels in American English, the greater degree of uncertainty of consonant production would result in greater difficulty. Like Brown, Taylor (1966a) seemingly based her segmental count for vowels on their orthographic representations instead of on actual vowel production factors; however, weakening her argument. When one considers production factors, as in the articulatory realization of orthographic symbols, there are 15 vowels in American English (Ladefoged, 2001). While this decreases the degree of uncertainty associated with consonant production compared to vowels that was asserted by Taylor (1966a), her assertion that phonetic factors associated with consonant production play a role in determining whether or not a word will be stuttered by an adult who stutters is still supported by Brown’s data.

In addition to the phonetic difficulty associated with the articulatory complexities required for consonant production, Taylor (1966a, 1966b) implies that the process of sentence planning is also related to stuttering. She proposes that words with more uncertainty are associated with an increased likelihood of being stuttered. While Taylor discusses this uncertainty in terms of the position of the word in the sentence, uncertainty is also associated with word frequency, which has been shown to be related to decreased speech reaction time (Levelt & Wheeldon, 1994). Levelt and Wheeldon hypothesize that this decrease in reaction time is related to the need for the additional computation required in the process of phonological encoding. Thus, the results of Taylor's (1966a) study suggested that increased complexity associated with the planning and production (i.e., phonological and phonetic complexity) of articulatory gestures is associated with increased stuttering.

Schlesinger et al. (1966) investigated the relationship of the same four factors studied by Brown (i.e., word-initial consonant versus word-initial vowel, word class, word position, and word length) to the occurrence of stuttering in children as young as 8 years old. No definition of stuttering was provided. Oral reading samples were obtained from 31 children, ranging in age from 8 to 16 years. These samples were analyzed in terms of word length (in syllables) and frequency of occurrence, determined using Reiger's Hebrew word count (as cited in Schlesinger et al., 1966). Although both factors were associated significantly with stuttering, word length was the better predictor of stuttered disfluency for the children as a group. Individual participant data was not presented. The findings in this study agreed with those utilizing older children and adults, thus suggesting that stuttering in children as young as 8 years old also may be related to phonological and/or phonetic factors (Brown, 1945; Quarrington, 1965; Taylor, 1966a, 1966b). Because the children in the Schlesinger et al. study were not near the age of stuttering onset, which is typically from 3 to 6 years of age (Andrews & Harris, 1964; Mansson, 2000; Yairi & Ambrose, 1999; Yaruss, LaSalle, & Conture, 1998), the relationship between stuttering and phonological and phonetic factors in the preschool-age population was still not known.

2.1.3. Summary of Early Studies with Adults and Older Children

In summary, these earlier studies of adults and older children who stutter suggested that stuttering is related, at least in part, to certain aspects of the planning and production of utterances. While Brown and colleagues (Brown, 1937, 1938a, 1938b, 1945; Brown & Moren, 1942; Johnson & Brown, 1935) were the first to identify a relationship between linguistic factors and stuttering, Brown later suggested that stuttering is related more to a speaker's desire not to stutter, than to the complexity of the factors that he had identified as linguistic in nature (Brown, 1945). Quarrington (1965) and Taylor (1966a, 1966b) suggested that it was the phonetic and/or phonological complexity of the word that was related to whether or not the word would be stuttered, not the speaker's reaction to the propositionality of the word. The relationship between phonological and phonetic complexity and stuttering in younger children near the onset age of stuttering was not addressed in this line of research. Children near the onset of the disorder exhibit minimal learned behaviors associated with stuttering (e.g., learned fears associated with sounds or words), that might lead to confounding results. This younger age group then, is an important population to study.

2.1.4. Loci of Disfluency in Younger Children

Bloodstein and Gantwerk (1967) examined the relationship between stuttering and grammatical word class in preschool children near the age of stuttering onset. No definition of stuttering was provided. Using spontaneous speech samples from 13 children aged 2 to 6 years of age, the proportion of words in different grammatical categories from the entire speech sample was compared to the proportion of stuttered words in these same categories. The findings of this experiment were in marked contrast to those with older children and adults who stutter. For the most part, stuttering was randomly distributed with respect to the grammatical categories studied.

Where not random, stuttering tended to more often occur on function words (i.e., closed class words that carry little meaning but primarily serve a syntactic function in the sentence [Au-Yeung et al., 1998]). The authors suggested that this might have been due to a positional effect, in that most instances of stuttering were associated with the first word of the sentence. They concluded that at this earliest stage of stuttering, there is no linguistic effect independent of position in the utterance. Rather, they hypothesized that stuttering in young children involved the fragmentation of syntactic units such as sentences, phrases, and clauses. Later, Bloodstein (1974) hypothesized that as syntactic complexity increases, a child's perception of the difficulty of producing the syntactic unit in its entirety increases, which leads to the unit being fragmented.

Williams et al. (1969), on the other hand, offered evidence that contradicted the findings of Bloodstein & Gantwerk (1967). They examined the speech of 76 children who stuttered and 76 normally fluent children in kindergarten through sixth grade to determine whether speech disfluencies occurred more often on words possessing the same four attributes that Brown found to be associated with stuttering in adults: word-initial phoneme, grammatical function, word position, and word length (Brown, 1945). Williams et al. did not differentiate between stuttered and nonstuttered disfluencies. For the participants as a group, they did *not* find the same random distribution of disfluency reported by Bloodstein and Gantwerk (1967). They found rather, that for both the children who stuttered and their normally fluent peers, disfluencies occurred more frequently on words possessing the same four attributes that Brown and others had previously found to be associated with increased stuttering in adults. The authors analyzed the data in terms of three age groups: kindergarten and first grade, second and third grade, and fourth, fifth and sixth grade. No significant difference was found among the three age groups. Therefore, the data from this study suggested that the same factors that had been shown to be related to disfluency in older children and adults also were related to disfluency in children as young as 5 years old.

2.1.5. Summary of Early Studies of Linguistic Complexity and Stuttering

A number of researchers have examined the relationship between syntactic, semantic, and phonological and/or phonetic factors and stuttering in adults and older children (Brown, 1937, 1938a, 1938b, 1945; Brown & Moren, 1942; Danzger & Halpern, 1973; Hahn, 1942; Johnson & Brown, 1935; Quarrington, 1965; Quarrington et al., 1962; Soderberg, 1962; Taylor, 1966a, 1966b; Wingate, 1967, 1979). While it might have appeared to the untrained listener that the loci of stuttering was random, the results of these studies suggested that stuttering occurred at points of linguistic (i.e., syntactic and phonological) and phonetic complexity.

Still, research that examined the relationship of these same factors to stuttering in preschool-age children was inconclusive. Bloodstein and Gantwerk (1967) examined the relationship of stuttering to one of Brown's (1945) linguistic factors – the grammatical factor of content versus function words. The results of their study suggested that unlike adults who stutter predominantly on content words, the young children in their study stuttered more on function words. Williams et al. (1969) examined the relationship of disfluency to all four of Brown's factors. They concluded that the same factors related to stuttering in adults also were related to disfluency in children as young as kindergarten age. This would suggest then, that phonological and/or phonetic factors may indeed be related to stuttering in younger children near the age of stuttering onset. More studies would be needed in order to understand this relationship in preschool-age children.

2.2. Recent Studies of Phonological Complexity and Stuttering in Children

The early studies of phonological and phonetic complexity and stuttering were interpreted in an historical context in which a psychological framework predominated (Bloodstein, 1949). This approach to understanding stuttering diminished the importance of various factors, especially as they related to phonological or phonetic difficulty. As such, this line of research was not revisited for many years until Throneburg et al. (1994) examined the relationship between phonological complexity and stuttering. In the years since Brown first examined the relationship between stuttering and linguistic complexity, our understanding of the speech planning and production process has increased significantly.

Current models of speech planning and production suggest that the preparation of a word for articulation proceeds through a number of processes, beginning with conceptual preparation and lexical selection. After the lexical item is selected, the abstract semantic representation (i.e., the lemma) is incrementally translated into a gestural score (Dell, 1986, 1988; Levelt et al., 1999; Roelofs, 1997). The speaker's intention is realized when this abstract output of the planning process, the gestural score, is executed by the articulatory system. More recent models propose two distinct planning stages which are particularly relevant to discussions of phonological complexity; phonological encoding and phonetic encoding. Phonetic encoding, part of the planning process, should not be confused with phonetic (or articulatory) complexity, which, while intricately related to linguistic complexity, refers to the motoric complexity required to produce the intended word (Gelfer & Eisenberg, 1995; Levelt, 1989)

Recent studies of phonological complexity, such as Throneburg et al. (1994), can be interpreted in light of our current understanding of speech planning and production. Therefore, before reviewing recent studies of phonological complexity and stuttering, a current model of speech planning and production will be summarized. The WEAVER++ model proposed by

Roelofs (1997) will be reviewed because it proposes separate stages for phonological and phonetic encoding, which are specifically relevant to the present study of the relationship of disfluency to phonological complexity. It is hypothesized that increased phonological complexity may interfere with the time-dependent process of phonological and/or phonetic encoding and therefore result in disfluencies. Using the WEAVER++ model as a starting point for exploring phonological and phonetic encoding may help to shed light on the role these planning processes play in the production of speech disfluencies and the development of stuttering.

2.2.1. A Current Model of Speech Planning and Production – WEAVER++

WEAVER++ is a computer simulation of a model of word-form encoding based on the model of lexical access proposed by Levelt et al. (1999; see also Roelofs, 1997). Like other models of speech production and planning, WEAVER++ postulates that there is a staged sequential process that is time-dependent (Dell, 1986, 1988; Levelt, 1989). The first stage involves a conceptual process when the appropriate lemma (those aspects of the word's stored information that is relevant to its syntactic environment) is selected from the mental lexicon (Levelt, 1989; Levelt et al., 1999; Roelofs, 1997). This stage is followed by a process of phonological encoding when the target word's syllabification and prosody are computed. In this process, the segmental information relating to a word's phonemic structure is associated with the metrical information which specifies the number of syllables in the word and the accent structure of that word. Unlike other models, such as that of Dell (1986, 1988), the domain of syllabification is the phonological word, not the lexical word. This means that syllabification is dependent on the context in which the word appears (Cholin, Schiller, & Levelt, 2004). The output of phonological encoding (an abstract, syllabified phonological word) serves as input for the next stage of phonetic encoding, when this abstract representation is translated into a syllabic articulatory gesture that serves as input for the articulatory system. If the process of phonological or phonetic encoding is interrupted or slowed down because of the phonological complexity of the syllable being planned, the transmission of a complete articulatory motor program will be delayed. This planning delay necessarily will result in the interruption of fluent speech. This suggests a possible mechanism whereby phonological complexity could play a direct role in the development of stuttering.

One assumption of the WEAVER++ model is that speakers have access to a repository of syllabic gestures (or articulatory scores). Levelt and colleagues refer to this repository, which was originally proposed by Crompton (1982), as the *mental syllabary* (Levelt, 1992; Levelt & Wheeldon, 1994). These authors propose that the articulatory scores for the high frequency syllables in a language are stored in this repository. The model assumes that as soon as the syllabified phonological word is made available from the process of phonological encoding, the corresponding syllabic gestures will be selected from the repository. The gestural scores stored in the mental syllabary represent highly overlearned gestural patterns. Until such time as a particular gestural score has been utilized enough times to be stored in the repository, a mechanism exists to compute the gestural pattern. In the case of a preschool-age child whose phonemic repertoire is rapidly expanding, the gestural score for new and/or low frequency syllables would need to be computed each time it is needed until the particular syllabic gesture has been produced enough times to be stored in the mental syllabary (Cholin et al., 2004; Levelt & Wheeldon).

Levelt and Wheeldon (1994) proposed that there is no reason to suggest that a more complex gestural score would take longer to retrieve from the mental syllabary than would a less complex score. These authors predicted that a complexity effect should, however, be present for new or very low frequency syllables. Levelt and Wheeldon provided experimental evidence demonstrating that a word latency effect did exist for low frequency words. The phonological complexity of new or low frequency syllables (or words composed of those syllables) might then be related to word latency (i.e., a delay in the planning process) and subsequent disfluency in the speech of young children near the onset of stuttering.

2.2.2. Phonological Complexity

According to Levelt et al.'s (1999) model of lexical access (that is the basis for WEAVER++), once the appropriate lemma has been selected, the speaker shifts from the conceptual/syntactic domain into the phonological/articulatory domain. In the phonological (i.e., planning) stage, the speaker incrementally prepares the appropriate articulatory gestures for the selected word in the appropriate prosodic context. As discussed above, Levelt et al. and Roelofs (1997) propose that two distinct processes are responsible for generating this articulatory plan; phonological encoding and phonetic encoding. In the papers to be reviewed in this section, some of the authors (Howell and Au-Yeung, 1995; Howell et al., 2000; Throneburg et al., 1994) appear to use the term phonological encoding in a broader manner where the term refers to both phonological encoding and phonetic encoding, as described by Levelt et al. (1999) and operationalized by Roelofs (1997). That is, it appears that these authors are not solely referring to the process by which the syllabification and prosody are computed, but are also referring to the process when the syllabified phonological word is translated into the gestural score which serves as input to the articulatory system.

The significant co-morbidity of stuttering and phonological disorders (Louko, Edwards, & Conture, 1990; Yaruss & Conture, 1996), coupled with St. Louis's (1991) suggestion that phonological skill can be used to subgroup children who stutter, led Throneburg et al. (1994) to question whether there was a relationship between phonological complexity and stuttering. Throneburg et al. identified stuttering-like disfluencies (i.e., part-word repetitions, monosyllabic word repetitions, and dysrhythmic phonation) in the spontaneous speech samples of 24 preschool-age children who stuttered. The phonological difficulty of the adult target word on which a child evidenced a stuttering-like disfluency (SLD), as well as the adult target of the word following the disfluent word, was analyzed with respect to three aspects of phonological difficulty; LEC, CS (i.e., clusters), and multi-syllabic words. The justification for analyzing the word following the SLD was that preschool-age children reportedly have difficulty distinguishing word boundaries (Kahmi, Lee, & Nelson, 1985).

LECs are defined based on when they are mastered during the phonological development of the typically-developing child. According to Sander (1972) the consonants that develop late in English-speaking children are / r, l, s, tʃ, ʃ, z, dʒ, ð, θ, ʒ /. Sander arrived at this list by reanalyzing the data from earlier studies of sound acquisition carried out by Poole; Poole-Davis; Templin; and Welman, Case, Mengert, and Bradbury (as cited in Sanders, 1972). It has been argued that these later-developing consonants are phonologically and motorically more difficult than those consonants that are mastered earlier in children's phonological development (Howell et al., 2000; Throneburg et al., 1994). In fact, these later-developing sounds may represent an increased level of phonological and motoric difficulty for adult speakers as well (Ferguson and Farwell, 1975, Schwartz, 1988).

With few exceptions, the proportion of disfluent words containing each type of phonological difficulty was similar to the proportion found in the speech sample as a whole. Throneburg et al. (1994) concluded therefore, that phonological difficulty, as defined in their study, was not clearly related to an occurrence of a stuttering-like disfluency. These findings are consistent with those of Bloodstein and Gantwerk (1967) which suggested that phonological difficulty does not exert a powerful influence on the occurrence of stuttering in preschool-age children.

Howell and Au-Yeung (1995) questioned whether the metrics utilized by Throneburg et al. (1994) were indeed a good measure of phonological difficulty. They argued that if the phonological categories utilized by Throneburg et al. were a valid measure of phonological difficulty, the proportion of those categories should change with age in a manner consistent with changes in the phonological development of normally fluent speakers. The speech of 31 children who stuttered and 41 normally fluent children (aged 2 years, 7 months to 12 years, 7 months), were analyzed in terms of the same phonological categories employed by Throneburg et al. It was shown that in terms of the proportion of words within each of the phonological categories, developmental differences did exist, and those differences were generally consistent with those seen in normal phonological development. Howell and Au-Yeung concluded that these results validated the appropriateness of the measure of phonological difficulty utilized by Throneburg et al. Howell and Au-Yeung then examined SLDs and the words following the SLD in terms of the same categories of phonological difficulty that were examined by Throneburg et al. It should be noted that Howell and Au-Yeung did not distinguish between monosyllabic and multisyllabic word repetitions in their analysis. Repetitions of a multisyllabic word typically are considered to be a type of normal disfluency (Campbell & Hill, 1987; Conture, 2000). Therefore, it is possible that Howell and Au-Yeung were identifying moments of more typical disfluency in the speech of both participant populations. The authors suggested that the results of their analysis supported the conclusion that phonological difficulty does not emerge as an important factor influencing stuttering in young children. The uncertainty as to whether or not more typical disfluencies were identified as stuttering, makes the interpretation of Howell and Au-Yeung's data difficult.

This being said, the findings of Howell and Au-Yeung (1995) are consistent with those of a more recent study (Weber-Fox, 2001) utilizing event-related brain potentials (ERP). Weber-Fox suggested that even when no overt speech is required, adults who stutter display atypical functioning for visual processing of linguistic stimuli. While she reported that it was not possible to determine the precise linguistic processes that were underlying the group differences found in her study, she suggested that the findings did not indicate a deficit in phonological processing for adults who stutter. Ratner (2005) has argued that there is little theoretical or empirical motivation to suggest that phonological factors might influence stuttering. Because phonological and phonetic encoding represents one of the last stages in the speech planning process, Ratner suggested that the output of phonological encoding is the result of higher-order processes related to syntactic, semantic, and morphological information, and thus is unlikely to be related directly to speech disfluencies.

Ratner's (2005) view is in contrast to other lines of research that offer support to a proposed relationship between phonological encoding and stuttering (Dell & Repka, 1992; Kolk, 1991; Postma & Kolk, 1993; Wijnen & Boers, 1994). Postma and Kolk proposed that stuttering is the result of covert phonological repairs that are secondary to a slower than normal activation rate during phonological encoding. This proposal forms the basis of the CRH (Kolk & Postma, 1997; Postma & Kolk, 1993). Support for a proposed deficit in phonological encoding also can be found in research carried out by Wijnen and Boers (1994). Wijnen and Boers suggested that the results of their priming experiment were compatible with a phonological encoding deficit in people who stutter in which the encoding of non-initial parts of syllables are delayed. They suggested that the repetition or prolongation of a syllable initial segment is the result of an attempt to begin articulation of a syllable before the articulatory plan for the syllable has been completed.

Levelt and Wheeldon (1994) have demonstrated that speech reaction time is slower when speakers are producing low-frequency syllables, presumably because these syllables must be constructed as opposed to being selected from the stored repository. It is hypothesized that retrieval of gestural scores from the syllabary is faster and less error prone than online computation of the same score. If sounds and sound sequences considered to be phonologically complex are not yet in a young child's mental syllabary, the slower activation rate associated with the need to compute a gestural score for these syllables could contribute to increased speech disfluency and stuttering. In this manner, phonological complexity might be related to disfluency in the speech of young children who still are actively and rapidly adding syllables to their mental syllabary.

A later study by Howell and colleagues (2000) questioned the conclusion of the earlier studies by Throneburg et al. (1994) and Howell and Au-Yeung (1995) that phonological complexity was not related to stuttering in young children. In those two earlier studies, disfluent words were assessed in terms of whether or not they contained an LEC or CS in any position in the word. Howell et al. (2000) agreed that later developing sounds may represent an increased level of phonological difficulty, but argued that the two earlier studies were limited in that they made no distinction regarding the position of the phonologically difficult sound. This is important, they argued, because: (a) most stuttering occurs on the first phone(s) of a word, and (b) there may be an interaction between CS and LEC if they occur together in the initial position (see also Natke, Sandrieser, Van Ark, Pietrowsky, & Kalveram, 2004). Howell et al. suggested that if a word begins both with a CS and LEC, the word would be highly prone to be stuttered. These authors designed an experiment to examine the relationship between stuttering and the phonological complexity of word-initial sounds in young children, teenagers, and adults who stuttered.

Howell et al.'s (2000) decision to make a distinction regarding the position of the phonologically difficult sound appears to be supported by the results of a recent study carried out by Natke and colleagues (2004). These researchers demonstrated that for the children in their study, aged 2 years, 1 month to 5 years of age, 76.5% of stuttered disfluencies occurred on the first sound of a word and 97.8% of stuttered disfluencies occurred on the first syllable of the disfluent word. With the vast majority of stuttering in preschool-age children occurring on the first sound or syllable, Howell et al.'s, decision to distinguish between the word position of phonologically complex sounds appeared to be a reasonable one.

Howell et al. (2000) gathered spontaneous speech samples from 51 participants in three age groups (young children, 3 – 11 years old, n = 21; teenagers, 11 – 18 years old, n = 18; and adults, > 18 years old, n = 12). These samples were phonetically transcribed broadly in fluent regions and narrowly in regions of a disfluency (see Kadi-Hanifi & Howell, 1992 for details on the transcription process). Each word in each speech sample was identified as either a content word or a function word, and then coded as either disfluent or fluent. These authors reportedly made a distinction between content and function words because of the potentially different role that these two word classes play in the production of speech disfluencies. According to their later developed EXPLAN theory of stuttering, speech disfluency occurs because different elements of the speech plan take different amounts of time to plan and execute (Howell & Au-Yeung, 2002). They hypothesized that speech disfluencies are the result of a speaker attempting to execute the articulation of a word before the phonological plan is complete. According to EXPLAN, fluency failures are most likely to occur when a phonologically difficult content word is preceded by a phonologically easy function word.

