University of Nevada, Reno

The Relation Between Error Variability and Stimulability in Children with SSD

A dissertation submitted in partial fulfillment of the
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by

Toby Macrae

Dr. Kerry E. Lewis/Dissertation Advisor

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We recommend that the dissertation
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TOBY MACRAE

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Kerry E. Lewis, Ph.D., Advisor

Ann A. Tyler, Ph.D., Committee Member

Thomas L. Watterson, Ph.D., Committee Member

Dennis L. Uken, AuD, Committee Member

Valerie Fridland, Ph.D., Committee Member

Thomas Kidd, Ph.D., Graduate School Representative

Marsha H. Read, Ph. D., Associate Dean, Graduate School

August, 2009

Abstract

The purpose of the present study was to examine relations among proposed measures of underlying phonological representations (UPRs) in children with speech sound disorders (SSD). Eighteen children with SSD, aged 3;6-5;5, were tested for their error variability, stimulability, nonword repetition (NWR), and intra-word production variability. Pearson Product Moment Correlations were calculated to determine the nature of relations among these variables. Results revealed substantial relations between error variability and stimulability and between error variability and NWR. Relations between stimulability and NWR and between error variability and intra-word production variability were negligible. These findings suggest that error variability and stimulability may each reflect different aspects of UPRs in these children. Error variability may reflect the distinctness while stimulability may reflect the correctness of UPRs. Intra-word production variability may reflect aspects of underlying lexical as opposed to phonological representations in these children. The construct of error variability requires further exploration for its prevalence and developmental course. Examination of change for individual sounds that vary along the dimensions of error variability and stimulability is needed to validate the proposal that they each reflect unique aspects of UPRs in children with SSD. Further research is also required to determine the best intervention strategies for treating children with high error variability.

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Chapter I

Introduction

Overview

Speech sound disorders (SSD) affect a considerable proportion of young children. The prevalence of SSD has been estimated at 15-16% in three-year-old children (Shriberg et al., 2005) and 3.8% in six-year-old children (Shriberg, Tomblin, & McSweeny, 1999). Children with SSD constitute a large proportion of the cases seen by pediatric speech-language pathologists. Broomfield and Dodd (2004a) found that SSD was the most common disorder type in children aged 16 years or younger referred to a pediatric speech-language service. Most of the children referred were aged between two and six years. SSD negatively impacts social, emotional, and academic development and this highlights the need to develop effective intervention strategies.

Children with SSD are a heterogeneous group. Many subgroups have been identified based on surface speech patterns, proposed underlying deficits, and etiologies (e.g., Broomfield & Dodd, 2004b; Lewis et al., 2006; Shriberg et al., 2005). Children with subtypes of SSD characterized by unique underlying deficits may require unique treatment strategies. Before these strategies can be evaluated for their efficacy in treating children with subtypes of SSD, proposed subgroups must first be confirmed and defined.

Like other areas of development, speech development is characterized by variability. Variability has received little attention in the literature for its role in speech development and disorders. Within an overall trend of decreasing variability throughout speech development (Holm, Crosbie, & Dodd, 2007; Kent, 1976; Smith, 1978, 1994), variability has been shown to peak during developmental change (Sosa & Stoel-

Gammon, 2006). Instead of being viewed simply as noise in the system, short-term variability in speech development may be seen as being advantageous in terms of developmental change. Variability may allow children to explore new patterns of speech behavior. Alternatively, for children with SSD, high variability may be characteristic of a subgroup with a unique underlying deficit. If this is the case, then children with high variability may require unique treatment strategies. There are many different types of speech production variability: (1) intra-word production variability, which refers to variability in repeated productions of the same word; (2) durational variability in words and sounds; (3) stimulability, which refers to the ability to imitate a sound produced in error; and (4) error variability, which refers to variability in the sound substitutions for a specific target sound. Little is known about relations among the various measures of speech production variability in children with SSD. The present study seeks to contribute to our understanding of underlying phonological knowledge and how it is manifested in overt speech production in children with SSD. Underlying phonological knowledge refers to perceptual and productive knowledge of speech sounds. This research is important for understanding SSD subgroups with unique underlying deficits and designing effective treatment strategies that target the deficits.

Two measures of phoneme-level speech production variability of interest in the present study are stimulability and error variability. Stimulability has received considerable attention in the literature for its relation with phonological change in children with SSD. Phonological change refers to the learning of speech sounds. Early studies revealed that the most stimulable children and sounds showed the greatest phonological change in the absence of treatment (Carter & Buck, 1958; Kisatsky, 1967;

Powell & Miccio, 1996; Tyler, 1996). Later studies revealed that the most stimulable sounds also showed the greatest change in the presence of treatment (Powell & Miccio, 1996; Rvachew & Nowak, 2001; Rvachew, Rafaat, & Martin, 1999, Study 1). Stimulability, therefore, is a type of speech production variability that may be advantageous in terms of phonological change. Error variability is a measure of speech production variability that has only recently been examined for its relation with phonological change in children with SSD. This research, however, has yielded conflicting results. Studies that have examined change for individual sounds have revealed that those with consistent substitutes have shown the greatest gains (Forrest, Dinnsen, & Elbert, 1997; Forrest, Elbert, & Dinnsen, 2000). One study revealed that error variability for all of a child's sounds produced in error predicted phonological change such that children with the most variable substitutes showed the greatest gains (Tyler, Lewis, & Welch, 2003). It is not so clear as to whether error variability is also advantageous in terms of phonological change.

It has been suggested that stimulability and error variability reflect underlying phonological representations (UPRs) in children with SSD (Dinnsen & Elbert, 1984; Forrest et al., 1997; Forrest et al., 2000; Tyler & Lewis, 2005). UPRs consist of tacit phonological knowledge of the acoustic-perceptual properties and productive requirements of sounds (Munson, Edwards, & Beckman, 2005a). It is proposed that because stimulability and error variability reflect UPRs, they have shown relations with phonological change. Just as variability in motor behavior has been shown to accompany changes in motor development, variability in speech behavior may accompany changes in speech development. Children who are stimulable for sounds produced in error may possess indistinct and partially correct UPRs for those sounds. Distinctness refers to how well defined an UPR is. Children with variable substitutes for sounds produced in error may possess indistinct and in some cases partially correct UPRs for those sounds. The relation between stimulability and error variability needs to be examined. If highly stimulable children show high error variability, it might be inferred that error variability is also advantageous in terms of phonological change, although this would need to be experimentally tested.

Nonword repetition (NWR) performance is a more established measure of the distinctness of UPRs (Munson, Edwards, & Beckman, 2005b). Nonword repetition tasks require a speaker to repeat nonsense words presented by another speaker. NWR is a measure of phonological working memory (PWM) and PWM assists in the formation of distinct UPRs. Children temporarily store new words in PWM before they are moved on to long-term memory (Gathercole & Baddeley, 1990). As the lexicon grows, words are analyzed into their component UPRs (Sosa & Stoel-Gammon, 2006). Children with deficits in PWM would have difficulty processing new words in memory. This would in turn disrupt the analysis of these words into distinct UPRs. Relations between stimulability and NWR and between error variability and NWR also require examination.

The following literature review will first address dynamic systems theory and its application to variability in speech development. This will be followed by a discussion of dynamic field approach, based on dynamic systems theory, and its application to UPRs. Next, studies that have measured the perceptual and productive phonological knowledge required for the formation of distinct and adult-like UPRs in children with typical speech development and SSD will be reviewed. The discussion will then turn to three productive measures of UPRs: NWR, error variability, and stimulability. Studies of NWR in children with typical speech development and SSD will be examined. Error variability and stimulability, and their relation with phonological change in children with typical speech development and SSD, will then be discussed. It will be proposed that error variability and stimulability reflect UPRs and it is for this reason they have shown relations with phonological change in children with SSD.

Dynamic Systems Theory and Variability in Speech Development

Dynamic systems theory is a theory of action that was formulated to account for real-time changes in motor behavior in infants (Thelen & Bates, 2003). This theory was extended to account for longer-term changes in motor development. According to the theory, variability is associated with transitions between developmental stages and is viewed as a potential driving force of development and indicator of ongoing processes (van Geert & van Dijk, 2002). When lying on their backs, for example, newborn infants perform highly coordinated alternating leg kicks (Thelen & Smith, 1994). At about 1 month of age, coordination between the legs becomes highly variable. This variability leads to new forms of coordination between the legs, for example, simultaneous kicking. Thelen and Smith suggested that infants must free themselves of the stable patterns of the newborn period before they can assemble new patterns of coordination. The variability present during developmental transitions provides infants with a wide array of coordinative possibilities. In other words, variability in motor development allows infants to explore new patterns of motor behavior.

Variability is inherent in the development of biological and psychological systems, including motor, emotional, and language development (Newell & Corcos, 1993; van Geert & van Dijk, 2002). Speech development is also characterized by variability. Dynamic systems theory has potential in explaining the variability seen in speech development. Peaks in variability in speech production may presage developmental change, just as variability has been shown to precede real-time changes in motor behaviors and longer-term changes in other areas of development. Speech production variability has been examined in children with typical speech development. Studies that have examined intra-word production variability tend to suggest that this type of variability is present in children with typical speech development, but only at a very young age (Holm et al., 2007; Sosa & Stoel-Gammon, 2006). Intra-word production variability has been found to peak at the age at which multi-word combinations are first observed in young children (Sosa & Stoel-Gammon, 2006). Sosa and Stoel-Gammon studied intra-word production variability in four children between the ages of 1 and 2 years. They used Ingram's (2002) measure of variability, the proportion of whole-word variation (PWV), which is calculated by dividing the number of different phonetic forms of a word by the total number of productions of that word in a speech sample. Sosa and Stoel-Gammon found that, for each child, variability fluctuated throughout the duration of the study and peaked at the acquisition of about 150-200 words. This coincided with the age at which two-word combinations were first observed. Sosa and Stoel-Gammon suggested that this peak in variability reflected a reorganization of the linguistic system in general that included a transition from holistic to phonemic representations as well as the analysis and flexible combination of individual words. This interpretation is consistent with a dynamic systems theory account of variability in speech production in that, in these children, the peak in variability reflected a transition between developmental stages.

Holm et al. (2007) also studied intra-word production variability in children with typical speech development. These authors observed low rates of variability in their participants, who were older (3;0-6;11) than the participants in Sosa and Stoel-Gammon's (2006) study. Variability was measured using Dodd's Inconsistency Assessment (Dodd, 1995). This assessment required children to name 25 colored pictures on three separate occasions within a session. The 25 words consisted of one to four syllables. The youngest group, aged 3;0-3;5, showed significantly more variability in their word productions than all other groups. An average of only 13.0% of total words produced, however, were variable over the three productions for children in the youngest group. Furthermore, 9.6% of total words produced by these children were variable with at least one accurate production. Holm et al. suggested that these cases reflected maturation or phonological change. Only 3.4% of total words produced by children in the youngest group, therefore, contained variable productions, all of which were inaccurate. As the age of the participants increased, intra-word production variability decreased. There is also evidence of an overall trend of decreasing durational variability in the production of words and phonemes throughout development (e.g., Kent, 1976; Smith, 1978, 1994). Speech production variability, therefore, has been shown to peak during developmental change (Sosa & Stoel-Gammon, 2006) and decrease throughout development (Holm et al., 2007; Kent, 1976; Smith, 1978, 1994).