Howell et al. (2000) then classified each content and function word with respect to whether or not it contained an LEC or a CS. The relative position within the word of the LEC or CS was noted as either initial (LEC_i, CS_i) or non-initial (LEC_x, CS_x). The authors utilized phonetic transcriptions and based the analysis on the actual production, as opposed to the adult target. If a child simplified the word "rabbit" by exchanging a /w/ for an /r/, the word would not be coded as LEC_i. Speakers in all three age groups produced significantly more disfluencies on words that contained a CS_i compared to words without a CS_i. The youngest group also was significantly more disfluent on words that began with an LEC_i. These results demonstrated that when a distinction was made regarding the position of phonologically difficult sounds, as represented by the two metrics utilized in this study (LEC and CS), phonological complexity was related to increased disfluency in younger children who stutter. The results of this study suggested that stuttering in children near the onset age of stuttering, like adults, may be related to phonological complexity. It must be noted, however, that of the 21 children in the youngest age group, only 5 children were 6 years of age and younger, so the relationship of phonological complexity and stuttering in preschool-age children is still unclear.

Recently, Weiss and Jakielski (2001) examined the relationship between phonetic (i.e., production) complexity and speech disfluency in 13 children who ranged in age from 6 years to 11 years, 5 months to determine whether disfluencies occurred on words of greater than average phonetic complexity. The phonetic complexity of each child's words in his/her spontaneous speech sample was analyzed using an index developed by Jakielski (2000). The IPC is composed of eight production-based indices that were derived from findings from studies of babbling and emerging language in infants and toddlers (e.g., MacNeilage & Davis, 1990). The results of these studies of early speech suggest that early speech acquisition is influenced by motor constraints in a predictable manner.

MacNeilage and Davis have suggested that the transition from babbling to first words involves the gradual resolution of production constraints on the independent articulators (e.g., MacNeilage & Davis, 1990, 2000). Jakielski (1998) hypothesized that the gradual resolution of these motor constraints continues throughout later stages of speech development. That is, as children gain more independent control over their articulators, they are able to produce more "adult-like" segments and segmental combinations (i.e., segments and syllables requiring increased degrees of freedom of articulatory movement). The degree of difficulty associated with sounds (and transitions from one sound to another) is hypothesized to be directly related to the degree of control over independent articulators. Consonants, which require a greater degree of control for production, would be more difficult to produce than vowels. A word with variegated singleton consonants (i.e., a word that requires a change in place, such as dorsal to labial, to move from one consonant to another) is hypothesized to be more difficult to produce than a similarly structured word that does not require a place change. An IPC score, which is calculated at the level of the word, reflects the relative complexity of the segmental variation within a word. As the degree of segmental variation (i.e., the degree of articulatory independence required to produce the sounds) in a word increases, so does the complexity score. The IPC score also reflects the complexity of sound-to-sound transitions within a word. This contrasts with the approach taken by Howell and colleagues (2000), which focused attention only on the word-initial sound(s).

Using the IPC as a metric of phonetic complexity, Weiss and Jakielski (2001) analyzed 20 minutes of the spontaneous speech sample from 13 children to determine whether disfluencies tended to occur on words or sentences of greater than average phonetic complexity. These speech samples, which were obtained from a previous study by Weiss and Zebrowski (1992), involved each child speaking with his or her parents in both a structured and unstructured context. The children's speech samples were analyzed using four different measures: (a) the average IPC score of all words produced by the child, (b) the average IPC score of disfluent words produced by the child, (c) the average IPC score for fluent sentences produced by the child, and (d) the average IPC score for sentences with one or more speech disfluencies produced by the child.

Weiss and Jakielski (2001) also were interested in examining the relationship between age and IPC scores. The small sample size and heterogeneity of the children reportedly necessitated the use of non-parametric statistics. Spearman rank correlations were calculated for both the structured and unstructured contexts. Age was correlated with the differences between the all-word IPC scores and the stuttered-word IPC scores, and between the all-sentence IPC scores and the stuttered-sentence IPC scores. While, Spearman rank correlation coefficients did not reach significance for any of the comparisons, the authors reported that a visual inspection of the data suggested that especially for the youngest children, the IPC scores for stuttered words and stuttered sentences were frequently higher than the all-word and all-sentence IPC scores.

The trend toward greater disfluency being associated with greater phonetic complexity was consistent with the authors' hypothesis that the youngest children would exhibit the greatest difficulty with phonetically difficult words or sentences. The rationale for this hypothesis was that younger children simultaneously have to allocate resources to maintain fluency and construct grammatically correct sentences, both of which they have not yet mastered (Crystal, 1987). Weiss and Jakielski (2001) hypothesized that because of the fact that the youngest children have not yet mastered multiple facets of speech and language production, the phonetic complexity of the words and sentences would prove more problematic. Weiss and Jakielski also suggested that phonetic complexity may only play a role in precipitating disfluency in a subgroup of young children who stutter. They hypothesized that for some children, who already have gained sufficient control over their speech sound repertoire, increased phonetic complexity does not play a detrimental role in speech production.

Howell and colleagues recently reanalyzed the data used in the Howell et al. (2000) study using the IPC as the metric for phonological complexity (Howell, et al., in press). Although the title of this latest study is, *Phonetic difficulty and stuttering in English*, it appears that the authors are referring to phonological (i.e., planning) complexity. The term *phonological complexity* has been replaced by the term *phonetic complexity* in the review of a number of earlier studies of the relationship between phonological complexity and stuttering (Howell & Au-Yeung, 1995; Howell, et al, 2000; Throneburg et al., 1994). Apparently these terms were interchanged because the IPC is being utilized to measure complexity. This conclusion is supported by the fact that in the discussion summary, the authors refer to planning difficulty, not production difficulty.

The IPC was developed as an independent production metric derived from motor-based findings in babbling and early words (Jakielski, 1998; MacNeilage & Davis, 1990). On a functional level it is somewhat artificial to separate planning from production. Gelfer and Eisenberg (1995) suggest that a child’s ability to produce a sound may play a role in whether or not that child attempts its production. If particular sounds are produced infrequently (secondary to production constraints) it is unlikely that syllables containing these sounds would be stored in the child's mental syllabary. The syllabic gestures for syllables containing difficult to produce sounds then, would need to be computed at the level of phonetic encoding, rather than simply being retrieved from the syllabic store. In this manner, words with higher IPC scores may very well represent a challenge at the level of speech planning.

While an earlier study (Howell et al., 2000) uncovered a significant relationship between stuttering rate and both CS_i and LEC_i in participants in the youngest age group (young children, 3 – 11 years old, n = 21), the results of this more recent study found no relationship between stuttering rate and IPC score for this same group (Howell et al., 2000; Howell et al., in press). Note that the five children under 6 years old were not included in the latest reanalysis. Howell et al. (in press) concluded that the IPC developed by Jakielski (2000) can be used to predict stuttering occurrences that arise out of planning difficulties for older children and adults but not for young children. Howell et al. (in press) suggested that the results of this latest study also support their contention that it is important to focus attention on the word-initial position when investigating the relationship between stuttering and phonological complexity. Because no speakers under 6 years of age were included in the analyses for this most recent study, the findings add little to our understanding of the relationship between phonological complexity and stuttering in preschool-age children.

2.2.3. Summary of Recent Findings of Phonological Complexity in Preschool-age Speakers

Results of Throneburg et al. (1994) and Howell and Au-Yeung (1995) were consistent with Bloodstein and Gantwerk's (1967) conclusion that disfluencies in preschool-age children were not influenced by phonological complexity in a manner similar to that found in adults and older children. Howell et al. (2000) and Weiss and Jakielski (2001) on the other hand, reported results similar to those of Williams et al. (1969) who reported that for both young children who stuttered and their normally fluent peers, disfluencies occurred more frequently on words possessing the same attributes that Brown and others found to be associated with increased stuttering in adults. One possible explanation for the contradictory results reported in the more recent studies of phonological and phonetic complexity may be found in the methodologies utilized by Howell et al. and Weiss and Jakielski, which are different from those utilized in earlier studies and from one another. Howell et al. utilized the same metric as earlier studies (i.e., LEC and CS), but made a distinction as to the position of the LECs and CSs. Weiss and Jakielski employed a whole-word metric that was developed from a different theoretical framework from that supporting the use of LECs and CSs.

LECs and CSs, which were utilized as a metric for phonological complexity by Howell et al., 2000, are considered to represent a greater level of difficulty than those sounds that are mastered earlier in children's typical development. In the case of Howell et al., the attention is focused on the presence or absence of a particular consonant in word-initial positions. The IPC, on the other hand, is a metric that was developed based on studies of early babbling and emerging language in infants and toddlers, and represents the degree of control needed to produce a sound or to move from one sound to another within a word. The articulatory complexity of a particular word is a factor of both the complexity of the individual phonemes within a word and the articulatory transitions between phonemes. As such, the IPC score is used to sum the phonological and/or phonetic difficulty of individual sounds and sound combinations in whole words.

The results of the two recent studies by Howell et al. (2000) and Weiss and Jakielski (2001) suggest that stuttering in younger children may be associated with increased phonological and/or phonetic complexity within words. Both studies, however, contained a minimal number of preschool-aged children. To improve our understanding of the role that phonological complexity plays in the onset of stuttering, this relationship must be examined in a larger number of preschool-age children near the age of onset of this disorder. Howell et al.'s assertion that it is important to distinguish between the position of phonologically difficult sounds can be examined by utilizing both a word-initial and whole-word metric for phonological complexity.

Several recent theories of stuttering suggest that speech disfluencies result from a disruption in the time-dependent process of phonological encoding (Howell & Au-Yeung, 2002; Karniol, 1995; Perkins et al., 1991; Postma & Kolk, 1993; Wingate, 1988). At present, however, relatively little is known about the role phonological complexity plays in the disruption of this planning process and the subsequent speech disfluency.

2.3. Statement of the Problem

Early studies of linguistic complexity and the occurrence of stuttered disfluencies in older children and adults suggested that linguistic complexity was associated with words being produced disfluently (Brown, 1937, 1938a, 1938b, 1945; Brown & Moren, 1942; Danzger & Halpern, 1973; Hahn, 1942; Johnson & Brown, 1935; Quarrington, 1965; Quarrington, et al., 1962; Soderberg, 1962; Taylor, 1966a, 1966b; Wingate, 1967, 1979). While results of studies by Silverman and colleagues (Silverman, 1974; Williams, Silverman & Kools, 1969) suggested disfluencies in young children was related to the same factors as adults, Bloodstein and colleagues provided evidence that contradicted this conclusion (Bloodstein & Gantwerk, 1967; Bloodstein & Grossman, 1981). A significant body of literature has supported Bloodstein and colleagues' conclusion that young children are more likely to stutter when producing syntactically more complex utterances (Bernstein, 1981; Bernstein Ratner & Costa-Sih, 1987;

Bloodstein & Grossman, 1981; Gaines et al., 1991; Logan & Conture, 1995, 1997; McLaughlin & Cullinan, 1989; Melnick & Conture, 2000; Pearl & Bernthal, 1980; Yaruss, 1999). A recent study by Yaruss (1999) however, demonstrated that while disfluent utterances were significantly more complex (on multiple syntactic measures), syntactic complexity alone was not able to meaningfully predict the likelihood of an utterance being produced disfluently. The most predictive variable in Yaruss' study, utterance length, was significantly predictive for only half of the children. Clearly, some other factor(s) are important in determining whether or not an utterance will be produced fluently or disfluently.

Logan and Conture (1997) have hypothesized that the increased length of an utterance may be associated with stuttering because of the increased phonological processing demands associated with the increase in length. They speculated that stuttered utterances might contain more syllables containing onsets and codas filled with consonants and consonant clusters, and suggested that it might be worthwhile to examine the relationship between speech fluency and the types of consonants within an utterance.

Current models of speech planning and production propose that the process of fluent speech production involves a number of different stages (Dell, 1986; Levelt et al., 1999; Roelofs, 1997). Levelt et al. and Roelofs propose that once a speaker has selected a syntactic word (or lemma), two distinct phonological processes are responsible for generating an articulatory plan so that the word can be realized. The first of these processes, phonological encoding, is the process by which a target word's syllabification and prosody are computed. The product of phonological encoding is a syllabified phonological word containing both segmental and metrical information. This abstract representation serves as input for the next phonological process, phonetic encoding, when a gestural score is retrieved or computed. This gestural score is then executed by the articulatory system. A number of current theories of stuttering suggest that the person who stutters exhibits either impaired phonological encoding or a dyssynchrony between this and other stages in speech planning and production (Howell & Au-Yeung, 2002; Karniol, 1995; Perkins et al., 1991; Postma & Kolk, 1993; Wingate, 1988). Wijnen and Boer (1994) reported evidence from priming studies that suggests that the repetition or prolongation of a syllable initial segment is the result of an attempt to begin articulation of a syllable before the articulatory plan for the syllable has been completed. It follows then, that phonological complexity may be related to the production of speech disfluencies.

Recent studies by Howell et al. (2000) and Weiss and Jakielski (2001) offer support to the contention that phonological complexity may be related to stuttering in the speech of young children. Neither of these studies, however, adequately examined the relationship of speech disfluency and phonological complexity in the speech of preschool children near the onset age of stuttering. The number of preschool-age children in both of these studies was quite small (n = 7 total). In addition, neither study reported the number of utterances that were analyzed for each child. While the results of these two recent studies are suggestive of a relationship between phonological complexity and stuttering, a study with adequate numbers of children and speech-sample size are needed to more thoroughly investigate this relationship. In light of the contradictory findings of other recent studies (Throneburg et al., 1994; Howell & Au-Yeung, 1995), further research is needed in order to adequately understand the role that phonological complexity plays in determining whether or not a word will be produced disfluently by young children who stutter.

The purpose of this study is to examine the influence of phonological complexity on instances of speech disfluencies in the speech of children near the onset age of stuttering.

Because of the fact that phonological and phonetic encoding plays a central role in the production of fluent speech, it is hypothesized that utterances with a higher degree of phonological complexity will be more likely to contain a disfluency than utterances with a lower degree of phonological complexity (Dell, 1986; Levelt, et al., 1999; Roelofs, 1997). Two different metrics will be utilized to assess phonological complexity: (a) the presence of word-initial LECs and CSs (LEC_i and CS_i, Howell et al., 2000), and (b) the IPC (Jakielski, 2000). Howell et al. suggested that because stuttering typically occurs on the first sound of a word, it is important to make a distinction between the various positions in which phonologically difficult sounds may occur (see also Natke et al., 2004). Current models of speech planning and production, however, suggest that the unit of planning is a larger unit (Levelt et al., 1999; Roelofs, 1997). Therefore a whole-word metric like the IPC may be more appropriate.

While the present experiment is not a direct test of a current theory of stuttering, an improved understanding of the relationship between phonological complexity and stuttering will help to clarify the role that phonological complexity plays in those theories of stuttering that suggest a specific role for phonological and phonetic encoding (Howell & Au-Yeung, 2002; Karniol, 1995; Perkins et al., 1991; Postma & Kolk, 1993; Wingate, 1988). The use of two metrics for phonological complexity, one focused on only the word-initial sound(s) and another that operates at the level of the whole word, will address Howell et al.'s (2000) concern regarding the importance of distinguishing between the word position of phonologically difficult sounds. Thus, the present study is designed to examine the relationship between phonological complexity and stuttering in young children near the age of stuttering onset.

2.3.1. Research Question

Is there a significant difference in the likelihood that a disfluency will occur in an utterance with increased phonological complexity versus an utterance with lower phonological complexity for preschool-age children who stutter?

2.3.2. Hypothesis

The null hypothesis is that an utterance with a higher phonological complexity score (as represented by the LEC_i/CS_i score and IPC score) will be no more likely to contain a disfluency than an utterance with a lower phonological complexity score. A rejection of the null hypothesis would suggest that stuttering in young children near the age of stuttering onset is related to phonological complexity and may therefore be the result of a delay in the transmission of a complete articulatory motor program. This would suggest the need to explore more closely the role of phonological and phonetic encoding in the production of disfluent speech in young children.

3. Method

3.1. Participant Information

Participants in this study were 12 monolingual English-speaking children who stutter, with a mean age of 55.2 months (*SD* = 8.8 months, range = 40-66 months). These children's speech had been analyzed previously for studies examining (a) stuttering and phonological disorders, (b) utterance timing, and (c) the relationship of utterance length and syntactic complexity to the occurrence of stuttering (Yaruss, 1994, 1997, 1999). The age range of these children represented an age range typical of the onset of stuttering, and was comparable to the age range used in earlier studies of linguistic complexity and stuttering (e.g., Howell et al., 1999, 2000; Logan & Conture, 1995, 1997; Yaruss & Conture, 1995). Participants' age, time since onset of stuttering (based on parental interview), and scores on the Stuttering Severity Instrument (SSI; Riley, 1980) are summarized in Table 1.

Table 1. Participants' Chronological Age, Time Since Onset of Stuttering, MLU, Total Overall Score on the Stuttering Severity Instrument, and Number of Fluent and Disfluent Utterances (SSI, Riley, 1980).

Participant Number	Chronological Age in Months	Time Since Onset in Months	MLU in Words	SSI Total Overall Score	Number of Utterances	Number of Fluent Utterances	Number of Disfluent Utterances
1	40	6	5.45	14	75	55	20
2	43	7	4.72	13	75	62	13
3	49	17	6.08	16	75	46	28
4	49	15	5.04	10	75	57	18
5	51	13	4.83	18	75	50	25
6	54	22	5.14	21	75	24	51
7	58	20	5.14	8	75	54	21
8	61	23	5.28	9	75	55	20
9	63	36	6.84	14	75	34	41
10	63	14	5.79	17	75	30	45
11	65	23	5.73	13	75	43	32
12	66	30	7.45	16	75	48	27
Mean	55.17	18.83	5.62	14.08	75	46.5	28.42
SD	8.80	8.77	0.82	3.82	0.00	11.73	11.73

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All participants were referred to a university speech-language clinic because of concerns about their speech fluency. Inclusion criteria for Yaruss' study were similar to those used in other studies involving children who stutter (e.g., Melnick & Conture, 2000; Pellowski & Conture, 2002; Yaruss & Conture, 1995). A child was considered a child who stutters if the following criteria were met: (a) the child produced at least 3 within-word disfluencies (e.g., repetitions of sounds, syllables, or monosyllabic whole words; audible or inaudible prolongations) per 100 words of conversational speech, (b) at least one adult familiar with the child had implicitly or explicitly expressed concern that the child was at risk for developing a stuttering problem, and (c) the child was judged to be a child who stutters by the investigator (a licensed and certified speech-language pathologist who specialized in the treatment of children and adults who stutter).

Prior to participation in Yaruss' (1994, 1997, 1999) studies, a certified speech-language pathologist administered a battery of formal and informal assessment tools to evaluate the speech and language development of each child to verify that none of the 12 participants exhibited any speech, language, or hearing concerns other than stuttering. The children's language abilities were assessed via administration of the Peabody Picture Vocabulary Test-Revised (PPVT-R; Dunn & Dunn, 1981) and the expressive components of the Test of Early Language Development-2 (TELD-2; Hresko, Reid, & Hammill, 1991). All participants also demonstrated age-appropriate articulation skills, as determined by performance on the Sounds-in-Words subtest of the Goldman-Fristoe Test of Articulation (GFTA; Goldman & Fristoe, 1986). All participants passed a 25 decibel pure-tone hearing screening at 500 Hertz (Hz), 2000 Hz, and 4000 Hz. Finally, mean length of utterance (MLU) was calculated for each child in accordance with Brown's (1973) morpheme collection rules. The MLU of all 12 children was less than 2 *SD* above or below the normative data for his or her age. This assessment protocol verified that, other than stuttering, all 12 participants exhibited normal speech, language, and hearing function. In addition to the testing described above, information pertaining to each child's speech, language, and motor development and medical and social history was obtained through case history questionnaires completed by the participant's parents or guardians. Based on informal analysis and the detailed parental interview, all children were judged to exhibit no known history of social, emotional, or neurological problems (see Appendix A for a summary of the screening tests utilized by Yaruss, 1994, 1997, 1999).

3.2. Data Collection

The data analyzed in this study were collected for three earlier studies carried out by Yaruss (1994, 1997, 1999). In the current study, orthographic transcriptions from these previously collected video recordings were phonetically transcribed and reanalyzed. No new data were collected. The data collection, instrumentation, and transcription protocols described below pertain to those utilized previously by Yaruss, unless otherwise noted. This information is included in order to provide the reader with an accurate description of the data collection procedures for the speech samples utilized in the present study.