Dynamic Field Approach

Dynamic field approach, based on dynamic systems theory, was formulated to account for the dynamics of representational states underlying motor behaviors in infants (Spencer & Schöner, 2003). Much of dynamic field approach can be applied to the dynamics of UPRs. According to Spencer and Schöner, a representational state is “a time-dependent state in which a particular pattern of neural activation that reflects, for instance, some event in the world is re-presented to the nervous system in the absence of the input that specified that event” (p. 393). UPRs can be interpreted with respect to this definition. An UPR may be thought of as a mental representation of a sound in the absence of the input (or output) of that sound.

Spencer and Schöner (2003) described three features of the dynamic field approach to representational states underlying motor behaviors in infants. These features may be applied to UPRs. First, representational states are characterized by graded certainty. In planning a motor response to an environmental stimulus, some responses are more strongly represented than others, thus resulting in graded certainty for the representational states underlying each possible response. With regard to UPRs, graded certainty can be seen in categorical perception tasks in which listeners label phonemes based on acoustic cues (e.g., Coady, Evans, Mainela-Arnold, & Kluender, 2007; Hazan & Barrett, 2000; Nittrouer, 2002). Acoustic cues are manipulated along a continuum ranging from values appropriate for one member of a phonemic contrast to those appropriate for the other member. Listeners are required to label each stimulus as either one or the other member of the contrast. For levels of the acoustic cue that are close to values appropriate for each member of the phonemic contrast, listeners reveal more consistent responses and, therefore, higher degrees of certainty in their labeling of phonemes. As values move further away from those appropriate for each member of the contrast, listeners reveal less consistency. Categorical perception tasks, therefore, reveal that UPRs, or at least perceptual representations, are characterized by graded certainty.

Studies of categorical perception have revealed an increase in the consistency of phonemic labeling with increasing age of participants (Hazan & Barrett, 2000; Mayo, Scobbie, Hewlett, & Waters, 2003; Nittrouer & Miller, 1997). This suggests an increase in the distinctness of UPRs with increasing age.

The second feature of dynamic field approach states that representational states may or may not be clearly defined. Perceptual information pertaining to an environmental stimulus may be incomplete. In these cases, a well-defined movement plan may not be formed. Representational states underlying possible motor responses to the stimulus, therefore, may not be clearly defined. With regard to UPRs, it is hypothesized that children in the present study will differ with regard to their UPRs for sounds produced in error. This claim is based on certain aspects of children's speech production patterns. Specifically, error variability and stimulability are thought to reflect UPRs for sounds produced in error in children with SSD (Dinnsen & Elbert, 1984; Forrest et al., 1997; Forrest et al., 2000; Tyler & Lewis, 2005). Children who use variable substitutes are thought to lack a category representation or a stable UPR for the target sound (Forrest et al., 1997; Forrest et al., 2000; Tyler & Lewis, 2005). Children who are stimulable for sounds produced in error are thought to possess correct UPRs for those sounds (Dinnsen & Elbert, 1984). According to dynamic systems theory, variability is associated with developmental change (van Geert & van Dijk, 2002). In line with this theory, variable substitutes and stimulability may reflect indistinct and in some cases partially correct UPRs that are in a state of change. As with representational states underlying motor behaviors, therefore, UPRs may or may not be clearly defined.

The third feature of dynamic field approach states that representational states are not necessarily continuous in content. For example, if the location of an environmental stimulus changes, there may be a discontinuous shift in an infant's representational state underlying the location of the stimulus. The infant may discontinuously change his/her underlying representation of the location of the stimulus from the old location to the new location, without representing the stimulus at intermediate locations. UPRs may be interpreted with regard to this feature. UPRs may be continuous when young speakers are in the process of acquiring a phonemic contrast (Tyler & Saxman, 1991). One cue to the distinction between voiced and voiceless members of a plosive contrast is voice onset time (VOT). VOT refers to the interval between the release of constriction and the beginning of vocal fold vibration. Adult speakers produce voiced plosives with shorter VOT values and voiceless plosives with longer VOT values. Infants with typical speech development do not produce perceptible contrasts between voiced and voiceless members of a plosive contrast. All plosives are perceived as voiced. Acquisition of this contrast is characterized by a gradual and continuous change to longer VOT values for voiceless plosives until there is a perceptible contrast. It may be assumed that the representational states underlying these phonetic behaviors also develop in a continuous fashion.

UPRs, however, may be discrete when speakers have acquired a phonemic contrast (Liker & Gibbon, 2008). When producing speech sounds, adult speakers do not utilize the entire range of possible articulatory gestures afforded by their mouth, lips, and tongue. For example, velar /k/ is produced with a constriction between the tongue and posterior hard palate. Despite variability within and across speakers, it is possible to define normal tongue-palate contact patterns for /k/ in adult speakers with typical speech development (Liker & Gibbon, 2008). These speakers also revealed clear separation between place of articulation for /k/ and that for alveolar /t/. There are no other voiceless plosives in English produced with a point of constriction between that for /k/ and that for /t/. Given that the articulatory gestures utilized in the production of voiceless (lingual) plosives are not continuous in adult speakers, it may be assumed that the representational states underlying these phonetic behaviors are themselves not continuous.

As with dynamic systems theory, the notion of variability, or instability, is a core feature of dynamic field approach. Instability is described with regard to representational states underlying real-time motor behaviors (Spencer & Schöner, 2003). Just as dynamic systems theory was extended to account for changes in development, dynamic field approach may be extended to account for developmental changes in representational states. More specifically, dynamic field approach may be employed to account for developmental changes in UPRs. It is hypothesized that, at any point in time, variability in speech production, as defined in the present study as variable substitutes for sounds produced in error and stimulability, reflects UPRs.

Underlying Phonological Representations

UPRs consist of tacit phonological knowledge of the acoustic-perceptual properties and productive requirements of phonemes, as well as higher-level knowledge of phonemic categories and how phonemes can be combined to form words (Munson et al., 2005a). The development of distinct and adult-like UPRs is influenced by lexical knowledge. As children are exposed to more and more words, a reorganization of the linguistic system takes place that includes a transition from holistic to phonemic representations (Sosa & Stoel-Gammon, 2006). Children learn to segment words into their component UPRs and to process and produce phonemes as discrete, categorical units that are separate from the words in which they appear (Munson, Swenson, & Manthei, 2005). Phonological rules convert the UPR into its various phonetic forms as determined by the phonetic context. An example provided by Gierut, Elbert, and Dinnsen (1987) is the case of regular plurals in English. A speaker learns the meaning of the plural morpheme and there is only one underlying representation of this morpheme. The speaker generates alternate pronunciations of the morpheme depending on the context, using phonological rules. For example, the UPR for the plural morpheme may be [s], and this is realized as [s] when preceded by a voiceless segment (e.g., *books*) and as [z] when preceded by a voiced segment (e.g., *bags*). These phonological rules are predictable and therefore not part of the UPR.

Children are thought to possess separate but related input (perceptual) and output (productive) representations of words (McGregor & Schwartz, 1992; Menn, 1992). Children may, therefore, possess separate perceptual and productive UPRs. An input representation contains all the perceptual knowledge necessary to recognize words and phonemes. Other researchers have distinguished between perceptual and productive *knowledge* as comprising the UPR (Munson et al., 2005a). An output representation contains all the knowledge necessary to produce words and phonemes. Speakers must possess sufficient perceptual knowledge of words and phonemes to allow each to be identified uniquely (Stackhouse & Wells, 1997). Regarding productive UPRs, Gierut et al. (1987) used the term productive phonological knowledge and defined this as a child's competence (tacit knowledge) and performance (explicit knowledge) of the sound system of the language. Competence refers to both unpredictable and predictable properties of language. The unpredictable properties must be learned and are stored as underlying representations. The predictable properties are the phonological rules discussed above. Performance refers to the phonetic and phonemic inventories used by the child, and the distributional properties of these sounds.

Traditionally, assumptions about the nature of children's UPRs have been based mainly on productive data (e.g., Gierut et al., 1987). More recently, perceptual data have been used to make inferences about the nature of children's UPRs (e.g., McGregor & Schwartz, 1992; Sutherland & Gillon, 2005). These data have typically pertained to children with SSD. Maxwell (1984) pointed out, however, that much of these data should hold for children with typical speech development.

Perceptual knowledge. The adult-like perceptual knowledge required for the formation of distinct UPRs develops throughout childhood in children with typical speech development (e.g., Edwards, Fox, & Rogers, 2002; Hazan & Barrett, 2000; Munson et al., 2005a). Children as old as 12 years have shown inferior abilities in comparison to adults in using acoustic information to make perceptual judgments as to the identity of phonemes (Hazan & Barrett, 2000). Hazan and Barrett varied synthetic acoustic cues along a continuum from values appropriate for one member of a phonemic contrast to values appropriate for the other member for four phonemic contrasts (/k/-/g/, /d/-/g/, /s/-/z/, and /s/-/ʃ/). Synthetic words containing the phonemes (*coat-goat, date-gate, Sue-zoo,* and *Sue-shoe*) were presented to listeners, who were required to identify each token as being one or the other member of each contrast. Children, including those aged 11;6-12;6, were less consistent than adults at identifying the stimuli. Furthermore, children aged 6;0-7;6 were less consistent than children aged 11;6-12;6 at identifying the stimuli. These results suggest that phoneme identification becomes more consistent with increasing age and continues to develop into adolescence.

Children have also shown inferior phoneme identification when listening to complete and degraded real-word stimuli (Edwards et al., 2002). Edwards et al. used whole-word and gated versions of two sets of minimally contrastive words (*tap-tack* and *cap-cat*). Minimally contrastive words differ with regard to one consonant. Gated versions consisted of tokens with progressively longer portions of the stop gap and final consonant release removed. Listeners were required to identify whole-word and gated tokens as being one or the other member of each contrast. Three- to four-year-old children showed less accurate phoneme identification than five- to eight-year-old children and adults when presented with the whole-word stimuli. Whole-word stimuli, therefore, were sufficient to detect decreased perceptual knowledge in the younger children in comparison to the older children. All children showed less accurate phoneme identification than adults when presented with the gated stimuli. These findings support those of Hazan and Barrett (2000) and suggest that children show protracted development of the adult-like perceptual knowledge required for the formation of distinct perceptual UPRs.

Children with SSD have shown decreased perceptual knowledge in comparison to children with typical speech development (Edwards et al., 2002; Munson et al., 2005a; Raaymakers & Crul, 1988; Rvachew, Ohberg, Grawburg, & Heyding, 2003; Sutherland & Gillon, 2005). Researchers have used various measures to infer levels of perceptual knowledge contained in children’s UPRs. First, English- and Dutch-speaking children with SSD have shown deficits in their ability to identify phonemes in comparison to children with typical speech development when listening to complete and degraded whole-word stimuli (Edwards et al., 2002; Raaymakers & Crul, 1988). Edwards et al. found that children with SSD performed more poorly than children with typical speech development in identifying phonemes in gated words. Both studies revealed similar findings with whole-word stimuli. That is, whole-word stimuli were sensitive enough to detect perceptual deficits in the children with SSD.

Children with SSD have also shown decreased perceptual knowledge in comparison to children with typical speech development when judging the correctness of words produced either correctly or with consonant or vowel changes (Rvachew et al., 2003; Sutherland & Gillon, 2005). In Rvachew et al.'s study, several tokens of each of the words *lake, cat, rat,* and *Sue* were recorded from children and adults. Half of the productions involved correct articulations; the other half involved misarticulations of the word-initial consonant. These tokens were presented to children with SSD and children with typical speech development who were required to judge whether the words were produced correctly or incorrectly. Children with SSD showed inferior performance on this task in comparison to children with typical speech development. In Sutherland and Gillon's study, 4-year-old children with SSD and same-aged control children with typical speech development completed a number of speech perception and production tasks. One of the perception tasks involved presenting participants with words spoken either correctly or with single or multi-vowel changes or deletions. As with Rvachew et al.'s study, participants were required to judge whether the words were produced correctly or incorrectly. Children with SSD showed poorer performance on this task in comparison to children with typical speech development.

Children with SSD have shown less pronounced deficits in perceptual knowledge than in productive phonological knowledge in comparison to children with typical speech development (Sutherland & Gillon, 2005). The magnitude of the group difference for each task in this study was dependent on whether the task assessed perceptual knowledge or productive phonological knowledge. The productive tasks lead to large effect sizes, whereas the perceptual tasks lead to medium effect sizes. Sutherland and Gillon suggested that the productive tasks may have overestimated UPR deficits due to the need for speech output, and that the perceptual tasks may have been more appropriate measures of UPRs than the productive tasks. Perceptual and productive phonological knowledge may even diverge for individual sounds produced in error in individuals with SSD (McGregor & Schwartz, 1992). The findings of these studies underscore the need to consider both perceptual and productive phonological knowledge when describing children's UPRs.

Productive phonological knowledge. Researchers have used various measures to infer levels of productive phonological knowledge contained in children's UPRs. Some researchers have inferred productive phonological knowledge of a phonemic contrast based on imperceptible acoustic differences between two phonemic categories perceived by listeners as being the same phoneme (McGregor & Schwartz, 1992; Tyler, Edwards, & Saxman, 1990). These differences are referred to as covert contrasts. The 4-year-old child with SSD in McGregor and Schwartz's (1992) study showed productive phonological knowledge for fricative and affricate targets, although these targets were all perceived as [θ]. This knowledge was revealed in the form of significant durational differences for preceding vowels depending on the word-final target and significant differences in the frequency characteristics of different word-initial targets realized as [θ]. These differences are consistent with those seen in adult speech. Moreover, children who have demonstrated covert contrasts have shown faster phonological learning for these contrasts than children who did not demonstrate this knowledge (Tyler et al., 1990). Of the three children with SSD in this study, the one that demonstrated productive phonological knowledge of a phoneme contrast showed faster phonological learning for that contrast than the two other participants, who did not show productive phonological knowledge.

Other productive measures have been used to infer the nature of UPRs in children with SSD. Three such measures are NWR, error variability, and stimulability. The ability to repeat nonsense words, or nonwords, depends on the distinctness of the speaker's UPRs (Munson et al., 2005b). Error variability and stimulability are thought to reflect UPRs for sounds produced in error in children with SSD (Dinnsen & Elbert, 1984; Forrest et al., 1997; Forrest et al., 2000; Tyler & Lewis, 2005). Error variability and stimulability have shown relations with phonological change in children with SSD (Carter & Buck, 1958; Forrest et al., 1997; Forrest et al., 2000; Kisatsky, 1967; Miccio, Elbert, & Forrest, 1999; Rvachew & Nowak, 2001; Rvachew et al., 1999; Tyler, 1996; Tyler & Lewis, 2005; Tyler et al., 2003; Tyler, Williams, & Lewis, 2006). It may be that, like covert contrasts, error variability and stimulability reflect speakers' levels of productive phonological knowledge and it is for this reason they have shown relations with phonological change. NWR in children with typical speech development and in children with SSD will now be discussed in greater detail. This will be followed by an examination of error variability and stimulability and their relations with phonological change.

Nonword Repetition

Typical speech development. Researchers have suggested that increasingly superior NWR performance with increasing age in children with typical speech development reflects the formation of distinct and adult-like UPRs throughout childhood (Chiat & Roy, 2007; Munson, Kurtz, & Windsor, 2005; Roy & Chiat, 2004). Roy and Chiat (2004) found that older children (3;0-3;11) repeated nonwords significantly more accurately than younger children (2;0-2;11). Chiat and Roy (2007) replicated this finding with a larger group of participants. NWR accuracy improved with increasing age in children 2-4-years-old. Munson, Kurtz, et al. found that 11-year-old children repeated nonwords significantly more accurately than 7-year-old children.

The development of distinct and adult-like UPRs appears to be mediated by increases in lexical knowledge (Munson et al., 2005b; Munson, Kurtz, et al., 2005; Roy & Chiat, 2004; Sosa & Stoel-Gammon, 2006). This is supported by the results of studies that have found relations between measures of lexical knowledge and NWR accuracy. Roy and Chiat (2004) found that receptive vocabulary was positively correlated with NWR accuracy in the young children in their study. Munson et al. (2005b) found that receptive vocabulary was a significant covariate in analyses of NWR accuracy in 3-6-year-old children with typical speech development. That is, receptive vocabulary differentially predicted NWR accuracy in these children. Munson, Kurtz, et al. found positive correlations between measures of expressive and receptive vocabulary and NWR accuracy in their entire group of participants comprising 6-13-year-old children with specific language impairment (SLI) and children with typical speech and language development.

Higher-level knowledge of phoneme sequences in words affects children's NWR abilities and this knowledge develops throughout childhood in children with typical speech development (Munson et al., 2005b; Munson, Kurtz, et al., 2005; Munson, Swenson, et al., 2005). Specifically, the speed with which children repeat nonwords depends on the phonemic composition of the nonwords and the children's knowledge of the frequency of occurrence in real words of the phoneme sequences in the nonwords. This is referred to as the frequency effect. Nonwords containing common phoneme sequences are typically repeated faster (Munson, Swenson, et al., 2005) and more accurately (Munson et al., 2005b; Munson, Kurtz, et al., 2005) than nonwords containing rare phoneme sequences. Older children, however, do not show as large an effect of phoneme sequence frequency on NWR as younger children (Munson et al., 2005b; Munson, Kurtz, et al., 2005). The larger frequency effect seen in younger children suggests that they rely more on lexical knowledge when combining phonemes into unfamiliar strings during NWR tasks. Nonwords containing rare phoneme sequences are repeated slower and less accurately by younger children than nonwords containing common phoneme sequences because of these children's lack of exposure to and experience speaking real words with rare phoneme sequences. Older children, who have more distinct and adult-like UPRs than younger children, are able to rely more on these UPRs and less on their lexical knowledge when combining phonemes into both common and rare sequences during NWR tasks.

Although age has been shown to be a significant predictor of the frequency effect, lexical knowledge appears to be a stronger predictor (Munson et al., 2005b; Munson, Kurtz, et al., 2005). Munson et al. found that a measure of expressive vocabulary was a significant predictor of the frequency effect in 3-6-year-old children with typical speech and language development. Munson, Kurtz, et al. found that a measure of receptive vocabulary predicted a significant amount of variance in the frequency effect in their entire group of participants comprising 6-13-year-old children with SLI and children with typical speech and language development. Lexical knowledge, therefore, appears to mediate the frequency effect in NWR in younger and older children. Munson and colleagues suggested that as children's vocabularies grow, their UPRs become more autonomous from their ULRs.

Speech sound disorders. Preschool children with SSD have shown deficits in the formation of distinct and adult-like UPRs, as revealed by inferior NWR performance, in comparison to children with typical speech development (Munson et al., 2005b; Sutherland & Gillon, 2005). Munson et al. also found that a measure of receptive vocabulary was a significant predictor of NWR performance in the children with SSD in their study. This finding is in line with the studies discussed above involving children with typical speech development and suggests that the formation of distinct and adult-like UPRs is influenced by increases in lexical knowledge in children with SSD. Sutherland and Gillon, however, found a very weak correlation between a measure of receptive vocabulary and NWR performance in their entire group of participants, comprising children with SSD and children with typical speech development. These authors suggested that the speech difficulties of children with SSD confound the use of NWR tasks and that receptive-based tasks may be more appropriate measures than production tasks to examine UPRs.

Very few researchers have examined NWR performance in children with SSD. As noted by Shriberg, Lohmeier, Dollaghan, and Campbell (2006) there is no NWR task appropriate for research with speakers with SSD. Many of the sounds to be repeated are not in the phonetic inventories of these children. Shriberg developed a NWR test, the Syllable Repetition Task (SRT) (Shriberg et al., 2006), with stimuli that comprise early-acquired phonemes (e.g. /b/, /d/, /m/, and /n/). This task will be used to assess NWR in the present study. Shriberg (1993) reported on the accuracy of production of the 24 English phonemes in conversational speech in 64 3-6-year-old children with SSD. Across all speakers, mean percent consonants correct (PCC) for each of the late-8 sounds was never greater than 25%. Mean PCC for each of the middle-8 sounds was always between 25% and 75%. Given the similarity in age between Shriberg’s participants and the participants in the present study, it is expected that the participants in the present study would experience difficulties with middle- and late-8 sounds. In contrast to many NWR tasks used in research that contain middle- or late-8 sounds (e.g., Nonword Repetition Test, Dollaghan & Campbell, 1998; Preschool Repetition Test, Roy & Chiat, 2004; Word Repetition Task, Kamhi & Catts, 1986), the SRT contains all early-8 sounds (/b, d, m, n/). In an archive search of 268 conversational speech samples from 3-6-year-old children with SSD, Shriberg et al. found that 100% of the children had the consonants /m, n, b/, the vowel /ɑ/, and 99.3% had the consonant /d/. It is not expected, therefore, that the consonants in the SRT will cause articulatory difficulties for the children in the current study.

Error Variability

Error variability, one type of speech production variability, has been examined in children with SSD for its relation with phonological change. Some studies have examined the effect of error variability on change for individual sounds produced in error (e.g., Forrest et al., 1997; Forrest et al., 2000). The results of these studies suggest that error variability for individual sounds has an effect on phonological change for those sounds. Specifically, change was found to be greater for sounds with a consistent substitute than for sounds with variable substitutes.

Consistency may be described with regard to one word position, for example, the word-initial position. For example, /tæt/ is produced instead of *cat* (i.e., word-initial /k/ is replaced by /t/), /tʌp/ is produced instead of *cup* (i.e., word-initial /k/ is replaced by /t/), and /tændi/ is produced instead of *candy* (i.e., word-initial /k/ is replaced by /t/). Consistency may also refer to productions across word positions, i.e., across both word-initial and word-final positions. For example, /tæt/ is produced instead of *cat* (i.e., word-initial /k/ is replaced by /t/) and /bæt/ is produced instead of *back* (i.e., word-final /k/ is replaced by /t/). Children with a consistent substitute for a sound produced in error replace that sound with the same substitute each time, although they may also produce the sound correctly in some words or contexts.