Data collection and instrumentation procedures for the previously collected speech samples were similar to those utilized in earlier studies (Yaruss & Conture, 1995, 1996; see also, Melnick & Conture, 2000; Pellowski & Conture, 2002; Wolk, Edward, & Conture, 1993). Each participant was videotaped with a parent or guardian while engaged in a free-play conversational interaction lasting for approximately 30 minutes. To obtain a speech sample in as natural a setting as possible, the children and their parents or guardians were seated next to each other at a small table containing a standard set of age appropriate toys (e.g., plastic food, outer space set, etc.). The adults were instructed to play with the child "as they would at home," and not to attempt to make the child talk more or to speak fluently or disfluently. As expected given the age range of the children, the conversational topics often were related to toys. The recording session continued until approximately 100 utterances were collected.

3.3. Instrumentation

The speech sample was video recorded using two high-quality color cameras. One of the cameras was directed at the child and the other was directed at the caregiver. Both cameras were positioned to obtain a view of the participant's head, neck, torso, arms, and hands. The output of the two video cameras was fed into a video switcher where the two signals were combined to form a single image with the child on the left half and the caregiver on the right half of the screen of a color television monitor.

The split-screen image and the associated audio signals were recorded on a videocassette recorder. Audio signals for both the child and adult were obtained using a two-channel wireless directional microphone system equipped with lapel microphones. The lapel microphones were attached to the participants' clothing, approximately 15 cm from their mouths.

3.4. Data Analysis Procedures

3.4.1. Transcription of Children's Spontaneous Speech

Following the parent-child interaction, each child's videotaped speech sample was orthographically transcribed verbatim into a customized computer database. If for example, morphological immaturity resulted in the child producing a word in a non-adult-like form (i.e., *gonna* for *going*) the word *gonna* was transcribed. This transcription was reviewed and refined based on repeated viewings of the videotapes. The reliability of these transcriptions was not calculated. Questionable items were resolved via consultation with a second trained investigator. An attempt was made to obtain each conversational sample from the middle 20 minutes of the parent-child interactions because prior research (e.g., Kelly & Conture, 1991; Zebrowski & Conture, 1989) had shown that children may be unfamiliar with the testing environment during the early portions of a recording session (i.e., the first 5 minutes), and more fatigued and restless during the final portions of a recording session (i.e., the last 5 minutes).

An utterance was defined as a string of words that (a) communicated an idea, (b) was set apart by pauses, and (c) was bound by a single intonational contour (Kelly & Conture, 1992; Logan & Conture, 1995; Meyers & Freeman, 1985). However, when two clauses were produced in a single breath without pauses or changes in intonational contour, they were coded as a single utterance (e.g., Golinkoff & Ames, 1979; Lee, 1974). In addition, repeated short formulaic utterances or lexicalized phrases (e.g., "I don't know.") were excluded.

For the current study, the orthographic transcriptions of the speech samples obtained by Yaruss (1994, 1997, 1999), were phonetically transcribed using broad symbols from the IPA. Because the intent of this study was to examine the effect of phonological complexity on the process of speech planning, these phonetic transcriptions were based on the adult targets, not the children's actual phonetic productions. It should be noted that post hoc testing was conducted to determine the effect that this decision had on the phonological complexity scores. The results of this testing is described in the results and discussion section.

3.4.2. Speech Fluency

For the previous studies (Yaruss, 1994, 1997, 1999), each of the participants' utterances were examined to identify the presence of all speech disfluencies, including within-word disfluencies (i.e., sound/syllable repetitions, monosyllabic whole-word repetitions, audible and inaudible prolongations) and between-word disfluencies (i.e., multisyllabic whole-word repetitions, phrase repetitions, interjections, and revisions/incomplete phrases) (Campbell & Hill, 1987; Pellowski & Conture, 2002; Yairi & Ambrose, 1992; Yaruss and Conture, 1995). Examples of these behaviors can be found in Table 2. Definitions of each disfluency type can be found in Appendix B. While within-word disfluencies were generally coded as *stuttered*, very short prolongations and sound or syllable repetitions that were accompanied by pauses greater than 250 msec were not considered to be an occurrence of stuttering. Between-word disfluencies were coded as *not stuttered* unless they were associated with increased physical tension (Yaruss, 1994).

Table 2. Examples of Types of Speech Disfluencies.

Disfluency Type	Example
Sound syllable repetition (SSR)	A- a- actually it's mine.
Monosyllabic whole word repetition (MWR)	And and and it goes there.
Audible sound prolongation (ASP)	Mmmmmmore cake please.
Inaudible sound prolongation (ISP)	He's a b- (silent pause) ad man.
Multisyllabic whole-word repetition (MultiWR)	It's going going over there.
Phrase repetition (PR)	And then- and then they went.
Revision (REV)	Hey mom its my- your turn.
Interjection (INT)	Does (uh) that come too?

Older models of speech planning and production were built around speech errors (Dell, 1986, 1988; Levelt, 1989; Shattuck-Hufnagel, 1979). Models such as WEAVER++, which were developed around chronometric data (i.e., response-time data from priming studies) rather than speech errors, still must be able to account for errors such as slips of the tongue and speech disfluencies (Roelofs, 1997). These psycholinguistic models of normal speech planning and production, however, do not differentiate between normal and stuttered disfluencies. To more easily interpret the influence of phonological complexity on instances of speech disfluencies in light of current models of speech planning and production, utterances were identified either as fluent or disfluent in the present study. No differentiation was made between *stuttered* and *normal* disfluencies.

3.4.3. Index of Phonetic Complexity (IPC)

Each child's utterances were evaluated for phonological complexity using the scoring criteria developed by Jakielski (2000) as delineated in Table 3. See Table 4 for examples of IPC scoring. For a detailed explanation of the IPC scoring procedure see Appendix C, D, and E. Specifically, the IPC value of each word in an utterance was calculated based on its phonetic transcription and then the sum of the IPC values were calculated for that utterance. This summation of the IPC scores will be termed *Utterance IPC* (U-IPC). The mean U-IPC score for the fluent and disfluent utterances for each child can be seen in Appendix F.

Table 3. Categories of Phonological Complexity and Scoring Criteria (Jakielski, 2000).

Category	One Point for
Consonant by place class	Each dorsal
Consonant by manner class	Each fricative, affricate, or liquid
Singleton consonants by place variegation (if any two singleton consonants vary in place, consider variegated)	Variegation
Vowel by class	Each rhotic
Word shape	Words ending with a consonant
Word length in syllables	Words $\geq$ 3 syllables
Contiguous consonants (cluster)	Each consonant cluster
Cluster by type (when place is different for any of the contiguous consonants, place is heterorganic)	Each heterorganic cluster

Note: These scoring criteria were obtained from K. Jakielski (personal communication, September 14, 2004).

Table 4. Examples of Index of Phonetic Complexity (IPC) Scoring (Jakielski, 2000).

Under points, the numbers are coded as follows:
1. Consonant by place
2. Consonant by manner class
3. Vowel by class
4. Word shape
5. Word length in syllables
6. Singleton consonants by place variegation
7. Contiguous consonants
8. Cluster by type

	Points								
Word	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
daddy									0
potato					1	1			2
fun		1		1		1			3
return		1	1	1					3
humble		2		1		1	1		5
washboard		1	1	1		1	1	1	6
artichoke	1	1	1	1	1	1			6
telephone		2		1	1	1			5
nonchalant		2		1	1		2		6
grumble	1	2		1			2	1	7
compliments	1	2		1	1	1	2	1	9
conversation	1	3	1	1	1	1	1	1	10
catastrophic	2	3		1	1	1	1		9
reflections	1	5		1	1		3	2	13

Note. From training material obtained from K. Jakielski (personal communication, September 14, 2004).

3.4.4. Word-initial Late-emerging Consonants (LEC_i) and Consonant Strings (CS_i)

Howell et al. (2000) suggested that it is important to analyze the word position of phonologically-difficult sounds. They reported that the youngest participants in their study were more likely to stutter on a word that began with an LEC or CS. For the current study, each phonetically transcribed word in the speech sample was classified with respect to whether or not it contained a word-initial LEC (LEC_i) or a word-initial CS (CS_i). Any consonant(s) occurring before the first vowel were coded as a word-initial consonant. The number of occurrences of

LEC$_i$s and CS$_i$s was tabulated for each utterance. An U-LEC$_i$/CS$_i$ score was computed by totaling the instances of LEC$_i$s and CS$_i$s in each utterance (see Table 5 for examples of U-LEC$_i$/CS$_i$ scoring). The mean U-LEC$_i$/CS$_i$ score for fluent and disfluent utterances for each child can be seen in Appendix G.

Table 5. Examples of Word-initial Late-emerging Consonant and Consonant String (LEC$_i$/CS$_i$) Scoring.

Utterance	U-LEC$_i$/CS$_i$
THat's where he came fRom	3
made a chRistmas tRee	4
are THey Still asleep	3
THis is a Special one	3
THe Red guy	2
where THey got Lost Somewhere	3
it's a Spinner	2
get him to bump his head in THere	1
Looks Like Star tRek	6
could I pLease take THis off	3

Note. LEC$_i$s are denoted by uppercase letters. CS$_i$s are underlined.

Prior studies that examined the relationship between the presence of LECs and the occurrence of a speech disfluency utilized Sander's (1972) list of 10 consonants (Howell & Au-Yeung, 1995; Howell et al., 2000; Throneburg et al., 1994). As noted earlier, Sander arrived at this list by reanalyzing the data from earlier studies of sound acquisition. More recently, Shriberg reported that in his study of 3-6 year old children (*N*=64), consonant mastery could be divided into three groups (Shriberg, 1993). These three groups were identified as Early-8, Middle-8, and Late-8 consonants. The rankings were fairly congruent with the Sander data. Two of the consonants however, which Sander considered to be late-emerging (/tʃ/ and /dʒ/), fell into the Middle-8 category. In addition to being a somewhat more conservative measure, involving 8 as opposed to 10 consonants, Shriberg's criteria for mastery were better defined than Sander's. For the purposes of this study, Shriberg's Late-8 consonants, /r, l, s, ʃ, z, ð, θ, ʒ/, were considered late-emerging. Shriberg's (1993) consonant mastery chart can be seen in Appendix H.

3.4.5. Intrajudge and Interjudge Measurement Reliability

Intrajudge and interjudge measurement reliability for analysis of the participants' 75 utterances were determined for: (a) occurrence of speech disfluencies, (b) U-IPC, and (c) U-LEC_i/CS_i. The intrajudge reliability measurements occurred no less than 2 months following the initial transcription and coding. Fifteen utterances (20%) were selected at random for each of the 12 participants (total = 180 utterances) and re-analyzed by the author. To complete the interjudge measurements, a speech-language pathology student trained in the analysis of children's spontaneous speech used the same methodology described above to analyze each child's disfluencies, U-IPC, and U-LEC_i/CS_i. The reliability measurements for the speech disfluencies were carried out by Yaruss (1994, 1997, 1999).

3.4.5.1. Speech Disfluencies

Cohen's (1960) Kappa statistic was used to assess the measurement reliability of the categorical judgments relating to speech disfluency. Because it is a relatively conservative test, Kappas that range from 0.60 to 0.75 are considered *good*, and those which range from 0.76 to

1.00 are considered *excellent* (Fleiss 1981). The intrajudge and interjudge Kappas for the occurrence of speech disfluencies found in Table 6 were previously reported by Yaruss (1994, 1997, 1999).

Table 6. Analysis of Measurement Reliability for Speech Disfluencies Based on Cohen's (1960) Kappa for Categorical Judgements.

	Intrajudge	Interjudge
Within-word speech disfluencies	$K = 0.79$	$K = 0.80$
Between-word speech disfluencies	$K = 0.88$	$K = 0.78$
Stuttered disfluencies	$K = 0.86$	$K = 0.80$

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3.4.5.2. Measures of Phonological Complexity

Because U-IPC, and U-LEC$_i$/CS$_i$ represent continuous measures, rather than discrete measures, measurement reliability is presented in terms of mean differences, rather than percent agreement. The mean intrajudge and interjudge reliability differences and standard deviations are presented in Table 7. The analyses revealed very small mean differences for both intrajudge and interjudge reliability. The mean differences ranged from 0.01 to 0.03 (*SD* ranged from 0.167 to 0.236). These scores represent a very high degree of reliability. For example, for the U-LEC$_i$/CS$_i$ interjudge reliability, the two raters scored 178/180 utterances with the exact same score. The two remaining scores differed by only one point.

Table 7. Analysis of Measurement Reliability for Phonological Complexity Scores Based on Mean Differences.

	Intrajudge	Interjudge
U-IPC	Mean difference = 0.01	Mean difference = 0.03
	SD = 0.236	*SD* = 0.234
U-LEC$_i$/CS$_i$	Mean difference = 0.01	Mean difference = 0.01
	SD = 0.183	*SD* = 0.167

3.5. Data Analysis

Phonological complexity was quantified using two complexity indices; (a) U-IPC, and (b) U-LEC$_i$/CS$_i$. The U-IPC and U-LEC$_i$/CS$_i$ scores were not adjusted for utterance length. Logan and Conture (1995) suggested that it might be best to consider utterance length a macrovariable that encompasses other variables of speech planning and production. They hypothesized that longer utterances might be related to increased speech disfluency secondary to the fact that increases in utterance length are related to increased phonological processing demands (Logan and Conture, 1997). The author of the current study reasoned that if length was factored out of the complexity score, an integral aspect of phonological complexity would be lost. Binary logistic regression was used to examine the relationship between the continuous explanatory variables of U-IPC and U-LEC$_i$/CS$_i$ and the binary outcome variable of fluent versus disfluent.

One advantage of the logistic regression analysis is that it is able to provide information regarding how disfluency is related to phonological complexity, not merely identify whether or not fluent and disfluent utterances differ in regards to the phonological complexity scores. The relationship between phonological complexity and the production of a disfluency is represented by the slope of the regression line in the logistic regression equation. The output then, shows how a given increase in the phonological complexity score is related to the probability that a given utterance will be produced disfluently. Like other regression analyses, the logistic regression also is able to provide information regarding child specific effects (e.g., how particular children respond to increased phonological complexity). Separate analyses were completed for U-LEC_i/CS_i and U-IPC to determine which metric was better able to identify a relationship between increased phonological complexity and disfluency.

To identify a relationship between phonological complexity and speech disfluency common to all children (i.e., the common underlying structure), the individual effects of the children were compared to one another in the form of dummy variables. This was accomplished by sequentially comparing the individual effect of one participant to the individual effect of each other participant. The model used in this analysis assumes that changes in phonological complexity affect the probability of an utterance being disfluent in a similar manner for all 12 children. This assumption is tested with the goodness-of-fit analysis (i.e., Hosmer-Lemeshow test) and the level of statistical significance of the regression coefficient for the explanatory variable (either U-IPC or U-LEC_i/CS_i). Since the model assumes that the slopes of the regression line (for all participants) is similar, a large p-value for the goodness-of-fit test suggests that the model is appropriate.

The logistic regression model fits a binary response (in this case fluent versus disfluent utterance) to an S-shaped curve where the effect of phonological complexity on this binary response varies along the curve. The relationship between phonological complexity and the occurrence of a disfluency can be described by a linear line by using a logit transformation. The *logit* is the logarithm of the ratio of the probabilities of the utterance being disfluent over fluent. The logit increases by beta (β) units for every one unit of change in phonological complexity score. Therefore, for a given increase in U-IPC or U-LEC_i/CS_i, the corresponding change in the likelihood that an utterance will be produced disfluently can be calculated.

4. Results

This study examined the relationship between phonological complexity and the probability of an utterance containing a disfluency in 12 preschool-age children. The following research question was proposed: Is there a significant difference in the likelihood that a disfluency will occur in an utterance with higher phonological complexity versus an utterance with lower phonological complexity? The null hypothesis was that an utterance with higher phonological complexity would be no more likely to contain a disfluency than an utterance with lower phonological complexity as quantified using U-IPC and U-LEC_i/CS_i scores. Results are presented separately for each of the two metrics in terms of the underlying common structure of the children as a group, and in terms of the relationship of the individual children to one another. In order to maintain an overall significance level of $\alpha = 0.05$ the significance levels for the individual analyses were Bonferroni-corrected (individual α for each of the two comparisons = .025).

4.1. Word-initial Late-emerging Consonants and Consonant Strings Analysis

4.1.1. Underlying Common Structure of the Participants as a Group

As noted earlier, goodness-of-fit was used to test the assumption that the common underlying relationship of phonological complexity (as represented in this case by U-LEC_i/CS_i) was similar for all 12 participants. This assumption was tested by the Hosmer-Lemeshow test. A non-significant p-value suggests that the assumption of no difference is plausible. If this model was inappropriate, the p-value would be very small. It can be seen in Table 8 that the Hosmer-Lemeshow test was not significant ($p = .882$), suggesting that U-LEC_i/CS_i scores were related to disfluency in a similar manner for all of the children in this study. If U-LEC$_i$/CS$_i$ was not related to the probability of an utterance being disfluent, the slope of the regression line, while similar, would have been equal to zero for all participants. It can be seen in Table 8 that the test that all slopes are zero was significant ($p < .001$).

Table 8. Binary Logistic Regression for Disfluency Versus Word-initial Late-emerging Consonant and Consonant String Score at the Level of the Utterance (U-LEC$_i$/CS$_i$) with Participant 1 as Control.

Predictor	Hosmer-Lemeshow	Regression Coeficient (Slope)	All slopes equal zero
U-LEC$_i$/CS$_i$ score	3.7085 ($p = .882$)	$\beta = .25721$ ($p < .001$)	G = 110.043 ($p < .001$)

Recall that in order for the logistic regression model to be deemed appropriate, in addition to a non-significant goodness-of-fit test, the regression coefficient (β) for the explanatory variable must be significant. It can be seen that $\beta = .25721$ and was statistically significant ($p < .001$). This suggests that a model using U-LEC$_i$/CS$_i$ as a covariate was indeed appropriate (i.e., U-LEC$_i$/CS$_i$ was related to the presence of disfluencies within the utterance). For every one unit of increase in U-LEC$_i$/CS$_i$, the logit (logarithm of the ratio of the probabilities of the utterance being disfluent over fluent) increased by .25721. Therefore, as complexity increased from U-LEC$_i$/CS$_i$ = 0 to U-LEC$_i$/CS$_i$ = 9, the probability of that utterance being disfluent increased by a factor of 3 to 4 for the children in this study. For example, for Participant 4, the probability of an utterance being disfluent (π) at U-LEC$_i$/CS$_i$ = 0, was π = .1707. At U-LEC$_i$/CS$_i$ = 5, the probability of an utterance being disfluent was $\pi = .4269$.

4.1.2. Relationship of Individual Participants to One Another

While the results of the logistic regression suggested phonological complexity was related to disfluency in a similar manner for all 12 participants, individual differences did exist. Between-participant differences were determined by sequentially comparing the individual effect of Participant 1 to the remaining 11 children. Because the relationship between phonological complexity and disfluency was similar for all of the participants, this comparison could have been made to any of the 12 children. That is, because the goodness-of-fit test demonstrated that the slope of the regression line was similar for all 12 children, any of the participants could have served as a control. Participant 1 was chosen by convention. A child with a significant negative β was less likely to be disfluent given the same U-LEC_i/CS_i as Participant 1, and a child with a significant positive β was more likely to be disfluent given the same U-LEC_i/CS_i as Participant 1. The coefficient term was positive and significant for 4 of the participants. (See Table 9 below, in which the 4 children for whom the effect was significantly different than Participant 1 are italicized and in bold type.) Given the same U-LEC_i/CS_i as Participant 1, these 4 children had a significantly greater probability of being disfluent than Participant 1. The 7 children for whom the probability was non-significant were no more likely or unlikely to be disfluent given the same U-LEC_i/CS_i score as Participant 1. That is, for all 12 children, as U-LEC_i/CS_i increased, the probability of an utterance being disfluent increased. Four of the children (Participants 6, 9, 10, and 11), however, had a greater baseline effect. At any given U-LEC_i/CS_i score these 4 children had a greater probability of being disfluent than the remaining children.

Table 9. Binary Logistic Regression Data for Word-initial Late-emerging Consonant and Consonant String Score (U-LEC$_i$/CS$_i$) Relative to Participant 1.

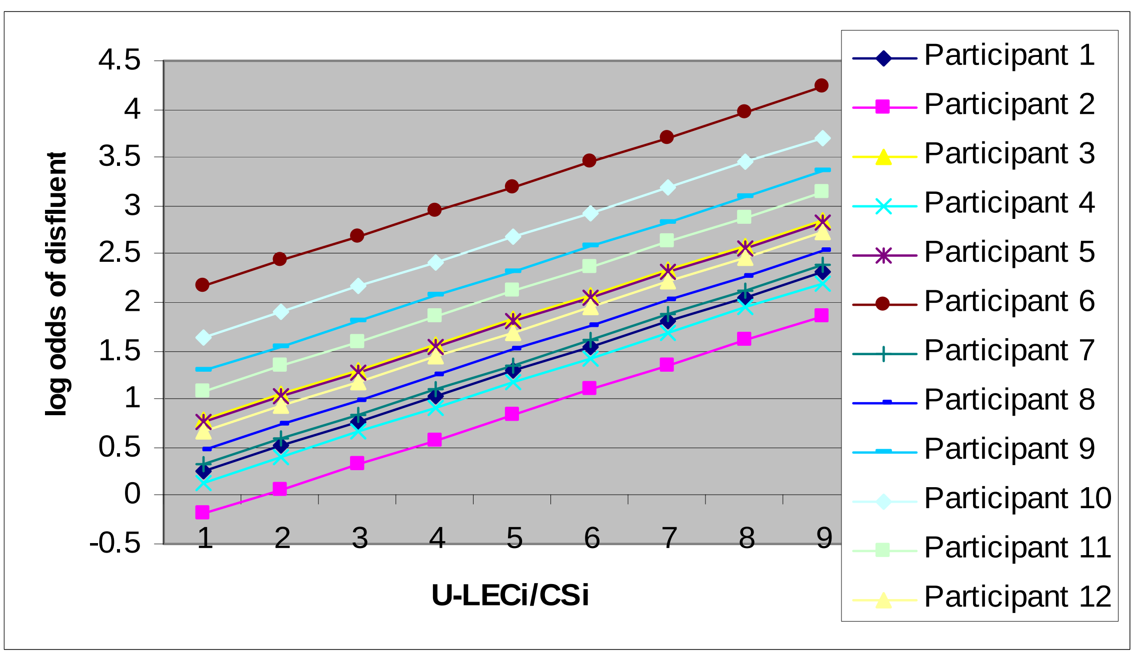
Participant	Regression Coefficient (β)	Standard Error Coefficient	Significance Level
2	-.4491	.4048	$p = .267$
3	.5361	.3584	$p = .135$
4	-.1147	.3810	$p = .763$
5	.5104	.3634	$p = .160$
6	***1.9105***	***.3653***	***p* < .001**
7	.0683	.3706	$p = .854$
8	.0221	.3734	$p = .953$
9	***1.0340***	***.3555***	***p* = .004**
10	***1.3865***	***.3560***	***p* < .001**
11	***.8261***	***.3559***	***p* = .020**
12	.4073	.3599	$p = .258$

Note: The scores for Participants 6, 9, 10, and 11 were significantly different than Participant 1.

4.1.3. Summary of U-LEC$_i$/CS$_i$ Logistic Regression Analysis

Results of the logistic regression analysis suggested that the probability of an utterance being disfluent was related to U-LEC$_i$/CS$_i$ in a predictable fashion. Results also suggested that it was reasonable to conclude that a significant common relationship existed for the 12 children in this study. If the idealized data from the mathematical model are plotted on an XY graph, Participants 6, 9, 10, and 11 show a greater y-intercept than the remaining 8 children (who would cluster around Participant 1). All 12 children are plotted with the same slope that was derived from the average across all of the children, because the underlying relationship of phonological complexity to disfluency was found to be similar for all of the children in the study. Figure 1 shows an illustration of this relationship, in which the common underlying slope is plotted out from the y-intercept of each participant. This figure demonstrates that for all 12 children, as phonological complexity increased, so did the probability of the utterance being produced disfluently. While the slope of the underlying common structure (β) was the same for all of the children, Participants 6, 9, 10, and 11, had a greater probability to be disfluent at a given U-LEC$_i$/CS$_i$.

Figure 1. Log Odds of an Utterance Being Disfluent as Word-initial Late-emerging Consonant and Consonant String Score (U-LEC$_i$/CS$_i$) Increases Across Participants. Note that Participants 6, 9, 10, and 11 are Significantly Different from Participant 1.



4.2. Index of Phonetic Complexity Analysis

4.2.1. Underlying Common Structure of the Participants as a Group

As described above, the assumption that the relationship of phonological complexity to disfluency was similar for all 12 participants was tested with a Hosmer-Lemeshow test. It can be seen in Table 10 that this test was not-significant (p = .043), suggesting that the U-IPC score was related to disfluency in a similar manner for all of the children in this study. The results of the test that all slopes are zero also indicated that U-IPC is related to disfluency.

Table 10. Binary Logistic Regression for Disfluency Versus Index of Phonetic Complexity Score (U-IPC) with Participant 1 as Control.

Predictor	Hosmer-Lemeshow	Regression Coefficient (Slope)	All slopes equal zero
U-IPC score	15.982 (p = .043)	β = .07755 (p < .001)	G = 121.925 (p < .001)

The regression coefficient of U-IPC for the 12 children (β = .07755) was significant (p < .001). This means that for every one unit of increase in U-IPC, the logit increased by .07755. Therefore, as complexity increased from U-IPC = 0 to U-IPC = 51, the probability of that utterance being disfluent increased by a factor of 5 to 6 for the children in this study. For example, for Participant 4, the probability of an utterance being disfluent (π) at U-IPC = 0, was π = .1150. At U-IPC = 27, the probability of an utterance being disfluent was π = .5132.

On initial inspection, this (β) value appears to be much smaller than the value for U-LEC$_i$/CS$_i$. It is true that the (β) value is numerically larger for U-LEC$_i$/CS$_i$ (β = .25721) compared to U-IPC (β = .0775). Recall however, that the (β) value represents the increase in the logit for every *one unit* of change in the phonological complexity score. In this study U-LEC_i/CS_i had a much smaller range (minimum score = 0, maximum score = 9) than U-IPC score (minimum score = 0, maximum score = 51). Therefore, a one unit increase in U-LEC_i/CS_i was comparable to a 5-6 unit increase in U-IPC.

4.2.2. Relationship of Individual Participants to One Another

As noted earlier, between-participant differences were determined by sequentially comparing the individual effect of Participant 1 to the remaining 11 children. The coefficient term was positive and significant for 4 of the children as seen in Table 11. The 4 children for whom the effect was significantly different than Participant 1 are italicized in bold type. Given the same U-IPC as Participant 1, these 4 children had a significantly greater probability of being disfluent than Participant 1. The 7 children for whom the probability was non-significant were no more likely or unlikely to be disfluent given the same U-IPC as Participant 1. That is, for all 12 participants, as U-IPC increased, the probability of an utterance being disfluent increased. Participants 6, 9, 10, and 11, however, had a greater baseline effect than the remaining 8 children. These were the same 4 children that were identified as having a greater baseline effect based on U-LEC_i/CS_i.

Table 11. Logistic Regression Data for Index of Phonetic Complexity Score (U-IPC) Relative to Participant 1.

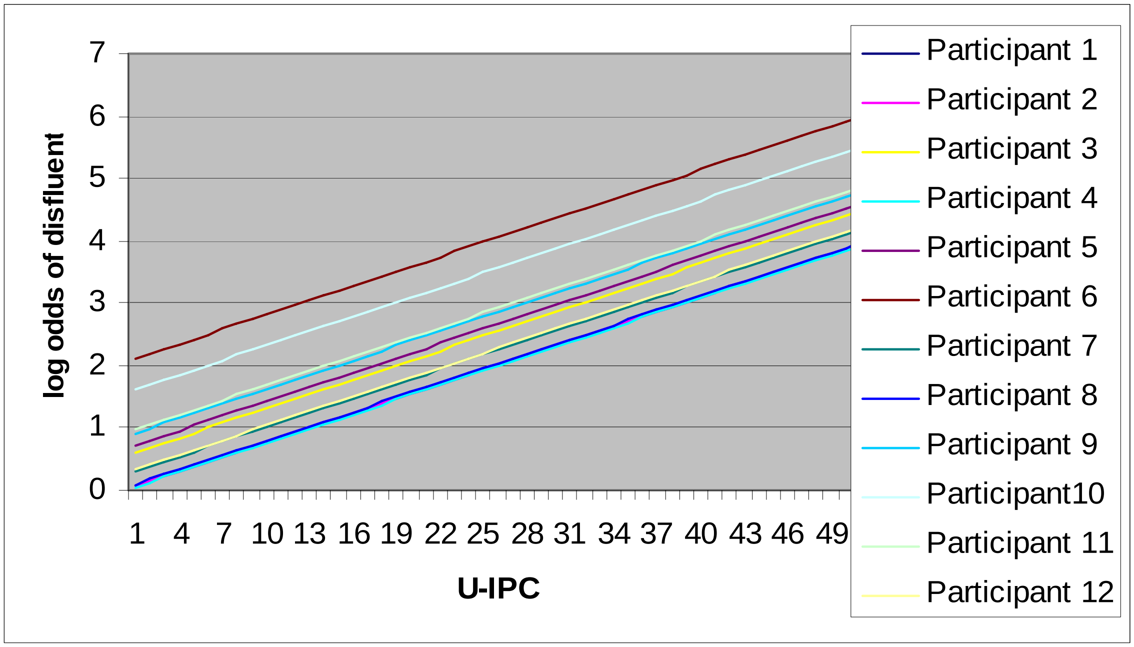
Participant	Regression Coefficient (β)	Standard Error Coefficient	Significance Level
2	-.2823	.4078	$p = .489$
3	.5324	.3604	$p = .140$
4	-.0245	.3817	$p = .949$
5	.6478	.3669	$p = .077$
6	***2.0364***	***0.3686***	***p < .001***
7	.2328	.3727	$p = .532$
8	.0164	.3758	$p = .965$
9	***.8411***	***.3613***	***p = .020***
10	***1.5437***	***.3589***	***p < .001***
11	***.9041***	***.3576***	***p = .011***
12	.2627	.3672	$p = .474$

Note: The scores for Participants 6, 9, 10, and 11 were significantly different than Participant 1.

4.2.3. Summary of U-IPC Logistic Regression Analysis

The results of the logistic regression analysis suggested that as U-IPC increased, the probability of an utterance being produced disfluently also increased. As was the case with U-LEC_i/CS_i, findings also suggested that it was reasonable to conclude that a significant common relationship existed for the 12 participants. Figure 2 shows an illustration of this relationship, where the common underlying slope is plotted out from the y-intercept of each participant. When the idealized data from the mathematical model are plotted on this XY graph, Participants 6 and 10 clearly are above the remaining 10 children. Participants 9 and 11, while plotted close to the other children, are still significantly different from Participant 1. All 12 children were plotted with the same slope that was derived from the average across all of the children, since the underlying relationship of phonological complexity to disfluency was similar for all participants. Figure 2 illustrates that for all 12 children, as phonological complexity increased, so did the probability of the utterance being produced disfluently. While the slope of the underlying common structure (β) was the same for all participants, Participants 6, 9, 10, and 11, had a greater probability to be disfluent at any given IPC score.

Figure 2. Log Odds of an Utterance Being Disfluent as Index of Phonetic Complexity Score (U-IPC) Increases Across Participants. Note that Participants 6, 9, 10, and 11 are Significantly Different from Participant 1.



4.3. Post-hoc Analysis to Test the Assumption of Independence for Logistic Regression

In the logistic regression analysis used in this study, each utterance was treated as if it was independent. The response (of fluent or disfluent utterance) however, is measured repeatedly for each child, and therefore might be correlated. If the responses are correlated, the estimation of the standard error of the regression coefficients obtained from the logistic regression would be underestimated. In order to assure that the assumption of independence was not violated, a Generalized Estimation Equation model (GEE) was fitted with exchangeable correlation structure (i.e., any two repeated responses are assumed to have the same correlation) (Liang & Zeger, 1986). Unlike the logistic regression, the GEE can account for the correlation inherent in the repeated measures. If the results of the GEE are similar to the logistic regression, the violation of independence did not affect the outcome of the logistic regression. The results of the GEE analysis are presented in Table 12. The regression coefficients for the logistic regression analyses and the GEE analyses were essentially the same for both U-IPC and U-LEC$_i$/CS$_i$. This suggests that the correlation between repeated responses were weak and therefore the logistic regression was an appropriate measure to use.

Table 12. Comparison of Regression Coefficient and Standard Error of the Regression Coefficients for the Generalized Estimation Equation (GEE) and the Logistic Regression (LR) for Word-initial Late-emerging Consonant and Consonant String Scores (U-LEC$_i$/CS$_i$) and Index of Phonetic Complexity Scores (U-IPC).

Predictor	GEE Regression Coefficient (β)	GEE Standard Error	LR Regression Coefficient (β)	LR Standard Error
U-LEC$_i$/CS$_i$	.2384	.0537	.25721	.0539
U-IPC	.0714	.0479	.07755	.01356

4.4. Post-hoc Analysis of Adult Target Versus Actual Production

Because this study examined the relationship between phonological complexity (i.e., planning) not phonetic complexity (i.e., production), the orthographic transcription of the adult *target* of each child's speech sample was used in the analyses of phonological complexity. Although none of the children in this study presented with a phonological disorder, some of the children did evidence normal developmental phonological processes (i.e., cluster reduction, gliding of liquids, etc.). In order to determine if the use of the adult target inflated the phonological complexity scores to a significant extent, two separate post-hoc analyses were performed to compare the phonological complexity scores derived from the phonetic transcription of the adult target to the phonological complexity scores derived from the children's actual production data. The appropriate data set to make this comparison was only available for 9 of the 12 children. Participants 1, 2, and 5 were not included in the post-hoc analyses utilizing actual production data. The speech samples for these 3 children were collected as part of an earlier study that did not code the children's actual productions. These 3 children were included for use in the present study because the original design did not require production data. The original videotapes were not available for review.

4.4.1. Intrajudge Measurement Reliability for Phonological Complexity Scores of the Children's Actual Production.

Intrajudge measurement reliability for analysis of the participants' 75 utterances was determined for: (a) U-IPC, and (b) U-LEC_i/CS_i. The intrajudge reliability measurements occurred no less than 2 months following the initial transcription and coding. Fifteen utterances (20%) were selected at random for each of the 9 participants (total = 135 utterances) and re-analyzed by the author. Because a high degree of inter-rater reliability was already established using the phonetic transcriptions of the adult targets, inter-rater reliability was not calculated for the post hoc analyses.

Because U-IPC, and U-LEC$_i$/CS$_i$ represent continuous measures, measurement reliability is presented in terms of mean differences. The analyses revealed very small mean differences for intrajudge reliability for both measures of phonological complexity. The mean difference for U-IPC was 0.02 (SD = .226). For the U-LEC$_i$/CS$_i$ scores, the mean difference was 0.04 (SD = .375). The same complexity score was calculated for 253 of the 270 utterances recalculated for the reliability measure. Of the 13 instances where the score was different, 11 of the scores differed by 1 unit, while the complexity scores of the remaining 2 utterances differed by only 2 units. These scores represent a very high degree of reliability. The mean U-IPC and U-LEC$_i$/CS$_i$ score for fluent and disfluent utterances, based upon each child's actual production can be seen in Appendix I and J.

4.4.2. Correlation Between Phonological Complexity Score for Transcriptions Utilizing the Adult Target and the Children's Actual Production Data.

Both U-IPC and U-LEC$_i$/CS$_i$ are ordinal in nature. That is, while an U-IPC or U-LEC$_i$/CS$_i$ score of 6 represents a greater level of complexity than a score of 3, the level of complexity is not necessarily twice as great. The relationship between the phonological complexity scores of the adult target and the phonological complexity scores of the children's actual production data were examined using a Spearman rho statistic. To account for the ordinal nature of the data, the Spearman rank correlation coefficient is calculated using the Pearson correlation formula on the ranks of the data rather than the actual data values. The correlation between the two transcription methods (i.e., adult target and actual production) for both of the phonological complexity measures was very strong, positive, and significant (r_s for U-IPC =

.984, p < .001; r_s for U-LEC$_i$/CS$_i$ = .953, p < .001). These results suggest a high degree of correlation between the two transcription methods for the 9 participants for which the production data was available.

As a further test of the relatedness of these two approaches, the output from the binary logistic regression for the two transcription methods was compared for the 9 participants. As can be seen in Table 13, the output from the analyses of the two different transcription methods is very similar. Of particular interest are the log likelihood (*LL*) values. The *likelihood* is the probability that the observed values of the dependent variable (i.e., fluent versus disfluent) can be predicted from the observed values of the independent variables (i.e., phonological complexity). The *LL* is the log of the likelihood, and ranges from 0 to minus infinity. The *LL* serves as the basis for tests of the logistic regression model. The *LL* for the two transcription methods is almost identical for both U-IPC and U- LEC$_i$/CS$_i$.

Table 13. Binary Logistic Regression for Disfluency Versus Phonological Complexity with Participant 1 as Control for the Adult Target and the Children's Actual Production.

	Log likelihood	Commom Slope (β)	Significance Level	Hosmer-Lemeshow
U-LEC$_i$/CS$_i$ adult target	-414.835	.2939	p <.001	0.979
U-LEC$_i$/CS$_i$ actual production	-414.460	.3135	p <.001	0.747
U-IPC adult target	-406.680	.0919	p <.001	0.700
U-IPC actual production	-406.860	.0931	p <.001	0.582

The results of the Spearman rho analyses and the binary logistic regression analyses using the data from the subset of 9 participants, suggests that the phonological complexity scores which were based on the children's adult targets was not significantly different from the complexity scores calculated using the children's production data. Additional post hoc testing will therefore utilize the phonological complexity scores from all 12 participants which were calculated using the adult target.

4.5. Post-hoc Analysis of the Effect of Length

The results of the initial two logistic regression analyses, suggested that for all 12 children, as phonological complexity increased, so too did the likelihood that an utterance would be produced disfluently. Four of the children were more likely than the control participant to produce an utterance disfluently at a given phonological complexity score. As noted earlier, the author of the current study had made an apriori decision to not control for utterance length. However, while examining the data more closely to better understand why these particular 4 children were more vulnerable to phonological complexity, it appeared that the phonological complexity of an utterance was closely related to the length of the utterance (for all 12 of the children). It seemed appropriate therefore, to investigate the relationship between phonological complexity (as represented by U-IPC and U-LEC_i/CS_i) and utterance length to determine if the results of the logistic regression were confounded by utterance length. Because both U-IPC and U-LEC_i/CS_i are calculated at the level of the word, utterance length was analyzed in terms of the number of words in an utterance.

4.5.1. Correlations Between Utterance Length and Phonological Complexity

Because both the U-IPC and U-LEC_i/CS_i are ordinal data, the non-parametric Spearman rho statistic was utilized to examine the relationship of length to phonological complexity. As noted earlier, the Spearman correlation coefficient accounts for the fact that the data is ordinal, by using the Pearson correlation formula for the ranks of the data rather than the actual data values. The correlations between both phonological complexity measures (i.e., U-IPC and U-

LEC_i/CS_i) and length were significant ($p < .001$). While the correlation between U-IPC score and utterance length was moderately strong ($r_s = .681$), the correlation between U-LEC_i/CS_i score and utterance length was only moderate ($r_s = .337$).

4.5.2. Analyses Controlling for Utterance Length

4.5.2.1. Logistic Regression Analyses for Length-adjusted Phonological Complexity

To control for the possible confounding effect of utterance length, logistic regression analysis was used to examine the relationship between length-adjusted phonological complexity and the occurrence of speech disfluencies. Both the U-IPC score and the U-LEC_i/CS_i score for each utterance was divided by the number of words in the utterance. This resulted in a length-adjusted IPC score (IPCadj) and LEC_i/CS_i score (LEC_i/CS_iadj) for each utterance. The mean U-IPCadj and U-LEC_i/CS_iadj score for fluent and disfluent utterances for each child can be seen in Appendix K and L.

As can be seen in Table 14 the regression coefficient was not significant for either of the length adjusted phonological complexity measures. These results suggested that when the phonological complexity scores were adjusted to account for the number of words in each utterance, phonological complexity was not significantly related to disfluency in these 12 children.

Table 14. Binary Logistic Regression for Disfluency Versus Length-adjusted Index of Phonetic Complexity (IPCadj) and Length-adjusted Late-emerging Consonants and Consonant Strings (LEC_i/CS_iadj) with Participant 1 as Control.

Predictor	Hosmer-Lemeshow	Regression Coefficient (β)	All slopes equal zero
IPCadj	2.257 (*p* = .972)	-.1574 (*p* = .113)	G = 88.870 (*p* < .001)
LEC_i/CS_iadj	2.640 (*p* = .955	.2685 (*p* = .358)	G = 87.177 (*p* < .001)

4.5.2.2. Logistic Regression Analysis for Utterance Length in Words

The results of the initial binary logistic regression analyses for U-IPC and U-LEC_i/CS_i suggested that phonological complexity was related to disfluency in a predictable manner for all of the children in this study. The results of the post-hoc analyses discussed above, suggest however, that the results of the initial logistic regression were confounded by the effect of the length of the utterance in words. In order to examine the relationship between utterance length in words and speech disfluency, logistic regression was carried out with utterance length as the explanatory variable.