As with consistency, variability may be described with regard to one word position, for example, the word-initial position. For example, /tæt/ is produced instead of *cat* (i.e., word-initial /k/ is replaced by /t/) and /gʌp/ is produced instead of *cup* (i.e., word-initial /k/ is replaced by /g/). Variability may also refer to productions across word positions, i.e., across both word-initial and word-final positions. For example, /gʌp/ is produced instead of *cup* (i.e., word-initial /k/ is replaced by /g/) and /bæt/ is produced instead of *back* (i.e., word-final /k/ is replaced by /t/). As with children with a consistent substitute for a sound produced in error, children with variable substitutes for a sound produced in error may produce the sound correctly in some words or contexts. When the sound is produced incorrectly, however, it is replaced by one of a number of different sounds depending on the word or context.

Forrest and colleagues (Forrest et al., 1997; Forrest et al., 2000) examined the effect of error variability on phonological change and generalization for individual sounds in 3-5-year-old children with SSD. Generalization here refers to the carryover of a newly-acquired sound to an untreated word position. Across both studies, all children who received treatment for a sound with a consistent substitute learned to produce the sound in the treated position and generalized its use to other word positions. In the earlier study, two children who used variable substitutes across word positions learned to produce the treated sound in the treated position, but did not generalize its use to untreated word positions. Four of the five children who used variable substitutes both within and across word positions did not learn to produce the treated sound in either treated or untreated word positions. The other child who used variable substitutes both within and across word positions learned and generalized the treated sound. In the later study, none of the children who received treatment for a sound with variable substitutes learned to produce the treated sound in either treated or untreated word positions. These findings suggest that children treated for sounds with a consistent substitute show greater phonological change and generalization for these sounds than children treated for sounds with variable substitutes.

Other researchers have examined system-wide error variability and phonological change in children with SSD (e.g., Tyler & Lewis, 2005; Tyler et al., 2003; Tyler et al., 2006). The results of these studies have been mixed. System-wide error variability was found to predict change in consonantal accuracy in children with SSD (Tyler et al., 2003). Groups of children selected for their extreme scores on a system-wide measure of error variability (one group with consistent substitutes; one group with variable substitutes), however, were found not to differ in several measures of phonological change during and after treatment (Tyler & Lewis, 2005; Tyler et al., 2006).

System-wide error variability, as measured by the error consistency index (ECI), was predictive of change in consonantal accuracy (PCC), in 3;0-5;11 children with SSD (Tyler et al., 2003). In contrast to Forrest and colleagues, the direction of the relation between these two variables was such that children with the most variable substitutes showed the greatest change. ECI reflects the total number of different sound substitutions/omissions used across initial and final word positions for all 23 phonemes from a single word elicitation task that samples each phoneme three times in each word position. ECI, therefore, is a measure of error variability as opposed to error consistency. The higher the ECI, the more variable a child’s speech sound substitutes. Two groups of children with SSD from the Tyler et al. study, selected for their extreme ECI scores, were found not to differ in two measures of phonological change (Tyler & Lewis, 2005). All children received treatment for a number of sounds produced in error. Both groups showed similar linear increases in PCC and decreases in ECI for their target sounds over the duration of the study. That is, speech sound production accuracy increased steadily and speech sound substitutes became more consistent at a similar rate for both groups. Another study found non-significant differences between these same two groups of children in several measures of phonological change (Tyler et al., 2006). Measures included PCC change, learning for target sounds in the treated position, and learning for target sounds and cognates in the untreated position.

The findings of Tyler and colleagues (Tyler & Lewis, 2005; Tyler et al., 2006) are in contrast to those of Forrest and colleagues, who examined the effect of error variability, as measured for individual sounds, on phonological change for those sounds. Tyler and colleagues compared both system-wide and target-specific phonological change for children with SSD grouped according to a system-wide measure of error variability. In contrast, Forrest and colleagues examined error variability in individual children as it related to one phoneme that was absent from the phonetic inventory. Phonological change and generalization of this phoneme was then measured following treatment targeting the phoneme.

The contrasting findings of Forrest and colleagues and Tyler and colleagues may also be due to the different populations under investigation. Forrest et al. (2000) paid particular attention to the status of one phoneme that was missing from the inventory. Due to their selection criteria, some of the participants demonstrated age-appropriate articulation skills, as evidenced by standardized articulation test scores within the typical range. In fact, this was not controlled for across the consistent substitute and variable substitute groups. The consistent substitute group contained more children with age-appropriate phonological development, and was characterized by a higher average percentile score, in comparison to the variable substitute group. These superior phonological skills may be responsible for the superior phonological gains made by the consistent group. Tyler and colleagues, on the other hand, examined children who had SSD, as evidenced by standardized articulation test scores at least one standard deviation below the mean, and morphosyntactic impairments. Intervention targeted phonological and morphosyntactic goals. Although all children in Tyler and colleagues' studies exhibited SSD, it is unclear how the morphosyntax intervention affected phonological change in these children. Clearly, more research is needed to clarify the relation between error variability and phonological change in children with SSD.

One possible explanation for Tyler et al.'s (2003) finding that phonological systems characterized by variable speech sound substitutes showed the greatest PCC change lies in the nature of UPRs and with dynamic systems theory. The variability of substitutes for sounds produced in error may reflect the distinctness of the UPRs of the sounds (Forrest et al., 1997; Forrest et al., 2000; Tyler & Lewis, 2005). Elbro, Borstrom, and Petersen (1998) referred to distinctness as "the relative distance between a phonological representation and its neighbours" (p. 40). Variable substitutes may reflect indistinct UPRs. One consistent substitute may reflect a distinct and incorrect UPR, relative to the adult target. Recall that, according to dynamic systems theory, variability is associated with transitions between developmental stages and is viewed as a potential driving force of development and indicator of ongoing processes (van Geert & van Dijk, 2002). In line with dynamic systems theory, therefore, variable substitutes may reflect an indistinct UPR that is in a state of change. Treatment capitalizes on the fact that these

UPRs are in a state of change. Children with the most variable substitutes for sounds produced in error, therefore, may show the greatest gains in treatment.

Powell and Miccio (1996) proposed a framework relating production accuracy, production consistency, and phonological knowledge (see Figure 1, top 3 rows).

ACCURACY	Never Correct		Correct when Imitated	Correct in Some Contexts	Always Correct
CONSISTENCY	Consistent		Inconsistent		Consistent
PHONOLOGICAL KNOWLEDGE	Least		Some		Most
ERROR VARIABILITY	*Consistent*	*Variable*	*Consistent or Variable*		*N/A*
UPRs	*Distinct/ Incorrect*	*Indistinct /Incorrect*	*Indistinct/Partially Correct*		*Distinct/ Correct*

Figure 1. A framework relating accuracy of production, consistency of production, phonological knowledge, error variability, and underlying phonological representations.

According to Figure 1, production accuracy is viewed along a continuum from never correct to always correct. Intermediate points along the accuracy continuum refer to productions that are correct only when imitated (stimulable) or correct in certain contexts. With regard to production consistency, sounds that are always incorrect or always correct are produced consistently. Sounds that are correct only when imitated (stimulable) or correct in certain contexts are produced inconsistently. Phonological knowledge is also viewed along a continuum. Consistently incorrect productions represent the least phonological knowledge. Consistently correct productions represent the most phonological knowledge. Inconsistent productions represent some phonological knowledge.

This framework could be extended to include two additional rows, describing error variability and UPRs. Error variability is a slightly different construct to that of production consistency. According to error variability, highly variable phonological systems are those that show a large number of different substitutes for sounds produced in error. The target sounds may or may not be produced correctly in certain contexts. UPR refers to both the distinctness of the representation of a phoneme and the correctness of the representation relative to the adult target. Production consistency, the degree of phonological knowledge, and error variability can be used to infer the nature of UPRs. The UPR for a sound never produced correctly with only one substitute is assumed to be distinct yet incorrect relative to the adult target. The UPR for a sound never produced correctly with more than one substitute (e.g., /tæt/ for *cat*, /gʌp/ for *cup*, /bæt/ for *back*, and /dʌʔ/ for *duck*) is assumed to be indistinct and incorrect relative to the adult target. The UPR for a sound sometimes produced correctly is assumed to be indistinct and partially correct relative to the adult target. The UPR for a sound always produced correctly is assumed to be distinct and correct relative to the adult target. The framework suggests a transition in phonological learning from a distinct and incorrect representation to an indistinct and partially correct representation to a distinct and correct representation in the acquisition of adult-like UPRs.

According to this framework, UPRs for sounds that are correct when imitated, i.e., stimulable, are further along in terms of acquisition than UPRs for sounds that are never correct, i.e., nonstimulable. Children might be expected, therefore, to acquire stimulable sounds more readily than nonstimulable sounds. The relation between stimulability and phonological change in children with SSD will now be discussed in more detail.

Stimulability

Stimulability for sounds produced in error is a productive measure that has received considerable attention in the literature for its relation with phonological change in children with SSD. Earlier studies examined the effect of stimulability on phonological change in children with SSD who did not receive treatment (Carter & Buck, 1958; Kisatsky, 1967; Tyler, 1996). Later studies involved children who received treatment (Miccio et al., 1999; Rvachew & Nowak, 2001; Rvachew et al., 1999, Study 1).

Phonological change in the absence of treatment. In the absence of treatment, phonological change is greater for children and sounds categorized as more stimulable than for those categorized as less stimulable (Carter & Buck, 1958; Kisatsky, 1967; Powell & Miccio, 1996; Tyler, 1996). More children with SSD showing high levels of stimulability for sounds produced in error spontaneously correct all of these sounds across time than children with low levels of stimulability (Carter & Buck, 1958; Kisatsky, 1967). The more stimulable children are, the more likely they are to correct all of their errors (Carter & Buck, 1958). In this early study, 92% of children who were stimulable for 75% or more of their sounds produced in error corrected all of these sounds approximately 9 months later. In contrast, only 26% of children who were stimulable for less than 25% of their sounds produced in error corrected all of these sounds 9 months later. Although a more liberal cut-off was used to categorize children as either high or low stimulability in the later study (Kisatsky, 1967), stimulability still differentiated between those who made the most and least phonological change. Children who were stimulable for 34% or more of their sounds produced in error were categorized as having high stimulability. Those who were stimulable for less than 34% of their sounds produced in error were categorized as having low stimulability. The high stimulability group produced significantly less sounds in error 6 months after stimulability testing than the low stimulability group, whereas both groups produced a similar number of errors initially. Furthermore, the high stimulability group’s decrease in the number of sounds produced in error from initial to final testing was significant, whereas the low stimulability group’s decrease was not. In contrast to these studies that examined phonological change in children categorized as either high or low stimulability, a more recent study examined phonological change for sounds categorized as either stimulable or nonstimulable (Tyler, 1996). A larger proportion (62%) of sounds categorized as stimulable was acquired across time by children with SSD who did not receive treatment than sounds categorized as nonstimulable (33%).