As was the case in the earlier logistic regression analyses, the Hosmer-Lemeshow test was used to test the assumption that the common underlying relationship of the variable of interest (i.e., utterance length in words) was similar for all 12 participants. A non-significant p-value suggests that the assumption of no difference is plausible. It can be seen in Table 15 that the Hosmer-Lemeshow statistic was not significant (p = .311), suggesting that utterance length was related to disfluency in a similar manner for all of the children in this study. If utterance length was not related to the probability of an utterance being disfluent, the slope of the regression line, while similar, would have been equal to zero for all participants. It can be seen in Table 15 that the test that all slopes are zero was significant ($p < .001$).

Table 15. Binary Logistic Regression for Disfluency Versus Utterance Length in Words with Participant 1 as Control.

Predictor	Hosmer-Lemeshow	Regression Coeficient (β)	All slopes equal zero
Utterance Length in Words	9.380 ($p = .311$)	.2793 ($p < .001$)	G = 158.865 ($p < .001$)

It also can be seen that the regression coefficient of utterance length in words for the 12 children was (β) = .2793 and was statistically significant ($p < .001$), suggesting that a model using utterance length as a covariate was indeed appropriate. For every one unit of increase in utterance length, the logit (logarithm of the ratio of the probabilities of the utterance being disfluent over fluent) increased by 0.2793. Therefore, as the utterance length increased, the probability of that utterance being disfluent also increased for the 12 children in this study.

As might have been expected based on the results of the initial logistic regression analyses using U-IPC and U-LEC$_i$/CS$_i$ as covariates, individual differences did exist. Four of the children (Participants 6, 9, 10, and 11) had a significantly greater probability of being disfluent at a given utterance length than did Participant 1 (See Table 16 below, in which the 4 children whom the effect was significantly different than Participant 1 are italicized and in bold type). These are the same 4 children highlighted in the earlier results.

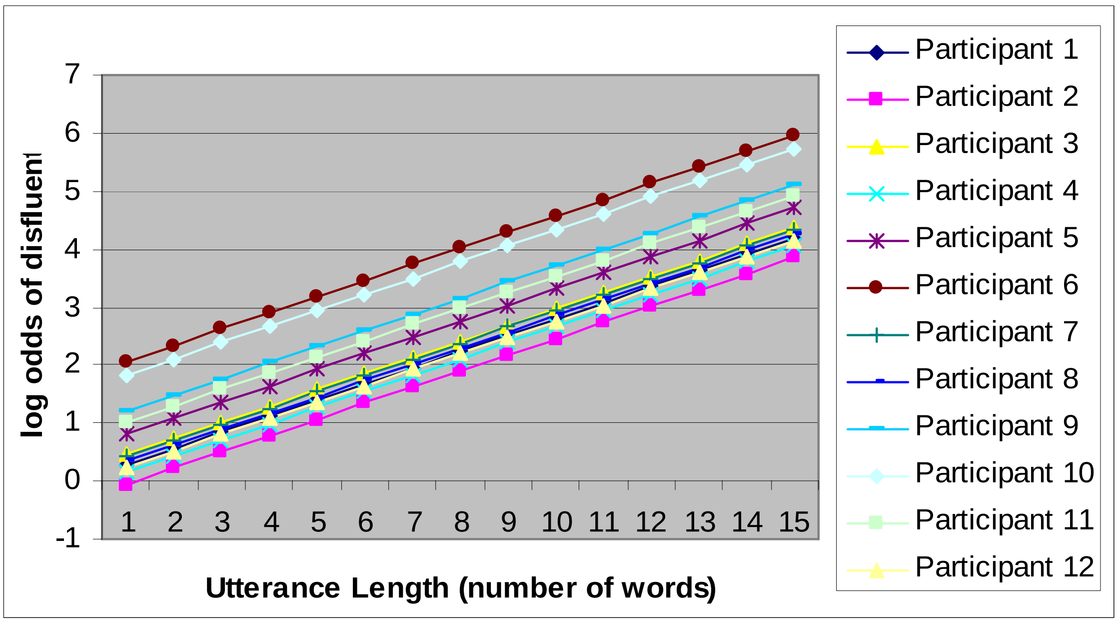
Table 16. Logistic Regression for Utterance Length in Words Relative to Participant 1.

Participant	Regression Coefficient (β)	Standard Error Coefficient	Significance Level
2	-.3357	.4091	$p = .412$
3	.1748	.3717	$p = .638$
4	-.1315	.3863	$p = .734$
5	.5241	.3666	$p = .153$
6	***1.7815***	***.3719***	***p < .001***
7	.1396	.3776	$p = .712$
8	.0563	.3788	$p = .882$
9	***.9169***	***.3634***	***p =.012***
10	***1.5445***	***.3632***	***p < .001***
11	***.7367***	***.3606***	***p =.041***
12	-.0356	.3803	$p = .925$

Note: The scores for Participants 6, 9, 10, and 11 were significantly different than Participant 1.

In summary, results of the logistic regression analysis suggested that the probability of an utterance being disfluent was related to the number of words in the utterance in a predictable fashion. Results also suggested that it was reasonable to conclude that a significant common relationship existed for the 12 children in this study. If the idealized data from the mathematical model are plotted on an XY graph, Participants 6, 9, 10, and 11 show a greater y-intercept than the remaining 8 children (who would cluster around Participant 1). All 12 children are plotted with the same slope that was derived from the average across all of the children. Figure 3 shows an illustration of this relationship, in which the common underlying slope is plotted out from the y-intercept of each participant. This figure demonstrates that for all 12 children, as utterance length increased, so did the probability of the utterance being produced disfluently. While the slope of the underlying common structure (β) was the same for all of the children, Participants 6, 9, 10, and 11, had a significantly greater probability to be disfluent at a given utterance length.

Figure 3. Log Odds of an Utterance Being Disfluent as Utterance Length in Words Increases Across Participants. Note that Participants 6, 9, 10, and 11 are Significantly Different from Participant 1.



To compare the *actual* slope of each child to the average slope calculated from the logistic regression model, the actual proportion of disfluent utterances was calculated for each child, for utterances of 3 – 6 words in length. There were an insufficient number of utterances at the remaining utterance lengths to provide meaningful data. This proportion was then plotted against the predicted probability as determined by the logistic regression common underlying slope. These plots can be seen in Appendix M. It should be noted that an R^2 value is not provided because in binary logistic regression analyses there is no widely accepted analog to a linear regression R^2 value (Agresti, 1996).

4.5.2.3. Logistic Regression Analyses for Utterance Length with Phonological Complexity as an Additional Covariate

In order to examine whether the addition of phonological complexity would improve the fit of the logistic regression model for length in words, both IPCadj and LEC_i/CS_iadj were added to the binary logistic regression as a covariates with utterance length. As was done previously, in order to maintain an overall significance level of $\alpha = .05$ the significance levels for the individual analyses were Bonferroni-corrected (individual α for each of the two comparisons = .025).

The results of the logistic regression analyses are presented in Table 17. It can be seen that neither IPCadj nor LEC_i/CS_iadj added significantly to the model (i.e., the *probability* of the regression coefficient for phonological complexity was not significant). That is, the addition of phonological complexity scores did not increase the model's fit compared to the number of words alone.

Table 17. Binary Logistic Regression for Disfluency Versus Utterance Length in Words + Length-adjusted Phonological Complexity with Participant 1 as Control.

Predictor	Hosmer-Lemeshow	All slopes equal zero	Regression Coefficient Utterance Length	Regression Coefficient Phonological Complexity
Utterance Length + IPCadj	11.378 ($p = .181$)	G = 158.930 ($p < .001$)	.2779 ($p < .001$)	-.0268 ($p = .798$)
Utterance Length + LEC_i/CS_iadj	9.582 ($p = .296$)	G = 162.100 ($p < .001$)	.2864 ($p < .001$)	.5574 ($p = .071$)

As a further test of the effect of phonological complexity, likelihood ratios were calculated for both covariates. The Likelihood Ratio Test (*LRT*) is a statistical test of the goodness-of-fit between two models (Agresti, 1996). The *LRT* is used to compare the log-likelihood of a more complex model to a simpler model. In this case, the *LRT* is used to compare the fit of the logistic regression model with utterance length as a single variable to the model with phonological complexity added. The *LRT* statistic equals

2 (log likelihood of the simpler model – log likelihood of the full model),

where the statistic follows a chi-square distribution. Because one additional parameter was added (in each separate analysis), the degrees of freedom is equal to one, and the critical value for the chi-square is 3.84. The more complex model is considered to be a significant improvement over the simpler model if the *LRT* is greater than the critical chi-square value. The results of the *LRT* (as seen in Table 18), suggest that the addition of phonological complexity to the model, does not result in a significantly better fit.

Table 18. Likelihood Ratio Test Results for the Addition of Phonological Complexity as a Covariate.

	Log-Likelihood	LRT	Chi-square (df = 1)
Utterance Length	-517.733		
Utterance Length + IPCadj	-517.701	.064	3.84
Utterance Length + LEC_i/CS_iadj	-516.116	3.234	3.84

Note: Utterance Length refers to the number of words in an utterance.

4.5.2.4. Fluent and Disfluent Utterances Matched for Length in Number of Words

The original rationale for not controlling for length in the logistic regression analyses was based on the assumption that length and phonological complexity were intricately connected. If this is the case, it is possible that by adjusting the phonological complexity scores by dividing the complexity scores by the number of words in an utterance, some important factor(s) related to phonological complexity might be lost. In an attempt to control for utterance length in a manner that would avoid this potential problem, an additional post-hoc analysis was carried out at the level of the utterance.

Logan and Conture (1997) reasoned that because randomly selected stuttered utterances tend to be longer than perceptibly fluent utterances, the probability of an utterance containing more of the various syllable constituents they were interested in, would be greater in disfluent utterances than in fluent utterances. Using similar reasoning, one might expect that randomly selected disfluent utterances would have a greater probability of having a higher phonological complexity score than fluent utterances that would likely be shorter. In a manner similar to that utilized by Logan and Conture, fluent and disfluent utterances were matched for length for each child, and then combined across participants. Separate paired-sample t-tests were then carried out on utterances ranging from three to eight words in length, and for all length-matched utterances combined. The number of length-matched fluent and disfluent utterances were not sufficiently large in the remaining utterance lengths, so those lengths were not included in this analysis. In order to maintain an overall significance level of $\alpha = .05$ the significance levels for the individual analyses were Bonferroni-corrected (individual α for each of the 14 comparisons = .0036). As can be seen in Table 19, only one of the tests even reached the uncorrected alpha level of α = .05, and that was in the opposite direction of what was hypothesized (i.e., the IPC of fluent utterances were greater than disfluent utterances).

Table 19. Paired-sample t-tests for Disfluent Versus Fluent Utterances Matched for Length.

Number of Words	Number of Matched Utterances	IPC Mean difference (Dis – Flu)	IPC Level of Significance	LEC_i/CS_i Mean difference (Dis – Flu)	LEC_i/CS_i Level of Significance
3	$n = 33$	-1.48	$p = .026$	.00	$p = 1.00$
4	$n = 41$	.12	$p = .843$	.10	$p = .688$
5	$n = 50$	.98	$p = .192$	.26	$p = .310$
6	$n = 47$	.30	$p = .608$	-.04	$p = .864$
7	$n = 26$	-.73	$p = .463$	.58	$p = .118$
8	$n = 19$	1.47	$p = .419$	-.37	$p = .392$
3-8 combined	$N = 216$	.13	$p = .693$	.11	$p = .349$

Note: Dis = Disfluent, Flu = Fluent

It can also be seen in Table 19, that the number of length-matched fluent and disfluent utterances was quite small at each of the utterance lengths examined, ranging from 19 to 50 utterances. With such a small sample size, one must question whether or not a difference would be uncovered, even if it existed (i.e., was there sufficient power to test the null hypothesis). In order to determine the power of the individual t-tests, an effect size must be established. Because prior research of a similar nature did not provide an estimate of effect size, it is necessary to utilize a conventional operational definition. Cohen (1988) suggests that if a phenomenon under study is not under good experimental or measurement control, the effect size is likely to be small. The literature reviewed for this study demonstrated that a number of factors are hypothesized to be related to the occurrence of a speech disfluency. While the metrics utilized to measure phonological complexity in this study, have been used in the past, normative data have not been established for their use. These facts, coupled with the fact that spontaneous speech samples (with their inherent variability) were used in this study, warrant the assumption of a small effect size.

If the effect size of phonological complexity is assumed to be small (i.e., d = .2), the power would range from 0.17 to 0.26 for the different utterance lengths (Cohen, 1988). Because the power to reject the null hypothesis was so low at each of the utterances lengths examined, the negative results have little meaning. Given a small effect size, the power of the combined utterances was equal to 0.65, suggesting that if a difference existed between the phonological complexity of the fluent and the disfluent utterances, the chance of uncovering that difference was approximately two out of three (Cohen). While the probability of rejecting the null hypothesis was greater than chance, it was still less than the generally accepted level of 0.80. The meaningfulness of these negative results therefore are suspect.

4.5.3. Phonological Complexity of Fluent Versus Disfluent Words

In an effort to more directly compare the results of this study to that of recent studies of phonological complexity (Howell & Au-Yeung, 1995; Howell et al., 2000; Throneburg et al., 1994), the phonological complexity of fluent and disfluent words were compared. Only fluent words from perceptibly fluent utterances were utilized in these analyses. The data from 3 of the 12 children was not used in this analysis secondary to the fact that the complete word by word data was not available for 3 of the children. As noted earlier, the videotapes for these 3 participants were not available for review. Two-sample t-tests for unequal variances were utilized because the number of the fluent words was greater than 10 times the number of disfluent words for some of the children. If the larger sample size is associated with a smaller variance (which was the case in some of the comparisons), the t-test for unequal variances should be utilized because the true alpha might exceed the apparent alpha, thus increasing the chance of a Type I error (Glass & Hopkins, 1984). In order to maintain an overall significance level of $\alpha = .05$ the significance levels for the individual analyses were Bonferroni-corrected (individual α for each of the 20 comparisons = .0025). As can be seen in Table 20, only two of the tests even reached the uncorrected alpha level of $\alpha = .05$, and these were both in the opposite direction of what was hypothesized (i.e., the IPC of fluent words were greater than disfluent words in two cases). Neither the IPC score nor the LEC_i/CS_i score of the fluent words was significantly different than the IPC score or LEC_i/CS_i score of the disfluent words.

Table 20. Phonological Complexity Scores of Disfluent Versus Fluent Words for 9 Participants.

Participant Number	Mean IPC Fluent	Mean IPC Disfluent	p value	Mean LEC_i/CS_i Fluent	Mean LEC_i/CSi Disfluent	P value
P3	1.95	1.79		.24	.24	
	$n = 241$	$n = 33$	$p = .6160$	$n = 241$	$n = 33$	$p = .8846$
P4	2.13	1.90		.22	.43	
	$n = 232$	$n = 21$	$p = .5251$	$n = 232$	$n = 21$	$p = .1345$
P6	2.02	1.36		.32	.21	
	$n = 81$	$n = 66$	$p = .0402$	$n = 81$	$n = 66$	$p = .2000$
P7	2.11	1.40		.31	.25	
	$n = 258$	$n = 21$	$p = .0536$	$n = 258$	$n = 21$	$p = .6244$
P8	2.29	2.24		.31	.29	
	$n = 251$	$n = 21$	$p = .8552$	$n = 251$	$n = 21$	$p = .8173$
P9	2.61	2.59		.35	.35	
	$n = 169$	$n = 49$	$p = .9487$	$n = 169$	$n = 49$	$p = .9825$
P10	2.16	2.07		.30	.33	
	$n = 132$	$n = 43$	$p = .7648$	$n = 132$	$n = 43$	$p = .8381$
P11	1.89	1.59		.21	.35	
	$n = 184$	$n = 37$	$p = .3211$	$n = 184$	$n = 37$	$p = .2148$
P12	2.10	2.11		.25	.26	
	$n = 295$	$n = 27$	$p = .9753$	$n = 295$	$n = 27$	$p = .9665$
All	2.04	1.63		0.23	0.29	
participants	$N = 1843$	$N = 318$	$p = .0164$	$N = 1843$	$N = 318$	$p = .5847$

Note: Only fluent words from perceptually fluent utterances were utilized in these analyses.

Assuming a small effect size (i.e., d = .2), the power of the statistical test for the individual children ranged from 0.14 to 0.23 (Cohen, 1988). This level of power is insufficient to uncover a difference in the phonological complexity scores between fluent and disfluent utterances even if a difference exists. When the scores from all of the children are combined however, the power of the t-test is sufficient to uncover a difference (power = 0.91). The result of this analysis suggests that the data do not support the conclusion that the phonological complexity score of disfluent words is greater than that of fluent words.

5. Chapter 5: Discussion

A number of current theories of stuttering propose that the occurrence of speech disfluencies may be related, at least in part, to the process of planning or formulating language (Howell & Au-Yeung, 2002; Karniol, 1995; Perkins et al., 1991; Postma & Kolk, 1993; Wingate, 1988). These authors hypothesized that disfluencies are the result of an interruption in the process of phonological or phonetic encoding as defined in Levelt, Roelofs, and Meyer's (1999) model of speech planning and production, and as simulated in Roelofs' WEAVER++ computer simulation of word-form encoding (Roelofs, 1997). Four of these research groups propose that the error occurs in the process of phonological encoding (Karniol, 1995; Perkins et al., 1991; Postma & Kolk, 1993; Wingate, 1988). In the process of phonological encoding, the segmental information relating to a word's phonemic structure is associated with the metrical information which specifies the number of syllables in the word and the accent structure of that word. In their EXPLAN theory of fluency control, Howell and Au-Yeung (2002) argue that the generation of a phonological plan is independent of articulation but takes place in parallel. That is, one word is being executed while the next word in the utterance is being planned. They hypothesize that if a complete plan is not available in a timely manner, execution is stalled. Howell and Au-Yeung do not specify whether the delay in planning occurs at the level of phonological or phonetic encoding. Like the other four theories though, EXPLAN hypothesizes that speech disfluencies are the result of a delay or error in the phonological planning process.

The purpose of this study was to examine the influence of phonological complexity on instances of disfluency in the speech of young children near the onset of stuttering. Because phonological and phonetic encoding play a central role in a number of theories of stuttering, as well as in the production of fluent speech, it was hypothesized that an utterance with higher phonological complexity would be more likely to contain a disfluency than an utterance with lower phonological complexity. Two different metrics were utilized to assess phonological complexity: (a) the presence of word-initial late-emerging consonants and consonant strings (LEC_i and CS_i), and (b) the Index of Phonetic Complexity (IPC). LEC_is and CS_is were utilized based on the recommendation of Howell and colleagues to distinguish among the positions in words of phonologically difficult sounds (Howell et al., 2000). This argument is supported by the results of a recent study by Natke et al. (2004), in which they demonstrated that the vast majority of stuttering occurs on the initial syllable of an utterance. The IPC was chosen as a second metric for phonological complexity because it is a whole-word measure, and would therefore be more consistent with current models of speech planning and production that suggest that the minimal unit for planning is the phonological word (Levelt et al., 1999; Levelt & Wheeldon, 1994; Roelofs, 1997, 2002).

Previously published studies utilizing these two metrics did not have a sufficient number of young children near the age of stuttering onset and/or did not analyze enough utterances from each child to obtain sufficient statistical power (Howell et al., 2000; Weiss & Jakielski, 2001). The present study analyzed a total of 900 utterances from 12 preschool-aged children who stuttered. A pilot study (Eldridge, 2004) had demonstrated that this sample size would have sufficient statistical power to answer the research question. In addition to providing a larger sample than previous studies, the use of two metrics for phonological complexity allowed for an examination of Howell et al.'s assertion regarding the importance of distinguishing among the word position of phonologically difficult sounds. The LEC_i/CS_i measure was applied to only the word-initial sound(s), while the IPC was applied to the whole word. By examining both stuttered and normal disfluencies in these 12 children, the results of this study can be more readily interpreted in light of current models of speech planning and production that make no distinction between disfluency type.

5.1. Summary of Findings

In the present study, spontaneous speech samples from 12 preschool-age children who stuttered were examined in an effort to better understand the relationship between phonological complexity and the occurrence of speech disfluency. The speech samples utilized in this current study had been previously collected for use in earlier investigations (Yaruss, 1994, 1997, 1999). Following an audio-video recording of a parent-child interaction, the adult target of each child's speech sample was orthographically transcribed into a customized computer database. Each of the participants' utterances was then examined to identify the presence of all speech disfluencies. For the current study, the orthographic transcriptions from these previous studies were then phonetically transcribed using broad symbols from the IPA. The phonetic transcriptions of 75 utterances from each child (900 total utterances) were initially analyzed utilizing two metrics for phonological complexity; U-LEC_i/CS_i and U-IPC. Logistic regression was utilized to examine the relationship between phonological complexity and disfluency for each individual child and to identify any common relationship between phonological complexity and disfluency for the group as a whole. Separate logistic regression analyses were calculated for each of the two complexity measures to determine if one of the measures was better able to explain the relationship of phonological complexity and speech disfluency.