Phonological change in the presence of treatment. More recently, research has revealed that phonological change is also greater for stimulable sounds than for nonstimulable sounds in children with SSD who have received treatment (Powell & Miccio, 1996; Rvachew & Nowak, 2001; Rvachew et al., 1999, Study 1). First, sounds categorized as nonstimulable have shown no change in production accuracy from pre- to post-treatment in children with SSD (Rvachew et al., 1999, Study 1), although only four sounds were categorized as nonstimulable in this study. Sounds categorized as stimulable showed a mean increase of 32% in production accuracy from pre- to post-treatment in the children in this study. Second, more stimulable sounds were twice as likely to be produced accurately in spontaneous sentences after treatment as less stimulable sounds across children with SSD (Rvachew & Nowak, 2001). Additionally, the mean highest step achieved in treatment was significantly higher for the more stimulable sounds than for the less stimulable sounds in this study. The more stimulable sounds also showed greater phonological knowledge and had earlier ages of mastery than the less stimulable sounds. It is possible then that, in addition to stimulability, these two variables had an effect on phonological change in this study. Finally, stimulable sounds are likely to be acquired during treatment even if these sounds are not treatment targets (Miccio et al., 1999). All non-target sounds that were stimulable at pre-treatment (n = 7) in this study were acquired at post-treatment across children with SSD.

As with error variability, a possible explanation for the effect of stimulability on phonological change lies in the nature of UPRs. Stimulability of sounds produced in error is thought to reflect UPRs for those sounds. Dinnsen and Elbert (1984) suggested that stimulability will only arise where the child has correct UPRs. Children who can imitate the production of a sound are assumed to have at least a partially correct UPR for that sound. That is, they have some productive phonological knowledge of the sound. Children who cannot imitate the production of a sound are assumed to have an incorrect UPR for that sound. That is, they have no productive phonological knowledge of the sound.

It is proposed that error variability and stimulability have shown relations with phonological change because they reflect degrees of underlying knowledge stored in speakers' representations for sounds produced in error. Variable speech sound substitutes are thought to reflect the lack of a categorical representation for the target sound (Forrest et al., 1997; Forrest et al., 2000; Tyler & Lewis, 2005). Children with a consistent substitute for a sound produced in error may have shown greater phonological gains for that sound than children with variable substitutes because the former possessed a distinct categorical representation for the misarticulated sound. Children who are stimulable for a sound produced in error are thought to have a correct UPR for that sound (Dinnsen & Elbert, 1984). This is perhaps why stimulability has shown a favorable effect on phonological change. Children with high variability in their speech production, for example, high error variability, may reflect a unique subgroup of children with SSD. If so, they may require a unique approach to treatment. Alternatively, high variability may simply be part of the developmental process. Little is known about relations among different measures of speech production variability in children with SSD. The purpose of the present study was to examine relations among several speech production variables in preschool children with SSD. The variables included error variability, stimulability, and intra-word production variability, three different types of speech production variability, and NWR, a measure of the distinctness of UPRs (Munson et al., 2005b).

Research Questions

The following research questions were posed:

1. What is the relation between error variability and stimulability in children with SSD?
2. What is the relation between error variability and NWR in children with SSD?
3. What is the relation between stimulability and NWR in children with SSD?

4. What is the relation between error variability and intra-word production variability in children with SSD?

Hypotheses

It was hypothesized that:

1. Error variability and stimulability would show a substantial or marked relation in children with SSD.
2. Error variability and NWR would show a substantial or marked inverse relation in children with SSD. That is, children who had the most consistent speech sound substitutes would show the best NWR performance.
3. Stimulability and NWR would show a substantial or marked relation in children with SSD.
4. Error variability and intra-word production variability would show a substantial or marked direct relation in children with SSD. That is, children who were variable at the phoneme level of speech production would also be variable at the word level of speech production.

Chapter II

Method

Participants

Eighteen children (13 males; 5 females), aged 3;6 to 5;5 (*M* = 4;8), participated in the study. This developmental period was chosen in order to be consistent with past practice (e.g., Shriberg & Kwiatkowski, 1994). All participants presented with SSD not structurally-based, age-appropriate receptive vocabulary, age-appropriate oral motor functioning, and normal hearing. Potential participants were recruited from early childhood programs in the Washoe County School District, Reno, Nevada and from the University of Nevada, Reno (UNR), Speech and Hearing Clinic. Letters of invitation (see Appendix A) were given to parents of children who were either waiting to receive services or were receiving services for SSD. The study was conducted under a protocol approved by the UNR Institutional Review Board. All parents signed an informed consent (see Appendix B) for their children to participate in the study.

Inclusion Criteria

Each participant was required to meet the following inclusion criteria:

1. The presence of SSD was confirmed by a score at least one standard deviation below the mean on the Bankson-Bernthal Test of Phonology (BBTOP) (Bankson & Bernthal, 1990).
2. Age-appropriate receptive vocabulary was confirmed by a score greater than one standard deviation below the mean on the Peabody Picture Vocabulary Test-Third edition (PPVT-III) (Dunn, Dunn, & Williams, 1997).

3. Normal oral motor functioning was confirmed by a score greater than one standard deviation below the age-appropriate mean on at least one subtest of the Oral and Speech Motor Control Protocol (Robbins & Klee, 1987).
4. Normal hearing was confirmed by positive responses to 1000, 2000, and 4000 Hz stimuli presented at 25 dB in audiometric testing.

In addition, while not an inclusion criterion, language abilities were assessed. Language abilities are traditionally reported for samples of children with SSD. They were measured using the Clinical Evaluation of Language Fundamentals–Preschool, Second Edition (CELF–P2) (Wiig, Secord, & Semel, 2004). The Sentence Structure, Word Structure, and Formulating Labels subtests were administered yielding a Core Language composite standard score for each participant.

Experimental Measures

Relations among a number of speech production variables were examined in children with SSD who met all the inclusion criteria. These variables included error variability, stimulability, intra-word production variability, and NWR.

Error variability. In order to measure error variability, ECI (Tyler et al., 2003) was calculated. ECI reflects the total number of sound substitutions/omissions used across initial and final word positions for all 23 phonemes in a single-word elicitation task. ECI, therefore, is a measure of error variability. The higher the ECI, the more variable a child's speech sound substitutes. ECI was calculated using responses from the BBTOP and 20 additional words so that each of the 23 consonants was sampled three times each in initial and final word positions. For each consonant, the total number of different substitutions/omissions, regardless of word position, was summed. For example,

/f/ occurred word-initially in the words *fish*, *fire*, and *feather* and word-finally in the words *knife*, *leaf*, and *chief*. If a child produced /pɪʃ/ for *fish*, *fire* for *fire*, /wɛdə/ for *feather*, /naɪs/ for *knife*, /lip/ for *leaf*, and *chief* for *chief*, the number of different sound substitutions/omissions for /f/ across initial and final word positions was three. This process was repeated for each of the other 23 consonants. The number of different sound substitutions/omissions was summed across all 23 consonants to yield ECI for each participant.

Stimulability. Stimulability was measured using a modified version of Miccio's (2002) task. This task was used to assess children's stimulability for a pre-determined set of sounds. This set includes sounds listed by Rvachew, Nowak, and Cloutier (2004) as the most difficult (produced with less than 60% accuracy) for the 3;5-4;11-year-old children with SSD in their study (/ŋ, k, g, v, ʃ, ʧ, ʤ, ð, θ, s, z, l, r/) as well as /ʒ/ from Shriberg's (1993) group of late-8 sounds. Stimulability was measured by having participants imitate each of the 14 consonants in isolation and in initial, medial, and final positions in nonsense syllables in three different vowel contexts, /i/, /ɑ/, and /u/. For example, participants were asked to imitate /k/ in isolation and in the nonsense syllables, /ki/, /iki/, /ik/, /kɑ/, /ɑkɑ/, /ɑk/, /ku/, /uku/, and /uk/. The total number of correct imitations across all 14 consonants was tallied. This yielded a total stimulability score out of 134: 10 productions for each of 12 sounds and 7 productions for /ŋ/ and /ʒ/. These sounds are not found in word-initial position in English and so were not assessed in this position in each of the three vowel contexts. Scores were divided by 134 and multiplied by 100 to yield percent stimulability for each child.

Intra-word production variability. In order to measure intra-word production variability, PWV (Ingram, 2002) was calculated. PWV is a ratio that is calculated by dividing the number of different phonetic forms of a word by the total number of productions of that word in a speech sample. Only consonant productions were considered when determining whether phonetic forms of a word were the same or different. Scores can range from 0.00 to 1.00 (completely consistent to completely variable). When all productions were identical, i.e., there were no different phonetic forms, the score was 0.00. When all productions were different, i.e., there were as many different phonetic forms as there were productions, the score was 1.00.

For the purposes of the present study, a system-wide measure of PWV was calculated across words attempted three or more times in a story retell. Only content words were included in the analysis. All function words were excluded. Furthermore, only words with consonant-vowel-consonant (CVC) or more complex syllable structures were included in the analysis. All words with more basic structures (i.e., V, CV, and VC) were excluded. System-wide PWV was calculated by dividing the total number of different phonetic forms of all words included in the analysis by the total number of productions of these words in the story retell. This ratio was multiplied by 100 to yield percent intra-word production variability for each child.

Nonword repetition. NWR was measured using the SRT (Shriberg et al., 2006). The SRT consists of 18 multisyllabic nonsense words made up of CV sequences: eight 2-syllable (CVCV) words; six 3-syllable (CVCVCV) words; and four 4-syllable

(CVCVCVCV) words. The nonsense words contain only early-developing consonants (/b, d, m, n/) and one vowel (/ɑ/). As per Shriberg et al. (2006), scoring for the SRT was based on PCC.

Instrumentation

All testing administered for the purpose of obtaining the experimental measures was audio-recorded using a Sony ICD-P320 digital audio recorder. Story retells were also video-recorded using a Panasonic AG-DV2500 video recorder and a Maxell Mini DV Digital Video Cassette.

Reliability

Inter- and intra-judge agreement were assessed for the identification of children's consonant productions in single words using International Phonetic Alphabet (IPA) narrow transcription, which was the basis for all experimental tasks.

Training. The examiner and a research assistant participated in a training session using single-word speech samples from another study. The examiner and research assistant listened to the recorded speech samples on a compact disc player (Marantz CDR300) at a comfortable listening level in a quiet room. The examiner and research assistant independently transcribed the single words produced by the speaker using IPA narrow transcription. If the examiner and research assistant disagreed on any consonant productions, they discussed their transcriptions until they reached agreement. This process continued until the examiner and research assistant were confident their transcriptions were in agreement.

Inter-judge agreement. Audio-recordings of BBTOP samples from 11% of the participants (two children) were selected at random. Using the recordings, the trained research assistant transcribed the responses from the BBTOP originally transcribed online during the assessment session by the examiner. Inter-judge agreement was calculated as the percent agreement between the examiner and the research assistant in the identification of consonants in the BBTOP sample. Percent agreement was 87.25%.

Intra-judge agreement. Using the same audio-recordings from the inter-judge agreement task, the examiner re-transcribed the responses from the BBTOP originally transcribed online during the assessment session. Intra-judge agreement was calculated as the percent agreement between the examiner's original transcription and the repeated transcription in the identification of consonants in the BBTOP sample. Percent agreement was 95.05%.

Procedures

All participants received a 2-hour assessment in order to determine if they met the inclusion criteria and to calculate the experimental measures. All testing was performed at the UNR Speech and Hearing Clinic in a quiet room across two sessions. The examiner is an ASHA-certified speech-language pathologist with Nevada state licensure who is trained in phonetic transcription. The following procedures were employed to obtain the four experimental measures:

Error variability. Participants were told that they were going to be shown some pictures and that they would be asked to name the pictures. Picture cards representing the words from the BBTOP and the 20 additional words were then presented to the participants. Responses were transcribed online using IPA narrow transcription. The examiner calculated ECI for each participant after the assessment session.

Stimulability. Participants were told that the examiner was going to say some sounds and some made-up words; words that they would not have heard before. They were told that after the examiner said each sound or word, they would be asked to say each sound or word back to the examiner. The sounds and nonsense syllables from Miccio's (2002) task were then presented to the participants. Responses were transcribed online using IPA narrow transcription. The examiner calculated percent stimulability for each participant after the assessment session.

Intra-word production variability. Speech samples used for the calculation of PWV were obtained by having participants retell a story. Pancakes for Breakfast (de Paola, 1978) is a wordless book with repetitive themes that consists of 28 pages and 34 pictures, each representing a different scene. A story script produced for the book (see Appendix C) was read to participants who were asked to retell the story to the examiner. The script takes approximately 5 minutes to read and was designed for the current study. It has 67 content words that are repeated at least once by the examiner. The repetitive themes and words have the potential to elicit repetitions of words in each child's story retell.

Participants were told that they were going to hear a story. They were told that they would hear the story again at the end of the session, and then it would be their turn to tell the story back to the examiner using the pictures. The story was first read to each participant in its entirety at the very start of the session. The story was again read to each participant, in six sections corresponding to six broad events in the story, toward the end of the session. At the end of each section, the examiner told the child that it was his/her turn to tell that part of the story back to the examiner, in his/her own words. The examiner pointed to each picture in turn while the child told the story. If the child did not provide at least one utterance relating to each picture, the examiner used prompts such as "what else happened?" and "tell me more" to encourage more responses. If the child did not respond to the prompt, the examiner moved onto the next scene. While the participant told the story using each of the pictures, the examiner covered the other pictures. When the child reached the end of a section, the examiner started reading the next section. The story was read by the examiner and retold by the child in sections to enable the child to recall and use the content words repeated by the examiner.

The child's story retell was video- and audio-recorded and transcribed later. When the audio-recording was unclear, the examiner reviewed the video-recording to obtain visual cues as to the child's production. If the video-recording was also unclear, the child's production was marked as unintelligible. The retell was first transcribed orthographically and from the transcript all content words produced at least three times were identified. These words were then transcribed and formed the analysis set for the calculation of PWV.

Nonword repetition. Participants were told that the examiner was going to say some made-up words; words that they will not have heard before. They were told that after the examiner said each word, they would be asked to say the word back to the examiner. The nonwords from the SRT were then presented to the participants. Responses were transcribed online using IPA narrow transcription. The examiner calculated PCC for each participant after the assessment session.

Statistical Analysis

Pearson Product Moment Correlations were calculated between the following experimental measures:

1. ECI and percent stimulability
2. ECI and NWR
3. Percent stimulability and NWR
4. ECI and PWV

Chapter III

Results

The main purpose of the present study was to determine the relation between error variability and stimulability in children with SSD. Relations between error variability and NWR and between error variability and intra-word production variability were also examined. Finally, the relation between stimulability and NWR was examined. Eighteen children with SSD, aged 3;6 to 5;5, were assessed in order to determine eligibility for participation in the study and to calculate the experimental measures. All participants met the inclusion criteria.

Experimental Measures

Means, standard deviations, and minimum and maximum values for the four experimental measures (for the 18 participants) are presented in Table 1.

Table 1

Experimental Measures

Measure	Mean	Standard deviation	Min - Max
ECI	21.94	7.97	12 - 38
% Stimulability	43.12	16.76	21.64 - 69.40
NWR	74.11	18.13	28 - 96
PWV	.20	.09	.07 - .37

Note. ECI = error consistency index; NWR = nonword repetition; PWV = proportion of whole-word variation.

Correlations

In order to answer the research questions, Pearson Product Moment Correlations were calculated between ECI and percent stimulability, ECI and NWR, percent stimulability and NWR, and ECI and PWV. Results revealed significant moderate (Guilford, 1956) negative correlations between ECI and percent stimulability, $r = -.63$, $p < .01$, and between ECI and NWR, $r = -.59$, $p < .05$. Participants with the most consistent speech sound substitutes, therefore, showed the highest levels of stimulability and best NWR performance. The correlations between percent stimulability and NWR, $r = .13$, and between ECI and PWV, $r = -.07$, were weak and nonsignificant.

Post-Hoc Analysis of Individual Sounds

The occurrence of a correct production among attempts for sounds produced in error on the single-word elicitation task might also reflect UPRs. Because of this, and the finding of a moderate correlation between ECI and percent stimulability, two post-hoc analyses were carried out. Phi correlations were calculated to determine relations between stimulability and the occurrence of a correct production and between error variability and the occurrence of a correct production for each of twelve sounds. These sounds were assessed in the stimulability probe and in word-initial and word-final positions on the single-word elicitation task and were produced in error by the majority (≥ 13) of participants (/k, g, v, ʃ, ʧ, ʤ, ð, θ, s, z, l, r/). Only sounds with two or more errors were considered in the analysis involving error variability as it was deemed that sounds with only one error could not be categorized as either consistent or variable.

Results revealed a moderate, high, or very high correlation (φ ≥ .40) between stimulability and the occurrence of a correct production across 9/12 sounds (/ʃ, ʧ, ʤ, s, z, k, g, l, r/). Phi coefficients for these sounds ranged from φ = .47 to φ = .87. In each of these nine cases, the correlation was positive. The direction of the relation was such that stimulable sounds were more likely to contain instances of a correct production in the single-word elicitation task and nonstimulable sounds were less likely to contain instances of a correct production. Results also revealed a moderate, high, or very high correlation between error variability and the occurrence of a correct production across 8/12 sounds (/ʃ, ʧ, ʤ, θ, s, z, l, r/). Phi coefficients for these sounds ranged from φ = .42 to φ = 1.00. In each of these eight cases, the correlation was positive. The direction of the relation was such that sounds with consistent substitutes were more likely to contain instances of a correct production and sounds with variable substitutes were less likely to contain instances of a correct production.

Chapter IV

Discussion

The main purpose of the present study was to determine the relation between error variability and stimulability in children with SSD. Based on the proposal that these measures reflect UPRs in children with SSD (Dinnsen & Elbert, 1984; Forrest et al., 1997; Forrest et al., 2000; Tyler & Lewis, 2005), it was hypothesized that they would show a substantial or marked relation. The present study also sought to determine the relation between error variability and NWR, a more established measure of the distinctness of UPRs (Munson et al., 2005b). Based on the proposal that error variability reflects UPRs in children with SSD, it was hypothesized that error variability and NWR would show a substantial or marked inverse relation. That is, children with the most consistent speech sound substitutes were expected to show the best NWR performance. The relation between stimulability and NWR was also examined. Based on the proposal that stimulability reflects UPRs in children with SSD, it was hypothesized that stimulability and NWR would show a substantial or marked relation. Finally, the relation between error variability and intra-word production variability was examined. It was hypothesized that these two measures of speech production variability would show a substantial or marked direct relation in children with SSD. That is, children who were variable at the phoneme level of speech production would also be variable at the word level of speech production. The results of the study will now be discussed as they relate to the research hypotheses.

Error Variability and Stimulability

The finding of a significant moderate negative correlation between ECI and percent stimulability supports the first hypothesis. Error variability and stimulability were related in children with SSD. Specifically, children with the most consistent speech sound substitutes showed the highest levels of stimulability. Children with the most variable substitutes showed the lowest levels of stimulability. The moderate correlation along with documented relations between error variability and phonological change (Forrest et al., 1997; Forrest et al., 2000) and between stimulability and phonological change (Carter & Buck, 1958; Kisatsky, 1967; Powell & Miccio, 1996; Rvachew & Nowak, 2001; Rvachew et al., 1999, Study 1; Tyler, 1996) supports the notion that error variability and stimulability both reflect UPRs in children with SSD (Dinnsen & Elbert, 1984; Forrest et al., 1997; Forrest et al., 2000; Tyler & Lewis, 2005). These two types of speech production variability may reflect some aspects, possibly different aspects, of UPRs in these children. It is proposed that error variability reflects the distinctness and stimulability reflects the correctness of UPRs. Each of these proposals will be elaborated on in sections to follow.

Error Variability and Nonword Repetition

The finding of a significant moderate negative correlation between ECI and NWR supports the second hypothesis. Error variability and NWR were related in children with SSD. Specifically, children with the most consistent speech sound substitutes showed the best NWR performance. Children with the most variable substitutes showed the worst NWR performance. Given that NWR is a more established measure of the distinctness of UPRs, this finding supports the proposal that error variability reflects the distinctness of

UPRs in children with SSD. Knowing what NWR tasks measure can inform our understanding of what error variability reflects.

Nonword repetition. NWR is a complex task involving several cognitive processes, including "perceiving and discriminating the acoustic signal, matching the signal with phonological representations in memory, planning the articulatory movements required to replicate the nonword, and executing the response" (Munson, Kurtz, et al., 2005, p. 1033). With regard to phonological representations, Gathercole (2006) suggested that NWR "is influenced by the quality and persistence of the phonological representations that are characteristic of an individual…and by prior factors affecting the initial construction of the phonological representation" (p. 519). In order for speakers to be able to combine phonemes into unfamiliar strings during NWR tasks, therefore, they must possess, among other things, distinct UPRs. Children with indistinct, poorly-formed UPRs would be expected to have difficulty with NWR tasks.

Distinctness of underlying phonological representations. The need for distinct UPRs in the repetition of nonwords and the substantial relation between error variability and NWR in the present study suggest that error variability may also reflect the distinctness of UPRs. Children with variable substitutes for a sound produced in error may lack a stable or categorical representation for that sound (Forrest et al., 1997; Forrest et al., 2000; Tyler & Lewis, 2005). Children with a consistent substitute may lack the ability to produce the sound, but they understand "the common features of the sound in different contexts and positions of a word" (Forrest et al., 1997, p. 65). That is, they understand the categorical nature of the sound. Speakers perceive and produce sounds categorically (e.g., Coady et al., 2007; Hazan & Barrett, 2000; Liker & Gibbon, 2008;

Nittrouer, 2002). Categorical representation of sounds develops with increasing age (Hazan & Barrett, 2000; Liker & Gibbon, 2008; Mayo et al., 2003; Nittrouer & Miller, 1997; Tyler & Saxman, 1991). Children's UPRs, therefore, likely become more distinct throughout speech development. Powell and Miccio's (1996) framework and the proposed extensions (see Figure 1) related production accuracy, production consistency, phonological knowledge, error variability, and UPRs. Sounds always produced in error are characterized by the least phonological knowledge and incorrect UPRs. Consistent or variable speech sound substitutes for these sounds reflect distinct or indistinct UPRs, respectively. Sounds that are sometimes produced correctly are characterized by some phonological knowledge and partially correct UPRs. Variability of production of these sounds in different elicitation tasks or contexts reflects indistinct UPRs. Sounds that are always produced correctly are characterized by the most phonological knowledge and correct UPRs. Consistently correct production reflects distinct UPRs.

Stimulability and Nonword Repetition

The present study revealed a negligible relation between stimulability and nonword repetition. This finding does not support the third hypothesis. Stimulability, therefore, may not reflect the distinctness of UPRs in children with SSD. As was suggested earlier, stimulability may instead reflect the correctness of UPRs. Dinnsen and Elbert (1984) suggested that stimulability "will only arise where the child has correct underlying representations" (p. 64). It is proposed here that stimulability will only arise where the child has at least partially correct underlying representations.