The results of the initial binary logistic regression analyses for both U-LEC_i/CS_i and U-IPC, suggested that a similar relationship existed for all 12 children; as phonological complexity increased, so did the probability of the utterance being produced disfluently. The results of these analyses also suggested that 4 of the 12 children had a greater probability of being disfluent at any given phonological complexity score than the control participant.

While examining the data to better understand any potential factors that might have been common to the 4 children identified as being more vulnerable to phonological complexity, it appeared that phonological complexity had been confounded with utterance length. A series of post-hoc analyses confirmed that length was the primary factor entering the logistic regression model. Phonological complexity, as represented by the IPC and LEC_i/CS_i measures did not improve the logistic regression model to a significant degree. In addition, the phonological complexity of (a) length matched fluent and disfluent utterances, and (b) fluent and disfluent words, were not significantly different. These results do not support the contention that increased phonological complexity is related to an increased likelihood that an utterance will be produced disfluently.

5.2. Transcription of Child Target Versus Actual Production

Before beginning the interpretation of the results, a procedural issue will be discussed. The present investigation was designed to test the hypothesis that an increase in the phonological complexity of an utterance would lead to an increased likelihood that the time dependent process of phonological encoding would be interrupted and subsequently result in a speech disfluency.

This study was designed to investigate the relationship between increased complexity and planning errors, not production errors. All 12 of the participants in this study presented with speech and language skills within normal limits for their chronological age. The 12 children also demonstrated age-appropriate articulation skills and were not diagnosed with a phonological disorder. In an attempt to derive the phonological complexity based on the children's planning, and not their production, the complexity scores were calculated based on the adult target of the word the child produced, not the child's actual productions. Note that if the child produced a morphologically or syntactically immature word (i.e., *gonna* or *taked*), the immature form was considered to be the target.

In the vast majority of cases (3664 out of 3901 words), the adult target matched the child's actual phonetic production. On occasion however, the children presented with phonological processes associated with normal phonological development (e.g., gliding of liquids, cluster reduction, etc.). In the case of a phonological process, it is generally assumed that children do not have full knowledge of the adult sound system and are therefore unable to match their phonetic output to the internal phonological representation of the target word (Edwards & Shriberg, 1983; Gierut & Morrisette, 2005). The adult form is modified by a rule governed process in which the child omits a sound or produces a sound that they have knowledge of as a substitute for the sound that is not in their repertoire (Gierut, Elbert, & Dinnsen, 1987;). For example, if a child exchanges /w/ for /r/, it is generally assumed that the internal representation of the adult target is modified during phonological encoding to generate an articulatory plan for the simplified form of the target word (Edwards & Shriberg, 1983). In the case of phonological processes then, it is assumed that the child is not planning the more complex adult target. If the phonological complexity score was calculated for the adult target instead of the actual production (e.g., a child produces /wæbɪt/ for /ræbɪt/), the complexity score would be artificially inflated.

In order to determine the extent to which the phonological complexity scores accurately portrayed the children's phonological planning, phonetic transcriptions of the adult target were compared to phonetic transcriptions of the children's actual productions. As noted earlier, phonetic transcriptions of the actual production were only available for 9 of the 12 children. As presented in the results section, the correlation between the two transcription methods (for these 9 participants) was very strong, positive, and significant for both U-LEC$_i$/CS$_i$ and U-IPC. The result of binary logistic regression analyses comparing the transcription methods suggested that the resultant phonological complexity scores from both transcription methods were statistically equivalent. The results of these post-hoc analyses suggested that the phonological complexity scores calculated from the phonetic transcriptions of the adult target, were a sufficiently accurate representation of the phonological complexity of the utterances that the children were planning. The U-LEC$_i$/CS$_i$ and U-IPC values derived using the adult target for all 12 participants were therefore utilized in all other analyses.

While the complexity scores calculated appeared to be an accurate representation of the phonological complexity of the utterances the child was planning, the fact that 6% of the children's actual productions were not consistent with the adult target, suggests on one hand, that the actual production should be considered when calculating phonological complexity in future studies. On the other hand, it has been suggested that a child's ability to produce a sound may play a role in whether or not that child attempts a production (Gelfer & Eisenberg, 1995). In this case, a sound may be in a child's speech sound repertoire (and syllables containing that sound may even be stored in the child's mental syllabary), but the child may choose to substitute a sound that can be more easily produced. In this situation, there is a degree of uncertainty regarding what the child is actually planning in the processes of phonological and phonetic encoding. Gelfer and Eisenberg suggest that the observation of a child's speech sound patterns are merely a description of the child's production. Whether that pattern reflects phonological constraints or production constraints is dependent on the child. It might be prudent then, to utilize criterion-type measures developed for each individual based on a more complete understanding of their speech sound repertoire and production abilities.

5.3. Position of Phonologically Difficult Sounds

Howell and colleagues have argued that the null findings associated with two previous studies of the relationship between phonological complexity and stuttering (Howell & Au-Yeung, 1995; Throneburg et al., 1994) might have been related to the fact that these two studies did not distinguish between the word position of phonologically difficult sounds (Howell et al., 2000). These authors argued that because speech disfluencies typically occur on the first sound of a word, it is important to distinguish the position of phonologically difficult sounds. They reported that speakers in all age groups in their study produced significantly more disfluencies on words that began with a CS. The children in the youngest age group in their study (aged 3 – 11 years old) also were significantly more disfluent on words that began with an LEC. Because neither the IPC nor LEC_i/CS_i were significantly related to the likelihood that an utterance would contain a disfluency in the current study, the results of this study can not directly refute or support Howell et al.'s assertion regarding the importance of distinguishing the position of the phonologically complex sound(s).

One significant methodological difference in the current study and the Howell et al. (2000) investigation is that Howell and colleagues focused their complexity score at the level of the word, rather than the utterance. While the purpose of this study was to look at a larger unit of phonological planning, in an effort to more directly compare the results of this study to those of Howell et al., the phonological complexity of fluent and disfluent words were compared. At the level of the word, like at the level of the utterance, the phonological complexity scores of the fluent and disfluent words were not significantly different for the 12 participants in the current study. Although the analyses at the level of the individual child lacked sufficient power to uncover a difference between the means (even if one existed) the analysis of the group data did have sufficient statistical power (power = .91) to support the negative findings.

In an attempt to explain the conflicting results of the present study, this author critically examined the statistics of the Howell et al. (2000) study. Howell et al. utilized the Friedman statistic to determine if the mean stuttering ratio of content words with an LEC_i or CS_i was statistically different from the mean stuttering ratio of content words without an LEC_i or CS_i. The Friedman statistic is frequently referred to as an analysis of variance for ranked data (Winer et al., 1991). Howell et al. did not adjust the individual α level to control for any of the multiple comparisons in their study. This particular analysis was carried out on three age groups. If the authors had maintained an overall significance level of $\alpha = 0.05$ for the three age groups of this one analysis, the significance levels for the individual α for each of the 3 comparisons would have been $\alpha = .01667$. The critical value of the chi-square statistic for $\alpha = .01667$ level with 2 degrees of freedom (as reported in their paper) is 8.1886. Howell et al. reported a chi-square value of 6.32 for the LEC_i analysis and 8.00 for the CS_i analysis. If the alpha levels had been corrected to account for these multiple comparisons, no significant difference would have been found between the phonological complexity of the fluent and stuttered words in this youngest age group. Howell et al.'s conclusions that, (a) phonological complexity is related to stuttering in young children, and (b) it is important to distinguish the position of the phonologically difficult sound(s), both appear to have been reached on faulty grounds. If this reexamination of the statistics is correct, the results of Howell et al.'s study do not support the conclusion that an increase in phonological complexity is related to an increased likelihood that a word will be produced disfluently. These results are consistent rather, with those of the current study and other recent studies that have utilized LECs and CSs as a metric for phonological complexity (Howell and Au-Yueng, 1995; Throneburg et al., 1994).

One explanation for the consistent negative findings is that increased phonological complexity is simply not related to the occurrence of speech disfluencies. Ratner (2005) has argued that because phonological planning represents one of the final stages of the speech production process, it is inevitably the result of higher order processes, and therefore is unlikely to have an independent effect on speech fluency. This position is counter to that taken by the proponents of stuttering theories that propose stuttering is the result of a dysfunction at that level of speech planning (Howell & Au-Yeung, 2002; Karniol, 1995; Perkins et al., 1991; Postma & Kolk, 1993; Wingate, 1988). Furthermore it has been argued that the distributional patterns of speech disfluency are similar to those of normal sound errors (i.e., slips of the tongue), which Levelt (1989) suggests occur during the process of phonological encoding (Wijnen, 1992, 1994). It follows therefore that speech disfluency might indeed be related to phonological complexity. The results of this study however, do not support that hypothesis.

Logan and Conture (1995) suggested that length is a macrovariable that encompasses other variables of speech production such as grammatical and/or phonological complexity. The relationship between increased length and speech disfluency might be due in part to the increased phonological complexity associated with increased length. When the utterance scores were adjusted for length, some aspect of phonological complexity which was not quantified in the U-IPC or U-LEC$_i$/CS$_i$ score, might have been lost. This explanation is not entirely satisfactory however, because no difference was found between the phonological complexity of the fluent and disfluent utterances which were matched for length. Because of the limited number of utterances at each length however, the data from the individual participants were combined. Yaruss (1999) pointed out that findings based only on group data need to be supplemented with individual data. The data from this study suggested that a subgroup of children might respond differently to phonological complexity. It is possible that the individual differences might have been masked by the other individuals in the group analyses.

It is also possible that the U-IPC and U-LEC$_i$/CS$_i$ scores were not able to accurately assess the phonological complexity associated with the planning stages of the speech production process. The speech production and planning literature, in particular literature regarding WEAVER++, suggests a couple of points that should be considered when determining a metric for phonological complexity (Cholin et al., 2004; Dell, 1986, 1988; Levelt et al., 1999; Roelofs, 1997) First, if as Levelt and colleagues suggest, the domain of phonological encoding is the phonological word, a whole-word measure of phonological complexity (e.g., the IPC) should be calculated at the level of the phonological word, not at the level of the lexical word (Cholin et al., 2004; Levelt et al., 1999). For example, as Levelt and Wheeldon (1994) point out, the utterance *professors demand it*, has three lexical words but only two phonological words. The unstressed function word *it* cliticizes to the head word *demand*, to form the phonological word *demandit*. From a planning perspective, it appears that the complexity score should be calculated on the one word *demandit*, rather than on the two words *demand* and *it*. Secondly, the model of lexical access proposed by Levelt et al. (2000) proposes that gestural scores are stored or computed at the level of the syllable. Currently the scoring procedure of the IPC considers any consonants that are produced consecutively to form a cluster, even if they cross syllable boundaries. It can be argued that this may be logical from a production perspective, where the transition from one consonant to another must be realized regardless of the syllable juncture. If the IPC is being utilized as a measure of phonological (as opposed to phonetic) complexity however, it would seem appropriate to change this scoring protocol to account for our understanding of the planning process. From this perspective, consecutive consonants crossing syllable boundaries would not be considered to form a cluster.

The existence of a repository for frequently used gestural scores is central to the model of word-form encoding proposed by Levelt et al. (1999). It is hypothesized that this repository, called the mental syllabary, contains the complete gestural scores for each speaker's most frequently used syllables. It is further hypothesized that the gestural scores for syllables stored in the syllabary can be retrieved immediately, while those not stored would need to be computed (Cholin et al., 2004). The economic advantage of such a system becomes apparent when one considers that less than 5% of the syllable inventory from English, Dutch, and German languages are used in approximately 80% of the speech in those languages (Cholin, Levelt, & Schiller, 2006; Schiller, Meyer, Baayen, & Levelt, 1996). The existence of a mental syllabary has been supported by a number of recent studies (Cholin et al., 2006; Cholin et al., 2004; Levelt & Wheeldon, 1994).

While Levelt and Wheeldon (1994) found a word latency effect for low frequency syllables (which are not found in the repository), they hypothesize that the complexity of the gestural score should not effect retrieval of syllables already stored in the mental syllabary. The phonological complexity of a syllable already in the mental syllabary then, should not result in a planning delay at the level of phonetic encoding. It seems reasonable to conclude that syllables composed of recently emerged consonants might not yet be stored in the syllabary. It would be important then, to know which sounds an individual has acquired. Instead of using Shriberg's (1993) Late-8 consonants, it might have been more profitable to develop a list of LECs for each individual child by gaining a better understanding of their speech sound repertoire prior to testing.

5.4. Participant Differences

The logistic regression for utterance length revealed that 4 children (Participants 6, 9, 10, and 11) exhibited a greater baseline effect than the other 8 participants in this study. For a given utterance length in words, the probability of these 4 children producing a disfluency was greater than for the remaining participants. It is possible that these 4 children are more vulnerable to utterance length than the remaining 8 children. The idea of subgroups of children who stutter is not novel. McLaughlin and Cullinan (1989) hypothesized that some children who stutter might be more susceptible to changes in utterance length, while other children might be more susceptible to changes in syntactic complexity. It has been suggested that it may be possible to subdivide people who stutter on a number of dimensions (e.g., family history, auditory processing, persistent versus recovered stuttering, language abilities, etc.) (Foundas, Corey, Hurley, & Heilman, 2004; Poulos & Webster, 1991; Yairi, Ambrose & Cox, 1996) Central to Smith and Kelly's (1997) dynamic multifactorial model of stuttering is the premise that different individuals take different paths into and out of stuttering. These authors suggest that stuttering emerges from the complex interaction of many different factors, which vary by individual.

It is also possible however, that factors other than length are responsible for the increased likelihood of the utterances being disfluent in these 4 participants. Examination of the raw data suggests a number of factors that might be responsible for the segregation of these 4 children. While the severity levels (based on SSI overall score) of Participants 6, 9, 10, and 11 do not appear to be different than the severity of the remaining 8 participants, these 4 children produced the four largest number of disfluent utterances in this study. In fact, the speech sample of 3 of the 4 children contained more disfluent utterances than fluent utterances. This was not the case for any of the remaining 8 participants. The experimental effect may simply be a mathematical confound due to the increased number of disfluent utterances in the speech samples of these 4 children.

Participants 9, 10, and 11 were also among the 4 oldest children in this study. It is possible therefore that a factor related to the children's age is responsible for inclusion in this subgroup. Rispoli and Hadley (2001) suggest that early in a child's speech and language development, the length of fluent and disfluent utterances are similar, since they both are equally difficult to produce. However, as children get older and their speech and language skills develop, the gap between the length of fluent and disfluent utterances increases. These authors suggest that a disfluency will be more likely to occur when the child is producing utterances at the "leading-edge" of sentence length or grammatical complexity (Rispoli & Hadley, p. 1140). They argue that the incidence of disruption (or disfluency) is increasingly influenced by length and grammatical complexity as children's speech and language skills develop. It is possible therefore that these older children are more affected by utterance length secondary to their level of speech and language development relative to the younger children in this study.

The speech samples utilized in this study had been analyzed previously in a study of the relationships among utterance length, syntactic complexity, and stuttering in children's conversational speech (Yaruss, 1999). Yaruss examined several different aspects of syntactic complexity at three different levels: sentence structure, clause structure, and phrase structure. The results of his study suggested that stuttering wasn't particularly related to syntactic complexity across a variety of different variables (for the same participant data utilized in the present study). A combination of the utterance length and selected measures of syntactic complexity were able to accurately predict whether an utterance would be stuttered for only 6 of the 12 children in his study. Length was the best predictor for all of those 6 children. An examination of the data from Yaruss' study revealed that utterance length was predictive of stuttering for 3 of the 4 children in question in the present study. While a significant amount of research has demonstrated a relationship between increased syntactic complexity and increased disfluency, syntactic complexity was not predictive of stuttering for any of these particular children.

Finally, it is possible that other factors that were not measured in this experiment could be responsible for the segregation of these 4 children. Yaruss (1999) has suggested that utterance timing, in combination with length and complexity might be related to the likelihood that an utterance will be disfluent. He suggested that longer or more complex utterances may be more likely to contain disfluencies when produced with a faster speaking rate or shorter response latency. Because utterance timing data was not collected for this study, it is not possible to examine the speaking rate and response latency of the 4 children who presented with a greater baseline response to the effect of utterance length. Other factors that have been shown to affect response latency include the number of phonological neighbors and syllable frequency (Levelt & Wheeldon, 1994; Ratner, 2005). Future research will be needed to examine the effects of these other potential factors, including potential production factors that were not addressed in this study.

5.5. Utterance Length as an Explanation

When this study was designed, it was decided apriori, that utterance length would not be controlled. A simple model of the relationship between utterance length and disfluency might be based on the fact that every word in an utterance brings with it, the opportunity for a disfluency. As the utterance length increases, so too does the opportunity for a word to be produced disfluently. Yaruss (1999), however, suggested that this approach is not entirely satisfactory because children who stutter usually do so at the beginning of an utterance regardless of the length (Brown, 1938b, 1945; Natke et al., 2004; Silverman & Williams, 1967; Wijnen, 1990). Yaruss also argued that to separate length from syntactic complexity (a variable of interest in his study) would be somewhat artificial since these two aspects of language can not be easily separated in conversational speech. It was reasoned that to separate length and phonological complexity during conversational speech would be similarly artificial. The phonological complexity of an utterance was deemed to be a factor of the relationships among the complexity of the phonemes in a word, the relatedness of those phonemes, and the length of the unit to be planned (Jakielski, 1998; Levelt, 1989; Throneburg et al., 1994).

The results of the post-hoc analyses carried out in this study however, suggested that utterance length alone was better able to predict the likelihood of an utterance containing a disfluency than was phonological complexity (as realized in the IPC and LEC_i/CS_i scores). In fact, when the length adjusted phonological complexity measures were added to the logistic regression analysis with utterance length as a covariate, they did not significantly increase the predictive ability of utterance length alone. It is not surprising that length was found to be predictive of speech disfluencies, since a number of studies have demonstrated a relationship between increased utterance length and increased disfluency (Gaines, et al., 1991; Logan & Conture, 1995, 1997; McLaughlin & Cullinan, 1989; Weiss & Zebrowski, 1992). Yaruss (1999) reported that length was the variable most predictive of stuttering in this very same group of 12 children. Length, however, was only predictive for half of the children in Yaruss' study, and for those children it was only able to predict approximately 50% of the stuttered utterances. Clearly other factors were related to disfluency in this particular group of children. Because of the fact that a number of recent theories of stuttering propose that speech disfluencies arise because of a disruption in the time dependent processes of phonological encoding, it was hypothesized that phonological complexity was one such factor that might be related to disfluency (Howell & Au-Yeung, 2002; Karniol, 1995; Logan & Conture, 1997; Perkins et al., 1991; Postma & Kolk, 1993; Wingate, 1988).

As noted above, this author had reasoned that phonological complexity was intricately related to the length of the utterance, and therefore the phonological complexity scores should not be adjusted for length. When it became apparent that the initial results had been confounded by utterance length, a length adjusted U-IPC and U-LEC_i/CS_i score was derived by dividing each utterance level score by the number of words in that utterance. This length adjusted score was not significantly related to speech disfluency. In an attempt to control for the length of the utterance without merely dividing the complexity score by the number of words in the utterance (and therefore possibly factoring out another variable central to phonological complexity) a post-hoc test of fluent and disfluent utterances matched for length was carried out. Neither U-IPC nor U-LEC_i/CS_i of the disfluent utterances was significantly different than the complexity scores of the length-matched fluent utterances. The results of these analyses did not support the hypothesis that phonological complexity, as represented by the IPC and the LEC_i/CS_i was related to disfluency. Because the statistical power of these particular post-hoc analyses was not adequate however, the negative findings have limited meaning.

The power of a statistical test is a function of the alpha level, sample size, and effect size. As discussed earlier, a number of variables (linguistic and non-linguistic) have been shown to be related to speech disfluency. Because it is not possible to adequately control for these variables when using conversational speech samples, the effect size of the variable of interest (i.e., phonological complexity) is appraised against the background of the other variables (Cohen, 1988). Cohen suggests that the operative effect size can be increased by improved experimental designs which limit the effects of these other variables. An increase in effect size is directly related to an increase in statistical power. A major implication of the present research study is that carefully crafted elicitation tasks should be utilized to examine the relationship between phonological complexity and speech disfluency.

5.6. Future Studies

Future studies investigating the relationship between phonological complexity and the occurrence of speech disfluencies should utilize elicitation tasks designed to control for variables known to be related to disfluency. An elicitation task could be developed that controls for utterance length, phonological complexity, and syntactic complexity. This multiple factor design might incorporate utterances of high and low syntactic complexity, high and low phonological complexity, and long and short utterance length. While the results from this experiment might not readily generalize to the conversational speech of children who stutter, the factorial design might allow for better understanding of the inter-relationships between the different variables by allowing the effect of the different variables to be examined separately and in combination.