Correctness of underlying phonological representations. Throughout phonological development, the correctness of children's UPRs relative to the adult targets likely forms a continuum. According to Powell and Miccio's (1996) framework with the proposed extensions (see Figure 1), the early stages of acquisition of adult-like UPRs are characterized by incorrect UPRs. Intermediate stages are characterized by partially correct UPRs. Later stages are characterized by correct UPRs. This framework suggests a transition in phonological learning from an incorrect representation to a partially correct representation to a correct representation in the acquisition of adult-like UPRs. Throughout phonological development, children must learn to use sounds both categorically and accurately, relative to the adult target.

Occurrence of a Correct Production

With respect to the construct of error variability reflecting the nature of UPRs, an important aspect of error variability may be that the child has the correct form, relative to the adult target, among his/her variable substitutes. This would suggest that the child has at least a partially correct UPR, whereas variable substitutes without the correct form may indicate an incorrect UPR. An indistinct UPR may only be advantageous when it is also partially correct. In line with Tyler and colleagues (Tyler & Lewis, 2005; Tyler et al., 2003; Tyler et al., 2006), the current study examined error variability as measured across the entire phonological system in children with SSD. Forrest and colleagues (Forrest et al., 1997; Forrest et al., 2000), in contrast, examined error variability as measured for individual sounds. Post-hoc analyses of individual sounds were carried out to determine: (1) the relation between stimulability and the occurrence of a correct production among attempts for sounds produced in error on the single-word elicitation task; and (2) the likelihood that sounds with variable substitutes contained a correct production among the attempts on the single-word elicitation task.

The results of the first post-hoc analysis revealed that there was a substantial, marked, or very dependable relation between stimulability and the occurrence of a correct production across participants for 9 of 12 sounds produced in error. In each case, the direction of the relation was such that stimulable sounds were more likely to contain instances of a correct production. Nonstimulable sounds were less likely to contain instances of a correct production. This finding suggests that, like stimulability, the occurrence of a correct production reflects a partially correct UPR. Children with partially correct UPRs for sounds produced in error may be able to produce the sounds correctly, if the conditions allow. Correct productions that occur spontaneously in some phonetic contexts but not in others may reflect UPRs that themselves are correct only in those phonetic contexts. Correct productions that occur when imitated may reflect UPRs that are indistinct and partially correct. These UPRs may lack certain information regarding the correct production of the sound. Visual, auditory, and/or phonetic placement cues may provide the child with this missing information so that, in the case of stimulability, the child possesses sufficient knowledge to be able to produce the sound correctly. If instances of a correct production and stimulability both reflect partially correct UPRs, one would expect them to be related.

The results of the second post-hoc analysis revealed that there was a substantial, marked, or very dependable relation between error variability and the occurrence of a correct production across participants for 8 of 12 sounds produced in error. In each case, the direction of the relation was such that sounds with consistent substitutes were more likely to contain instances of a correct production. Sounds with variable substitutes were less likely to include instances of a correct production. This finding is perhaps not surprising given the finding in the present study of a substantial relation between error variability and stimulability as measured across the entire phonological system, and the proposal that, like stimulability, the occurrence of a correct production of a sound reflects the correctness of UPRs in children with SSD. If error variability and the occurrence of a correct production both reflect aspects of UPRs, one would expect them to be related.

Dynamic Field Approach

Error variability and the status of UPRs may also be interpreted with regard to dynamic field approach, which was based on dynamic systems theory (Spencer & Schöner, 2003). How well UPRs are explained by this approach is in some ways a test of the applicability of dynamic systems theory to phonological development. Just as dynamic field approach attempts to account for the representational states underlying motor behaviors in infants, its three features may be invoked to account for phonological representations underlying speech sound production. In a broad sense, error variability may be a surface reflection of the representational states underlying speech sound production. More specifically, each feature of dynamic field approach has potential in linking error variability to UPRs in children with SSD.

According to the first feature of this approach, representational states underlying motor behaviors are characterized by graded certainty. Variable speech sound substitutes may be thought of as reflecting uncertainty in the production of a target sound, depending on the phonetic context. According to the second feature of dynamic field approach, representational states underlying motor behaviors may or may not be clearly defined. It is proposed that variable speech sound substitutes reflect poorly-defined, or indistinct, representational states underlying the attempted productions. That is, variability in the surface realizations of speech sounds may reflect lack of distinctness in how they are represented at an underlying level. According to the third feature of dynamic field approach, representational states underlying motor behaviors are not necessarily continuous in content. With regard to phonological development, UPRs may be less categorical when young speakers are in the process of acquiring a phonemic contrast (Tyler & Saxman, 1991). They may be more categorical, however, when speakers have acquired a phonemic contrast (Liker & Gibbon, 2008). The error variability seen in the children in the present study revealed varying degrees of knowledge of the categorical nature of the sounds they produced in error. Children with a consistent substitute across and within word positions are assumed to have knowledge that the phoneme is realized in much the same way in different words and phonetic contexts. Children with variable substitutes across word positions but consistent substitutes within each word position are assumed to have some categorical knowledge for the sound produced in error. Children with variable substitutes across and within word positions are assumed to have little or no categorical knowledge for the sound produced in error.

Dynamic field approach also has potential in linking stimulability to the status of UPRs in children with SSD. With regard to the first feature, stimulability may also be thought of as reflecting uncertainty in the production of a target sound depending on the elicitation task. A child may be uncertain as to how to produce the target sound when unassisted and so produces it in error spontaneously. When provided with a model production of the sound, however, the child may be more certain as to how to produce the sound and so produces it accurately in imitation. With regard to the second feature, it is proposed that low stimulability reflects a poorly-defined representational state underlying the attempted production. With regard to the third feature, stimulability also revealed varying degrees of categorical knowledge for sounds produced in error. Some children were stimulable for sounds produced in error in certain syllable positions, e.g., syllable-initial position. Other children showed no pattern to their stimulability for sounds produced in error.

Error Variability and Intra-Word Production Variability

The results of the present study revealed a negligible relation between error variability and intra-word production variability. This finding does not support the fourth hypothesis. Children who were variable at the phoneme level of speech production were not necessarily variable at the whole-word level, and vice versa. It is possible, therefore, that error variability and intra-word production variability reflect different things. It has been proposed that error variability reflects the distinctness of UPRs. Perhaps intra-word production variability reflects the distinctness of underlying lexical representations (ULRs). An ULR comprises the meaning and all the unpredictable and therefore learned phonological properties of a word (Dinnsen, 1984). Words are stored in long-term memory as ULRs (Gathercole & Baddeley, 1990). As the lexicon grows, ULRs are analyzed into their component UPRs (Sosa & Stoel-Gammon, 2006). In other words, the development of ULRs precedes that of UPRs. Variability in the development of ULRs, therefore, might be expected to precede variability in the development of UPRs.

Intra-word production variability, as measured using Dodd’s Inconsistency Assessment (Dodd, 1995), occurs only at a very young age in children with typical speech development (Holm et al., 2007). This assessment requires children to name 25 colored pictures on three separate occasions within a session. For the youngest group of participants in the Holm et al. study, aged 3;0-3;5, an average of only 13.0% of the 25 words were variable. Children aged 3;6-5;5, the same age as children in the current study, showed even less variability. Intra-word production variability was measured in children with SSD in the present study using PWV (Ingram, 2002). This is a ratio that was calculated by dividing the total number of different phonetic forms of all words attempted three or more times in a story retell by the total number of productions of these words. This measure, therefore, does not reflect the proportion of word types produced with variability. Rather, it reflects the proportion of total word productions that were variable. PWV ranged from .07 to .37 for the children in the present study. The different measures used and the different populations of children examined across these two studies make comparisons difficult. Given the low rates of intra-word production variability seen in older children with typical speech development (Holm et al., 2007) and the suggestion that UPRs develop from ULRs (Sosa & Stoel-Gammon, 2006), however, it is possible that variability in UPRs was more prominent than variability in ULRs for the children in the present study. This was perhaps why error variability and intra-word production variability were not related.

Future Research

The current study assessed error variability in children with SSD at one point in time. To date, no studies have examined the developmental trajectory of error variability in children with SSD. Children with SSD may show delayed but similar developmental trajectories of error variability in comparison to children with typical speech development. Alternatively, children with SSD may show patterns of development that differ considerably from those of children with typical development. This may be characteristic of children with persistent SSD. Longitudinal case studies are required to compare the developmental patterns of error variability in children with SSD and children with typical speech development.

Children are thought to possess separate but related perceptual and productive underlying representations for words and sounds (McGregor & Schwartz, 1992; Menn, 1992; Munson et al., 2005a). The present study inferred the nature of UPRs in children with SSD using only speech production tasks. Other researchers have used speech perception tasks (e.g., McGregor & Schwartz, 1992; Sutherland & Gillon, 2005). Children with SSD have shown inferior speech perception skills in comparison to children with typical speech development (Edwards et al., 2002; Munson et al., 2005a; Raaymakers & Crul, 1988; Rvachew et al., 2003; Sutherland & Gillon, 2005). Within the population of children with SSD, categorical perception tasks may be used to determine the distinctness of children's UPRs. Specifically, children with variable speech sound substitutes could be compared to children with consistent substitutes with regard to their categorical perception skills. Such studies must control for hearing status across groups as even mild hearing impairment may have a negative impact on the ability to form distinct perceptual UPRs. Error variability may reflect the distinctness of productive UPRs. Categorical perception skills may reflect the distinctness of perceptual UPRs. If this is the case, one might expect to find a relation between error variability and categorical perception skills.

Further research is required to clarify the effect of error variability on phonological change in children with SSD following treatment. Studies that examined phonological change for individual sounds found that those with consistent substitutes showed the greatest gains (Forrest et al., 1997; Forrest et al., 2000). Forrest et al. (2000), however, did not control for severity of SSD across the consistent substitute and variable substitute groups. Two groups of children selected for their extreme scores on a system-wide measure of error variability were found not to differ in several measures of phonological change during and after treatment (Tyler & Lewis, 2005; Tyler et al., 2006). As with the Forrest et al. (2000) study, the two groups of children in these studies differed with regard to their pre-treatment severity of SSD. Differing levels of severity of SSD may lead to differences in degrees of phonological change in children grouped according to their error variability, and is therefore a confounding variable in these studies. A regression analysis could be used to determine whether error variability is a unique predictor of phonological change over and above the effect of severity.

Little is known about effective treatment strategies for children with SSD and high error variability and whether these children are a unique group with high error variability being a unique intractable characteristic. With regard to Powell and Miccio’s (1996) framework and the proposed extensions (see Figure 1), intermediate stages of phonological development may be characterized by indistinct and partially correct UPRs. Later stages of development may be characterized by distinct and correct UPRs. Perhaps in children with variable substitutes, treatment should involve creating some stability in the phonological system, alongside stimulability training for sounds that are nonstimulable (Carter & Buck, 1958; Miccio et al., 1999; Rvachew et al., 1999, Study 2). Children must ultimately learn to use sounds categorically and this requires consistency across productions. As was noted by Forrest et al. (2000), treatment that involves contrasting a child’s error with the target sound is problematic for children with variable substitutes because they have multiple errors for the target. Forrest et al., therefore, used a traditional approach that targeted the error sound only and did not contrast it with substituted sounds. An approach that targets consistent production of a sound across word positions, in different vowel contexts, and in many different words needs to be evaluated for its efficacy in treating children with high error variability. Such an approach might serve to reinforce “the common features of the sound in different contexts and positions of a word” (Forrest et al., 1997, p. 65). Treatment may also involve perceptual training, if research suggested earlier points to indistinct perceptual UPRs for sounds with variable substitutes.