As mentioned above, the speech production and planning literature, in particular literature regarding WEAVER++, suggests a couple of points that should be considered when designing an elicitation task as described above (Cholin et al., 2004; Dell, 1986, 1988; Levelt et al., 1999; Roelofs, 1997) First, if as Levelt and colleagues suggest, the domain of phonological encoding is the phonological word, a whole-word measure of phonological complexity (like the IPC) should be calculated at the level of the phonological word, not at the level of the lexical word (Cholin et al., 2004; Levelt et al., 1999). If the IPC is being utilized as a measure of phonological (as opposed to phonetic) complexity, it would seem appropriate to change the scoring protocol to account for our understanding of the planning process. Consecutive consonants crossing syllable boundaries would not be considered to form a cluster.

According to Levelt and Wheeldon (1994), the phonological complexity of a syllable already in the mental syllabary should not result in a planning delay at the level of phonetic encoding. However, because children's sound repertoires are rapidly expanding in the pre-school years, the phonological complexity of newly learned syllables (not yet stored in the child's mental syllabary) might result in planning delays associated with the need to generate the gestural scores for these less frequently used syllables. This suggests that an elicitation task designed with low and high frequency syllables of both low and high phonological complexity might be able to illuminate the relationship of phonological complexity and disfluency. If disfluency is more closely related to phonetic complexity (i.e., is a production phenomenon) one might expect increased disfluency for high phonological complexity syllables regardless of syllable frequency, since the motoric difficulty will be the same whether or not the syllable is stored in the mental syllabary. If however, disfluency is primarily related to errors or delays in planning, phonologically complex low frequency syllables should be produced disfluently in greater proportion than phonologically complex high frequency syllables.

This might be accomplished by utilizing syllables found in the names of children's television programs as higher frequency syllables and similarly complex syllables (phonologically) that are not associated with words familiar to the children as low frequency syllables. Alternately, a criterion-type design might be utilized that is based on an understanding of each child's sound repertoire at the time of testing. A criterion-type design would allow for longitudinal testing of the effect of phonological complexity at the level of phonetic encoding for these children as their speech and language skills develop.

The elicitation task described above is designed to examine the effect of phonological complexity at the level of phonetic encoding. Some of the recent theories of stuttering discussed above, suggest that the errors or delays that are responsible for the disruptions that lead to disfluency, occur in the planning process that proceeds phonetic encoding (i.e., phonological encoding) (Karniol, 1995; Perkins et al., 1991; Postma & Kolk, 1993; Wingate, 1988). Postma and Kolk (1993) hypothesize that disfluencies are the result of slowed activation rate in the process of phonological encoding. This slowed rate, they suggest, increases the chance of a selection error which results in the need for repair (Dell & O'Seaghdha, 1991; Postma & Kolk, 1993). Wijnen & Boers (1994) have shown that children who stutter benefit from a CV phonological prime. If increased phonological complexity is related to decreased activation rates as hypothesized in Postma and Kolk's CRH, one might expect that the benefit from a phonologically complex prime might be greater than the benefit from a phonologically simple prime.

A well-designed priming experiment might be able to test this hypothesis. Using an experimental paradigm similar to Wijnen & Boers (1994), the effect (as measured by speech reaction time, SRT) of initial primes composed of phonologically simple and phonologically complex syllables could be examined in young children who stutter and those that do not. In this type of experiment response words are spoken in reaction to a visually presented cue word (or line drawings) which is associated with the response item in a short learning phase. Test trials alternate with learning phases. In one condition (i.e., the phonologically simple prime condition) the response words would share the same phonologically simple first syllable. In the phonologically complex prime condition, the response words would share the same phonologically complex first syllable. The situation where all of the response words have the same first syllable is considered the homogenous condition. The two homogeneous conditions would each be matched with a heterogeneous condition where the phonological complexity of the first syllable is similar (i.e., phonologically simple or complex), but phonologically unrelated.

The experiment might consist of five trials (of five words each) for each condition. For example, in one learning phase the children would be taught five cue-response pairs for phonologically simple homogeneous targets (i.e., they would learn the name of 5 line drawings). Following the completion of the learning phase, the children would be asked to respond to the line drawings as quickly as possible while maintaining accuracy. If increased phonological complexity is problematic for children who stutter secondary to impaired phonological encoding, the SRT benefit from a phonologically complex prime should be greater than the benefit from a phonologically simple prime. That is, the mean SRT difference in a homogeneous versus heterogeneous trial would be greater for the phonologically complex syllabic primes.

The literature review demonstrated that stuttering-like disfluencies are not only present in the speech of children who stutter but also are present in the speech of typically-developing children. If the elicitation tasks described above demonstrate a relationship between phonological complexity and speech disfluency in young children who stutter, the same tasks could be presented to normally fluent children. By examining the relationship of phonological complexity to stutter-like and normal disfluencies in the speech of typically-developing preschool children and children who stutter near the age of stuttering onset, researchers could examine the similarities and differences that exist between those two participant populations. A clearer understanding of the relationship of phonological complexity and speech disfluency, especially as it relates to stuttering-like disfluencies in typically-developing children, would add much to our understanding of the disorder of stuttering.

The findings of Rispoli and Hadley (2001) mentioned above, suggest that older preschool-age children may be differentially affected by variables such as syntactic or phonological complexity. Previous work, including the current study, examined the speech of preschool-age children ranging in age from approximately 3 to 6 years of age. If Rispoli and Hadley are correct, future studies should study children with a smaller age range (e.g., examine the speech of 3 and 4 year old children separately from those that are 5 to 6 years of age).

5.7. Caveats

Spontaneous speech samples were utilized in this study because they offered a number of advantages over studies using imitation or modeling. One of the main advantages is that children typically are more disfluent in spontaneous speech than in sentence imitation or modeling tasks. The language elicited from a spontaneous speech sample also is more representative of a child’s normal communicative behaviors (Silverman & Ratner, 1997). It has been argued that by allowing a child to use speech that is appropriate to his/her own linguistic development, the samples have an inherent high level of ecological validity (Dworzynski, Howell, & Natke, 2003). Shriberg (1993) suggests that the “validity, stability, and utility” (p. 109) of spontaneous speech has been supported by a number of studies. Spontaneous speech samples have the potential to provide a representative sample of each child’s communicative abilities, while providing a reasonable opportunity for the child to produce speech disfluencies typical of his everyday speech.

The use of spontaneous speech, and the decision not to control for utterance length however, turned out to be a significant limitation in the present study. Because spontaneous speech samples vary widely, the children may not have produced all of the sentence types, utterance lengths, or phonemes that were in their repertoires. It also was difficult to separate the independent effects of utterance length and phonological complexity in these samples. Additionally, this sample method did not control for lexical factors such as word (or syllable) frequency which are hypothesized to play a central role in phonetic encoding (Levelt et al., 1999; Roelofs, 1997; Silverman & Ratner, 1997). Future studies using elicitation tasks designed to control for some of these variables have been discussed.

It is also possible that the complexity measures that were chosen for this study were not the appropriate measures to capture phonological complexity from the perspective of phonological and phonetic encoding. While it has been argued that both measures represent phonological (i.e., planning) and articulatory (i.e., production) complexity (Howell et al., 2000; Jakielski, 2000; Throneburg et al., 1994), both the IPC and the LEC/CS were developed based on production data. These measures might not have been appropriate to address the complexity of the planning process. Changes to these metrics that might more directly reflect what is known about planning speech production have been discussed. It might also prove fruitful to explore the use of a criterion-type measure that is based on each individual child's speech sound repertoire at the time of testing. Such a measure might allow for longitudinal examination of the effect of the phonological complexity of different newly acquired sounds and syllables over time.

While it may not necessarily be a limitation, it is worth noting that previous studies examining the relationship between phonological complexity and disfluency compared the phonological complexity of words or utterance that contained a *stuttering-like disfluency* to words or utterances that were produced fluently (Howell & Au-Yeung, 1995; Howell et al., 2000; Throneburg et al., 1994). This differs methodologically from the current study in which the author examined the probability that phonological complexity is related to an occurrence of a speech disfluency (whether stuttering-like or not).

As noted earlier, the rational for the methodology utilized in the current study was that it would be easier to interpret the influence of phonological complexity in light of current models of speech planning and production if utterances were simply identified as either fluent or disfluent. Current models of speech planning and production, like that represented in WEAVER++ account for speech errors and disfluencies, but they do not account for stuttered speech (Levelt et al., 1999; Roelofs, 1997). Ratner (2005) has argued quite strongly that research in stuttering must be carried out with a better understanding of psycholinguistic research related to normal speech production. Future studies examining potential relationships between planning errors or delays and stuttering might well benefit from analyzing all speech disfluencies, rather than distinguishing between stuttered and non-stuttered disfluencies.

5.8. Conclusions

The results of Yaruss' (1999) recent study of the relationship between syntactic complexity, utterance length, and speech disfluency suggested that factors in addition to utterance length and syntactic complexity are related to the occurrence of disfluency in preschool-age children. Current models of stuttering suggest that the occurrence of speech disfluencies may be related, at least in part, to the process of planning or formulating language

(Howell & Au-Yeung, 2002; Karniol, 1995; Perkins et al., 1991; Postma & Kolk, 1993; Wingate, 1988). More specifically, these theories suggest that disruptions in fluent speech are the result of errors or delays in the processes of phonological and/or phonetic encoding. It was hypothesized that if increased phonological complexity interfered with these time-dependent processes, speech planning (and subsequent speech production) would be interrupted, resulting in speech disfluency. In this manner, phonological complexity was hypothesized to be related to the occurrence of speech disfluency in children near the age of the onset of stuttering.

The present findings however, do not support the hypothesis that an increase in phonological complexity is related to an increased probability that an utterance will contain a disfluency. The results of this study suggest that increased utterance length (in words) was associated with an increase in disfluency, but that phonological complexity was not a significant factor. The phonological complexity of fluent and disfluent words also was not significantly different in this study. Ratner (2005) has suggested that there is little empirical or theoretical motivation to expect that phonological factors might influence disfluency. She argued that because the phonological representation of an utterance is constructed on the basis of lexical, syntactic, and prosodic processes (i.e., it is far downstream in the planning process), it is unlikely that phonological complexity (on its own) would be predictive of disfluency.

The simple fact that other linguistic processes precede phonological and phonetic encoding, however, does not preclude phonological complexity from exerting an influence in the fluent (or disfluent) production of speech. That being said, the fact that phonological factors operate *downstream* from a number of linguistic factors that are known to influence disfluency, can no longer be ignored. It is possible that if the effects of the linguistic processes that precede phonological and phonetic encoding are controlled in well designed experiments, the relationship between phonological complexity and disfluency can be examined. The results of this experiment demonstrate that in order to further the field's understanding of factors related to disruptions in speech fluency, current psycholinguistic research in normal speech planning and production must be integrated into experimental design. Drawing from these psycholinguistic models of speech planning and production, the author of this study has discussed a number of points that should be considered when designing such an experiment (Cholin et al., 2004; Levelt et al., 1999; Roelofs, 1997). Future experiments incorporating this information may be able shed light on factors associated with speech disfluency in preschool-age children who stutter as well as those who present with normally fluent speech.

APPENDIX A

Summary of Screening Tests (Yaruss, 1994)

Prior to inclusion in previous studies, the children's speech and language abilities were screened by a licensed/certified SLP. All participants performed within normal limits on the following formal and informal measures of speech and language development:

- **General History**
    - Parent questionnaire
    - Parent interview
- **Disfluency** (based on a 300-word conversational speech sample)
    - Average frequency of speech disfluencies
    - Ranking of most common disfluency types
- **Articulation / Phonology**
    - *Goldman-Fristoe Test of Articulation* (GFTA; Goldman & Fristoe, 1986)
    - Informal phonological process analysis
- **Receptive and Expressive Language**
    - *Test of Early Language Development — Second Edition* (TELD-2; Hresko, Reid, & Hammill, 1991)
    - *Peabody Picture Vocabulary Test — Revised* (PPVT-R; Dunn & Dunn, 1981)
    - Mean Length of Utterance (MLU; Brown, 1973), based on a 50-utterance conversational sample

    - Informal structural analysis of syntactic and grammatical development, based on a 50-utterance conversational sample

- **Oral/Motor Development**
    - *Selected Neuromotor Tasks Battery* (SNTB; Wolk, 1990)
- **Hearing**
    - Pure-tone audiometric screening (25 dB HL)
    - Tympanometric screening

Note: Reprinted with permission from "*Stuttering and phonological disorders in children: Examination of the covert repair hypothesis*," by J.S. Yaruss, 1994, Unpublished doctoral dissertation, p. 149.

APPENDIX B

Operational Definitions of Disfluencies

Although no distinction was made between an occurrence of stuttering or normal disfluency during any of the analyses in this research project, all disfluencies were coded as to specific type when the speech samples were transcribed for earlier studies by Yaruss (1994, 1997, 1999). Definitions of the particular disfluency types will follow, along with examples of each disfluency type (e.g., Campbell & Hill, 1987; Pellowski & Conture, 2002; Yaruss, 1994, 1997, 1999). The conveyed message of each example is underlined. The disfluency, or break in the conveyed message, is italicized.

Definitions of Types of "Normal" Disfluencies

Interjection (INT). A sound, syllable, or word that is irrelevant to the meaning of the conveyed message is interjected into the utterance. Examples include:

The ball *um* went out of bounds.

I can't find *um ah* the spaceman.

Revision (REV). A change in the content of the intended message, grammatical form, or pronunciation of a word. Examples include:

Hey mom its my- your turn.

He tooked- took it to the teacher.

Phrase Repetition (PR). The repetition of at least two complete words of the conveyed message. The final word in the phrase may either be produced in its entirety, or it may be abandoned (i.e., left unfinished). Examples include:

And then- *and then* they went.

She wants choc- *she wants* vanilla ice cream. Multisyllabic Whole-word Repetition (MultiWR). A complete multisyllabic word is repeated, at least once, with a pause of at least 250 msec occurring between iterations. Examples include:

Where is the TV *TV* remote.

I want the yellow *yellow* spaceman.

Definitions of Types of Stuttering Like Disfluencies (SLDs)

Sound/Syllable Repetition (SSR). A portion of a word, consisting of a sound or syllable, is produced then repeated at least one time (stuttered portion), followed by a complete production of the original word (nonstuttered portion). Examples include:

[D *d d*id you see it?

I want the ba *ba ba*nana.

Monosyllabic Whole-word Repetition (MWR). A complete monosyllabic word is produced, then repeated in its entirety at least one time in a relatively rapid manner (i.e., < 250msec between repetitions). Examples include:

And *and and* it goes there.

Put the *the* dog inside.

Audible Sound Prolongation (ASP). A segment within a word is audibly prolonged beyond its normal duration. The sound is not repeated, rather it is stretched out. Examples include:

M----------*m*ore cake please.

It's my s--------*s*and box.

Inaudible Sound Prolongation (ISP). A segment within a word (or at the beginning of a word) is silently prolonged beyond its normal duration. The prolongation can not be heard. In the case of an ISP at the beginning of a word, the disfluency is commonly associated with the presence of physical tension in the oral articulators. Because no audible cue is available with an ISP at the beginning of a word, video images are utilized to make the determination of disfluency type. These inaudible prolongations are sometimes referred to as *blocks*. Examples include:

I hurt my (silent pause) –finger.

(silent pause with articulatory posturing) -Take mine.

Note: The definitions in this appendix were derived from those utilized by Yaruss (1994) and subsequently by Yaruss (1997, 1999). Certain aspects of the definitions, such as durational features that were not relevant to the present study, were not included. For the complete definitions see Yaruss (1994).

APPENDIX C

Analysis Steps for the Index of Phonetic Complexity (Jakielski, 2000)

Counting Complexity

IPC scores can be computed from transcriptions of target forms or actual productions. When calculating the score for a word, work from the top of the IPC chart downward.

The word "school" /skul/ will be used as an example of how to calculate the score.

1. **Consonants by Place**: Each *dorsal* gets one point. There is one dorsal in this example, /k/, so *place* gets **1 point**.
2. **Consonants by Manner**: Each *fricative, affricate,* and *liquid* gets a point. There is one fricative, /s/, and one liquid, /l/, so the example gets **2 points**.
3. **Vowels**: Each *rhotic* gets one point. There are no rhotics in our example, so **0 points** are added.
4. **Word Shape**: If the word ends with a consonant, it gets 1 point. This example gets **1 point** for *word shape* because /skul/ ends with the consonant /l/.
5. **Word Length in Syllables**: Words with three or more syllables get 1 point. This example has only one syllable, so it gets no points here. However, the word *dictionary* has four syllables so it would get **1 point**.
6. **Singleton Consonants by Place Variegation**: If a word has *place variegated* singleton consonants, the word gets 1 point. A word can only get up to 1 point for this parameter. Do not count variegation if one of the consonants is included in a cluster. There is no variegation that we can count in our example of /skul/, so we have

0 points. (However, in the word "kittycat," / kIdikæt /, there are four singleton consonants. Place moves from dorsal /k/ to coronal /d/ (variegated) to dorsal /k/ (variegated) to coronal /t/ (variegated). These place variegations would score 1 point for the word "kittycat".)

7. **Contiguous Consonants**: Each *cluster* gets one point, no matter how many consonants comprise the cluster (i.e., the /st/ cluster would get 1 point; likewise, the /str/ cluster would get 1 point). This example has the cluster /sk/, so **1 point** is awarded. Any consonants produced consecutively are considered to form a cluster, even if they cross syllable boundaries. The word "pizza" /pitsɑ/ would get 1 cluster point, even though the /t/ and /s/ are in different syllables.
8. **Cluster Type**: If there is place variegation between the consonants comprising a cluster, then it is *heterorganic.* The /sk/ cluster in this example requires a move from the coronal /s/ to the dorsal /k/; therefore, **1 point** is added for "cluster type."

Add points: The points that were scored for each parameter of the IPC are added. For this example, /skul/ has a value of **6 points**.

Note: This protocol was obtained from K. Jakielski (personal communication, September 14, 2004).

APPENDIX D
Index of Phonetic Complexity Scoring Categories (Jakielski, 2000)

The Index of Phonetic Complexity
(Jakielski, 2000)

Category	Points assigned for:	No points for:	One point for *each*:
1	consonants by place class	labials coronals glottals	dorsal
2	consonants by manner class	stops nasals glides	fricative affricate liquid
3	vowels by class	monophthongs diphthongs	rhotic
4	word shape	words that end with a vowel	word that ends with a consonant
5	word length in syllables	monosyllabic or disyllabic words	word with three or more syllables
6	singleton consonants by place variegation	words with place reduplicated singletons	word with place variegated singletons
7	contiguous consonants	no clusters	consonant cluster
8	cluster by type	homorganic clusters	heterorganic cluster

Note: This scoring protocol was obtained from K. Jakielski (personal communication, September 14, 2004).

APPENDIX E

Explanation of Index of Phonetic Complexity Scoring Classifications (Jakielski, 2000)

Consonants: Place classifications

labials	p b m w f v
coronals	t d ɾ n j θ ð s z ʃ ʒ tʃ dʒ r l
dorsals	k g ŋ
glottals	h ʔ

Consonants: Manner classifications

stops	p b t d ɾ k g ʔ
nasals	m n ŋ
glides	w j
fricatives	θ ð f v s z ʃ ʒ h
affricates	tʃ dʒ
liquids	l r

Vowels: Manner classifications

monophthongs	i I e ɛ æ ə œ a u U o O
diphthongs	aI aU OI
rhotics	ɚ Ir Er ar ur Or aUr aIr

Syllable designations:
Every vowel denotes a separate syllable.
A vowel equals a syllable (consonants are optional).

Consonant variegation:
If place varies when moving from one singleton consonant to the next singleton, then place is considered *variegated*. A word with an instance of variegation is awarded 1 point.
Contiguous consonants are equivalent to a consonant cluster.
A cluster is *heterorganic* when place is different for any of its contiguous consonants.

Note: This material was based on an explanation of the scoring classification obtained from K. Jakielski (personal communication, September 14, 2004).

APPENDIX F

Index of Phonetic Complexity Scores for Fluent and Disfluent Utterances

Participants	Fluent Utterances			Disfluent Utterances		
	n	Mean U-IPC (SD)	Range	*n*	Mean U-IPC (SD)	Range
P1	55	12.73 (4.68)	3-27	20	12.20 (4.69)	1-21
P2	62	9.32 (3.67)	1-19	13	8.46 (3.43)	3-14
P3	47	10.51 (5.60)	2-27	28	14.96 (5.75)	6-29
P4	57	10.18 (4.30)	3-20	18	13.56 (6.26)	4-28
P5	50	8.56 (3.29)	2-20	25	8.60 (3.85)	3-16
P6	24	7.83 (3.82)	2-16	51	10.67 (4.62)	5-21
P7	54	10.09 (4.63)	2-27	21	11.52 (4.73)	5-22
P8	55	11.42 (4.49)	2-21	20	14.55 (8.07)	4-35
P9	34	15.09 (5.79)	5-32	41	20.24 (8.27)	7-41
P10	30	10.17 (5.30)	3-30	45	12.67 (6.15)	2-33
P11	43	9.30 (4.51)	0-18	32	11.88 (5.88)	0-23
P12	48	13.45 (7.45)	0-34	27	16.96(11.10)	0-51
All Participants	559	10.74 (5.17)	0-34	341	13.33 (7.22)	0-51

Note. This table presents the number of fluent and disfluent utterances for each participant individually, and for the participant group as a whole. The mean U-IPC score (as well as the range of scores) is provided for both the fluent and disfluent utterances. U-IPC score = Utterance level Index of Phonetic Complexity score.

APPENDIX G

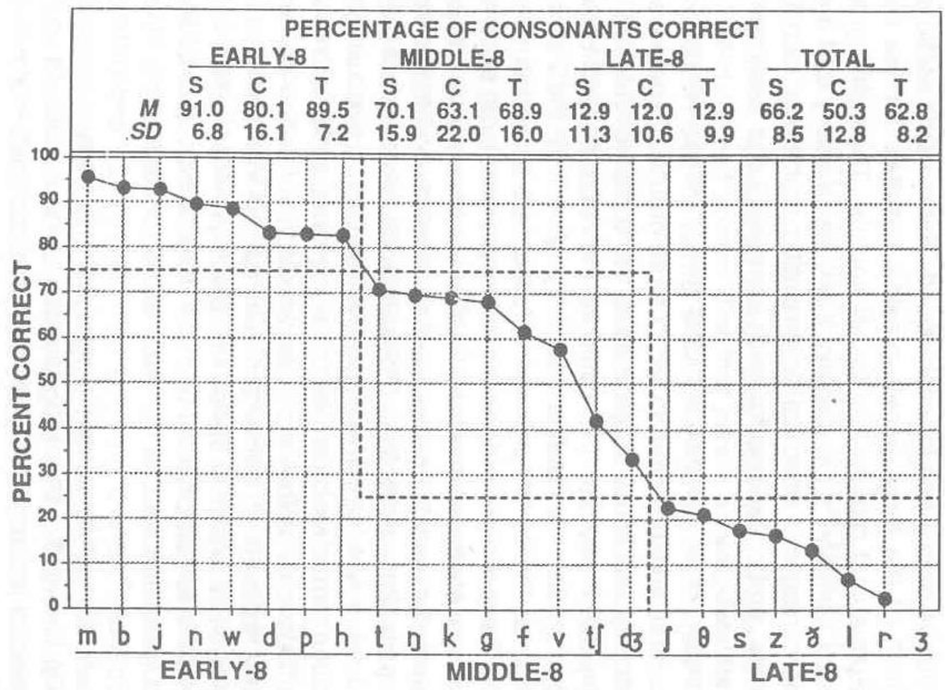
Word-initial Late-emerging Consonants and Consonant String Scores for Fluent and Disfluent Utterances

Participants	Fluent Utterances			Disfluent Utterances		
	n	Mean $U\text{-}LEC_i/CS_i$ (SD)	Range	n	Mean $U\text{-}LEC_i/CS_i$ (SD)	Range
P1	55	1.80 (1.22)	0-6	20	1.40 (0.88)	0-3
P2	62	1.26 (0.96)	0-4	13	1.46 (1.05)	0-3
P3	47	1.30 (1.41)	0-6	28	1.96 (1.40)	0-5
P4	57	1.14 (1.08)	0-4	18	2.78 (2.05)	0-9
P5	50	0.90 (0.97)	0-4	25	1.16 (0.80)	0-3
P6	24	1.17 (1.13)	0-3	51	1.33 (1.34)	0-5
P7	54	1.59 (1.38)	0-6	21	1.86 (1.28)	0-5
P8	55	1.51 (1.28)	0-4	20	1.75 (1.62)	0-5
P9	34	2.12 (1.47)	0-6	41	2.76 (1.89)	0-7
P10	30	1.43 (1.28)	0-5	45	2.29 (1.50)	0-6
P11	43	1.05 (1.21)	0-5	32	1.69 (1.75)	0-6
P12	48	1.63 (1.44)	0-6	27	2.15 (1.68)	0-7
All Participants	559	1.40 (1.27)	0-6	341	1.91 (1.57)	0-7

Note: This table presents the number of fluent and disfluent utterances for each participant individually, and for the participant group as a whole. The mean $U\text{-}LEC_i/CS_i$ score (as well as the range of scores) is provided for both the fluent and disfluent utterances. $U\text{-}LEC_i/CS_i$ score = Utterance level word-initial late-emerging consonant and consonant string score.

APPENDIX H

Shriberg's Late-8, Middle-8, and Early-8 Consonant Mastery Chart (Shriberg, 1993)



Note: This chart is a profile of consonant mastery. The percentage correct for each consonant is represented by the black dot. The most obvious breaks allow for division of the 24 consonants into three groups of 8 sounds which Shriberg (1993) termed Early-8 (averaging over 75% correct), Middle-8 (averaging 25% to 75% correct), and Late-8 (averaging less than 25% correct). Reprinted with permission from "Four new speech and prosody-voice measures for genetics research and other studies in developmental phonological disorders," by L.D. Shriberg, 1993, *Journal of Speech Hearing Research, 36,* p. 120. Copyright 1993 by the American Speech-Language-Hearing Association.

APPENDIX I

Index of Phonetic Complexity Scores for Fluent and Disfluent Utterances Based on the Participants' Actual Production

Participants	**Fluent Utterances**			**Disfluent Utterances**		
	n	**Mean U-IPC (SD)**	**Range**	***n***	**Mean U-IPC (SD)**	**Range**
P3	47	10. 47 (5.54)	2-27	28	14.89 (5.72)	6-29
P4	57	9.61 (4.27)	1-20	18	12.67 (5.91)	4-28
P6	24	7.42 (3.86)	2-16	51	10.31 (4.54)	5-21
P7	54	8.67 (4.18)	2-26	21	10.38 (4.24)	4-20
P8	55	11.04 (4.55)	2-21	20	14.00 (7.66)	3-35
P9	34	14.79 (5.78)	5-32	41	19.85 (8.11)	7-40
P10	30	10.17 (5.30)	3-30	45	12.64 (6.23)	2-33
P11	43	9.16 (4.50)	0-18	32	11.56 (5.80)	0-23
P12	48	13.38 (7.46)	0-34	27	16.85(11.06)	0-51
All Participants	392	10.55 (5.49)	0-34	283	13.70 (7.40)	0-51

Note. This table presents the number of fluent and disfluent utterances for each participant individually, and for the participant group as a whole. The mean U-IPC score (as well as the range of scores) is provided for both the fluent and disfluent utterances. Production data for Participants 1, 2, and 5 were not available. U-IPC score = Utterance level Index of Phonetic Complexity score.

APPENDIX J

Word-initial Late-emerging Consonants and Consonant String Scores for Fluent and Disfluent Utterances Based on the Participants' Actual Production

Participants	Fluent Utterances			Disfluent Utterances		
	n	Mean U-LEC$_i$/CS$_i$ (SD)	Range	n	Mean U-LEC$_i$/CS$_i$ (SD)	Range
P3	47	1.30 (1.41)	0-6	28	1.93 (1.38)	0-5
P4	57	1.07 (1.08)	0-4	18	2.61 (1.98)	0-9
P5	50	.90 (.97)	0-4	25	1.16 (.80)	0-3
P6	24	1.00 (1.02)	0-3	51	1.22 (1.27)	0-5
P7	54	.96 (1.081)	0-5	21	1.29 (.96)	0-4
P8	55	1.24 (1.14)	0-4	20	1.50 (1.50)	0-5
P9	34	1.94 (1.50)	0-6	41	2.61 (1.82)	0-7
P10	30	1.43 (1.28)	0-5	45	2.24(1.51)	0-6
P11	43	.98 (1.14)	0-5	32	1.53 (1.65)	0-6
P12	48	1.63 (1.44)	0-6	27	2.07(1.64)	0-7
All Participants	392	1.26 (1.26)	0-6	283	1.88 (1.60)	0-9

Note: This table presents the number of fluent and disfluent utterances for each participant individually, and for the participant group as a whole. The mean U-LEC$_i$/CS$_i$ score (as well as the range of scores) is provided for both the fluent and disfluent utterances. Production data for Participants 1, 2, and 5 were not available. U-LEC$_i$/CS$_i$ score = Utterance level word-initial late-emerging consonant and consonant string score.

APPENDIX K

Length-adjusted Index of Phonetic Complexity Scores for Fluent and Disfluent Utterances

Participants	**Fluent Utterances**			**Disfluent Utterances**		
	n	**Mean U-IPCadj (SD)**	**Range**	***n***	**Mean U-IPCadj (SD)**	**Range**
P1	55	2.45 (.75)	1-4.75	20	2.14 (.72)	.33-3.50
P2	62	2.04 (.63)	.33-3.33	13	1.86 (.53)	1-2.60
P3	47	1.91 (.66)	.67-4	28	1.91 (.81)	.75-3.80
P4	57	2.16 (.82)	.86-4.7	18	2.01 (.80)	.80-3.60
P5	50	1.91 (.67)	.50-3.33	25	1.81 (.75)	.60-3.20
P6	24	2.03 (.92)	.50-4	51	1.67 (.67)	.50-3
P7	54	2.17 (.83)	.67-5	21	1.94 (.60)	1-3.6
P8	55	2.23 (.63)	.67-3.40	20	2.34 (.61)	1-3.33
P9	34	2.71 (.78)	1.40-5	41	2.67 (.61)	1.36-4.40
P10	30	2.20 (.84)	.75-4.67	45	2.25 (.76)	.67-4
P11	43	1.91 (.77)	0-4.33	32	1.96 (.93)	0-4
P12	48	2.11 (.88)	0-5	27	2.10 (.86)	0-4
All Participants	559	2.14 (.78)	0-5	341	2.07 (.78)	0-4.40

Note. This table presents the number of fluent and disfluent utterances for each participant individually, and for the participant group as a whole. The mean U-IPCadj score (as well as the range of scores) is provided for both the fluent and disfluent utterances. U-IPCadj = Utterance level Index of Phonetic Complexity score adjusted for length in words.

APPENDIX L

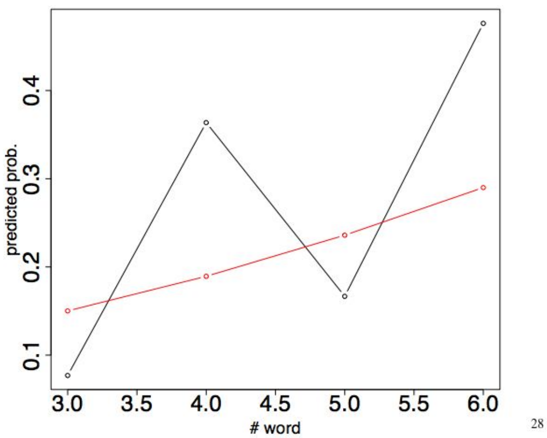
Length-adjusted Word-initial Late-emerging Consonants and Consonant String Scores for Fluent and Disfluent Utterances

Participants	Fluent Utterances			Disfluent Utterances		
	n	Mean $U\text{-}LEC_i/CS_i adj$ (SD)	Range	n	Mean $U\text{-}LEC_i/CS_i adj$ (SD)	Range
P1	55	.36 (.27)	0-1.33	20	.25 (.15)	0-.50
P2	62	.28 (.21)	0-1	13	.30 (.19)	0-.60
P3	47	.23 (.25)	0-1.20	28	.24 (.17)	0-.60
P4	57	.24 (.21)	0-.67	18	.40 (.27)	0-.82
P5	50	.21 (.24)	0-1	25	.26 (.18)	0-.60
P6	24	.31 (.32)	0-1	51	.20 (.18)	0-.63
P7	54	.35 (.31)	0-1	21	.32 (.21)	0-.80
P8	55	.26 (.25)	0-1	20	.23 (.20)	0-.60
P9	34	.37 (.23)	0-1	41	.35 (.18)	0-.83
P10	30	.31 (.26)	0-.75	45	.43 (.28)	0-1
P11	43	.23 (.28)	0-1	32	.28 (.29)	0-1.20
P12	48	.25 (.19)	0-1	27	.32 (.33)	0-1.50
All Participants	559	.28 (.25)	0-1.33	341	.30 (.24)	0-1.50

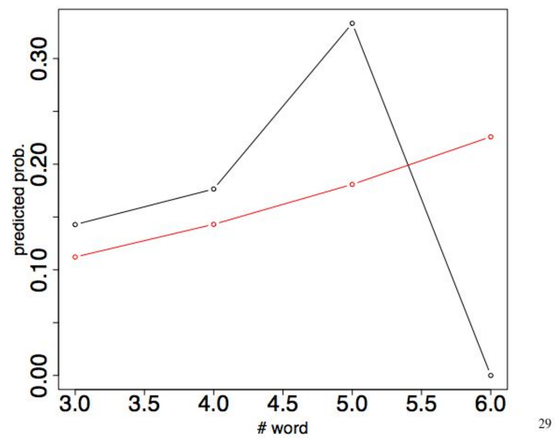
Note: This table presents the number of fluent and disfluent utterances for each participant individually, and for the participant group as a whole. The mean U-LECi/CSiadj score (as well as the range of scores) is provided for both the fluent and disfluent utterances. U-LECi/CSiadj = Utterance level word-initial late-emerging consonant and consonant string score adjusted for length in words.

APPENDIX M

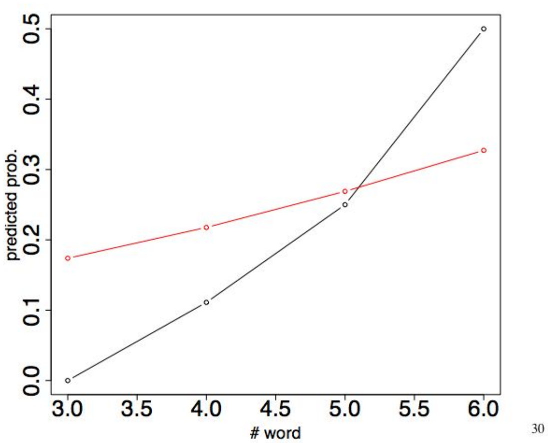
Actual Proportion of Disfluent Utterances Plotted Against the Modeled Probability (in RED) of Disfluent Utterances of 3 to 6 Words in Length



Participant 1

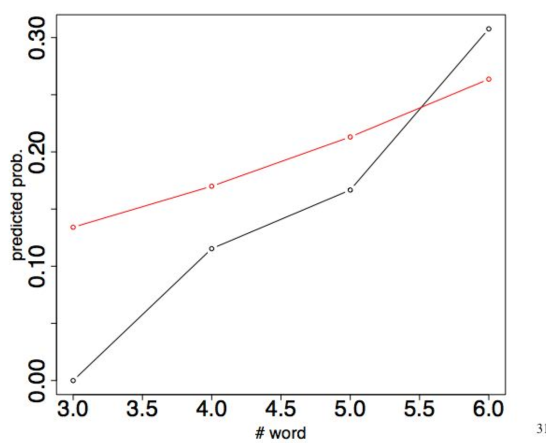


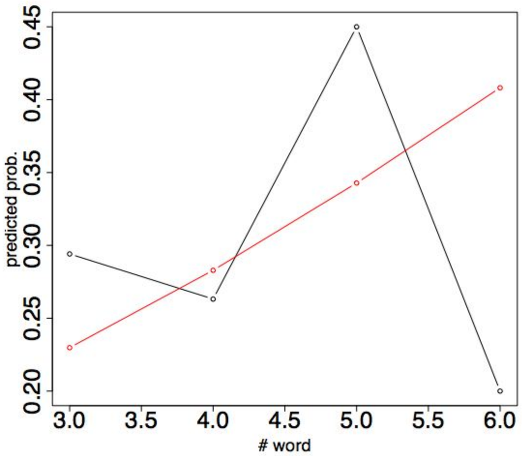
Participant 2



Participant 4

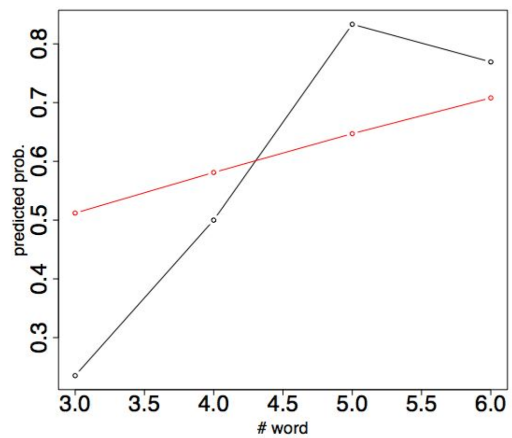
Participant 3





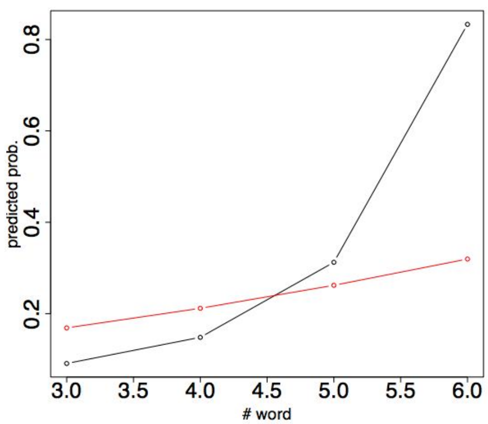
32

Participant 5



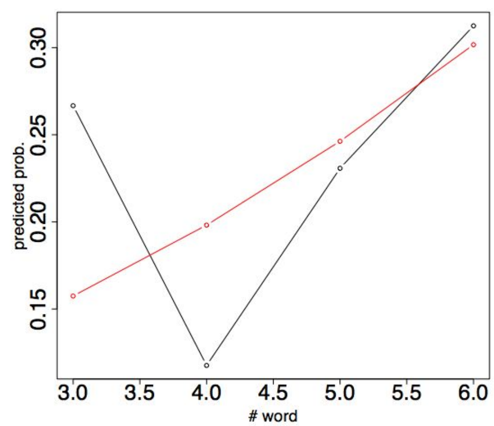
33

Participant 6



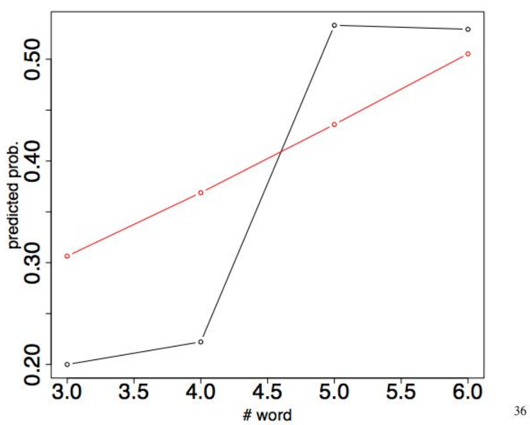
34

Participant 7

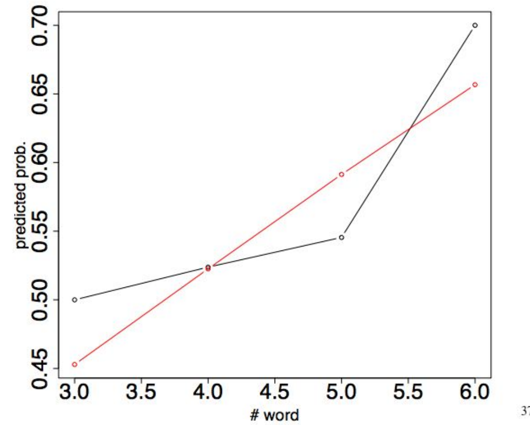


35

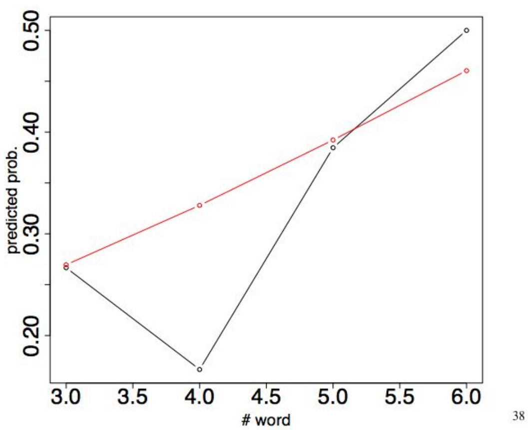
Participant 8



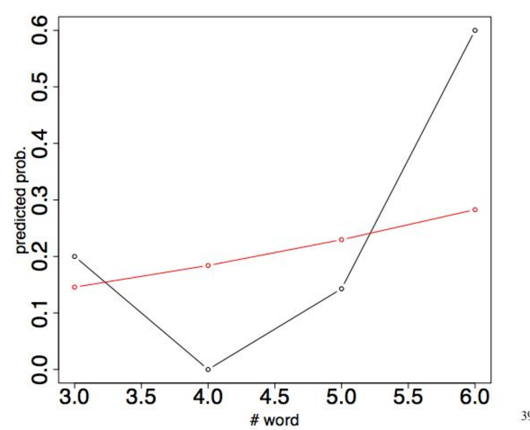
Participant 9



Participant 10



Participant 11



Participant 12

Note. The y-axis was determined by the range of scores of the individual children. Therefore, it varies across participants.

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