Finally, a single-subject design might be employed to examine the extent of phonological change following treatment for individual sounds produced in error. These sounds would be categorized according to the variability of their substitutes and whether or not they are stimulable. Multiple-baseline single-subject studies examining real-time phonological change are an appropriate next step in this line of research. Such studies may lead to more refined measures and may increase our knowledge of the relation between error variability and stimulability. It is unclear whether stimulability, i.e., a partially correct UPR, or consistency, i.e., a distinct UPR is more advantageous with regard to phonological change. Knowing this would assist in prioritizing treatment goals. Phonological change could be compared for stimulable sounds with variable substitutes and nonstimulable sounds with consistent substitutes. If both types of sounds were to receive similar types of treatment, and stimulable sounds with variable substitutes were to show the greatest gains, it might be inferred that stimulability, and therefore a partially correct UPR, is more advantageous than consistency, and a distinct UPR. Alternatively, if nonstimulable sounds with consistent substitutes were to show the greatest gains, consistency and a distinct UPR might be considered more advantageous.

Conclusions

The results of the present study revealed that error variability and stimulability were related in children with SSD such that children with the most consistent speech sound substitutes showed the highest levels of stimulability. These measures may both reflect aspects of UPRs in these children (Dinnsen & Elbert, 1984; Forrest et al., 1997; Forrest et al., 2000; Tyler & Lewis, 2005). Error variability and NWR performance were also related in children with SSD such that children with the most consistent substitutes showed the best NWR performance. Error variability, therefore, may reflect the distinctness of UPRs. Results also revealed a negligible relation between stimulability and NWR. It was proposed that stimulability does not reflect the distinctness but may instead reflect the correctness of UPRs. For a majority of individual sounds, the occurrence of a correct production for sounds produced in error was related to both stimulability and error variability. This suggests that the occurrence of a correct production also reflects the correctness of UPRs. The relation between two different measures of variability, error variability and intra-word production variability, was negligible in children with SSD. Intra-word production variability, therefore, may not reflect aspects of UPRs in these children. It may instead reflect aspects of underlying lexical representations.

Error variability may reflect the distinctness of UPRs in children with SSD. Further research is required to determine whether high error variability reflects a unique underlying deficit requiring a unique approach to treatment or is part of the developmental process. The developmental course of error variability requires examination. The relation between error variability and phonological change needs further investigation. If high error variability is shown to be a unique and intractable characteristic, research will need to determine the best intervention strategies for treating children with high error variability.

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Appendix A

Participant Recruitment Letter Approved by the University of Nevada, Reno Institutional Review Board

Protocol #: SA07/08-035

Invitation to Participate in a Research Study

You are being invited to allow your child to participate in a research study, entitled:

"The relationship between error consistency and stimulability in children with SSD"

This study is being conducted at the University of Nevada, Reno (UNR) Speech and Hearing Clinic as part of a doctoral dissertation.

The purpose of this study is to examine relations between several speech pronunciation measures in 3-6-year-old children with speech sound disorders (SSD). You are being asked to give permission for your child to participate because he/she has SSD and is aged between 3 and 6 years.

If you give permission for your child to participate, he/she will receive a comprehensive speech and language assessment. The assessment is not expected to take longer than one session lasting approximately 2 hours. Following the assessment, you will receive a comprehensive assessment report detailing your child's performance on each of the tests administered. Assessment data obtained for the purposes of this study will be added to your child's client file. If your child is recruited through the UNR Speech and Hearing Clinic, your child's clinician, the clinician's supervisor, and the Clinic Director will be permitted to view data obtained for the purposes of this study. If your child is recruited through the Washoe County School District (WCSD), a WCSD representative will be permitted to view data obtained for the purposes of this study.

If you give permission for your child to participate, or you would like more information about the study, please contact either the principle investigator, Dr Kerry Lewis, at 682-7016, or the student investigator, Toby Macrae, at 682-7026, within one week from receiving this letter.

01/08/2008

Appendix B

Permission Form Approved by the University of Nevada, Reno Institutional Review Board

UNIVERSITY OF NEVADA, RENO SOCIAL BEHAVIORAL INSTITUTIONAL REVIEW BOARD
PARENTAL PERMISSION TO PARTICIPATE IN A RESEARCH STUDY

TITLE OF STUDY: The relationship between error consistency and stimulability in children with SSD.
INVESTIGATOR(S): Kerry Lewis, Ph.D. (775-682-7016) and Toby Macrae, MSLT (775-682-7026)
PROTOCOL #: SA07/08-035

PURPOSE

You are being asked to allow your child to participate in a research study. The purpose of this study is to examine relations between several measures of speech pronunciation in children with speech sound disorders (SSD). The measures include: (a) error consistency – how consistent children are when they produce one sound instead of another; (b) stimulability – how well children can imitate sounds they've just produced incorrectly; and (c) whole-word production consistency – the number of different ways children produce entire words. First, the study will look at how well error consistency and stimulability are related. Second, the study will look at how well error consistency and whole-word production consistency are related.

PARTICIPANTS

You are being asked to allow your child to participate because he/she has been identified as having SSD. Your child is also in the target age range (3 years, 6 months to 5 years, 11 months). Participants will also need to show age-appropriate receptive vocabulary (understanding of single words), oral motor functioning, and hearing. If your child is shown to have persistent fluid or wax in his/her ear, he/she will not be able to participate in the study. The investigators are seeking 20 children to participate in the study.

PROCEDURES

If you agree to allow your child to participate in this research study, you will be asked to bring your child to the University of Nevada, Reno (UNR) Speech and Hearing Clinic for an assessment. It is expected that the assessment will take one session lasting approximately 1 hour 40 minutes to 2 hours. Your child's speech, understanding of single words, nonverbal intelligence (if required), use of muscles and structures of the mouth, hearing, made-up word repetition, stimulability, and language will be assessed. Testing will involve having your child speak sounds, words, or sentences, point to pictures, open his/her mouth so that the examiner can look inside, use muscles of the mouth and face, and indicate if he/she heard a sound. It will also involve your child allowing the examiner to check his/her ear using a small machine that produces sounds and takes pictures and assesses the eardrum's response to these sounds. If the picture of your child's ear reveals fluid or ear wax we will ask you to return in 2 weeks. If, after 2 weeks, your child still has fluid or ear wax, testing will stop and your child will no longer be able to participate in the study. If your child is recruited from the UNR Speech and Hearing Clinic, and any of these assessments were performed within one month before the current assessment, they will not need to be repeated. If this is the case, the results from those assessments will be used for this study. These results will be taken from the assessment forms in your child's file. All assessments will be performed for children recruited from the Washoe County School District (WCSD). Your child's assessment session will be videotaped and audiotaped so that assessment results that are not able to be obtained during the assessment can be obtained later. Assessment results obtained for this study will be added to your child's UNR Speech and Hearing Clinic or WCSD file. The combined results from all testing for all participants will be used to look at how well error consistency and stimulability are related and to look at how well error consistency and whole-word production consistency are related in children with SSD. This study is expected to take approximately one year to complete. Your child's participation is only expected to take approximately 1 hour 40 minutes to 2 hours.

DISCOMFORTS, INCONVENIENCES, AND/OR RISKS

Your child may become fatigued during the testing session. All efforts will be taken by the examiner to create a safe, comfortable, and friendly environment for you and your child. If, during the sessions, your child becomes too fatigued or noncompliant/nonresponsive for any reason, the session will be terminated and the examiner will make arrangements with you to continue testing at another time.

There are no known risks associated with participation in this study. However, there may be unknown or unforeseen risks associated with participation.

BENEFITS

You will receive a full assessment report detailing the results of your child's testing. There may be no other direct benefits to you if you allow your child to participate in this study. However, it is anticipated that this study will yield benefits to society and science in general. The results of the study are expected to enhance our understanding of the underlying processes involved in SSD in children.

CONFIDENTIALITY

Your child's identity will be protected to the extent allowed by law. Your child will not be personally identified in any reports or publications that may result from this study.

The Department of Health and Human Service (HHS), other federal agencies as necessary, and the University of Nevada, Reno Social Behavioral Institutional Review Board may inspect your study records.

Study records will be securely stored in a locked cabinet in the office of the principle investigator in the UNR Speech and Hearing Clinic for a period of five years. The investigators will be permitted to view data for all participants. If your child is recruited through the UNR Speech and Hearing Clinic, the Clinic Director, your child's student clinician, and the clinician's supervisor will also be permitted to view your child's data obtained for the purposes of this study. If your child is recruited through the WCSD, a WCSD representative will also be permitted to view your child's data obtained for the purposes of this study. All assessment data obtained for the purposes of this study will be added to your child's UNR Speech and Hearing Clinic or WCSD file.

Any further use of video and audio recordings will not occur unless written permission is obtained.

COSTS/COMPENSATION

There will be no cost to you or your child nor will you or your child be compensated for participating in this research study.

DISCLOSURE OF FINANCIAL INTERESTS

The investigators have no financial interests that will be affected by the proposed research.

RIGHT TO REFUSE OR WITHDRAW

You may refuse to allow your child to participate or withdraw your child from the study at any time and your child will still receive the care he/she would normally receive if he/she were not in the study. If the study design or use of the data is to be changed, you will be so informed and your permission re-obtained. You will be told of any significant new findings developed during the course of this study, which may relate to your willingness to allow your child to continue to participate.

If you withdraw your child from the study before all testing is completed, then you will receive an assessment report detailing the results of the testing that has been completed.

QUESTIONS

If you have questions about this study, please contact Kerry Lewis, Ph.D., at 775-682-7016, or Toby Macrae, MSLT, at 775-682-7026 at any time.

You may ask about your child's rights as a research subject or you may report (anonymously if you so choose) any comments, concern, or complaints to the University of Nevada, Reno Social Behavioral Institutional Review Board, telephone number (775) 327-2368, or by addressing a letter to the Chair of the Board, c/o UNR Office of Human Research Protection, 205 Ross Hall / 331, University of Nevada, Reno, Reno, Nevada, 89557.

CLOSING STATEMENT

I have read (   ) this permission form or have had it read to me (   ). [Check one.]

_________has explained the study to me and all of my questions have been answered. I have been told of the risks or discomforts and possible benefits of the study.

If my child does not take part in this study, my refusal to allow him/her to participate will involve no penalty or loss of rights to which my child is entitled. I may withdraw my child from this study at any time without penalty [or loss of other benefits to which my child is entitled].

I have been told my child's rights as a research subject, and I voluntarily give permission for my child to participate in this study. I have been told what the study is about and how and why it is being done. All my questions have been answered.

I will receive a signed and dated copy of this permission form.

____

Signature of Parent   Date

____

Signature of Person Obtaining Permission   Date

____

Signature of Investigator   Date

Appendix C

Story Script for Eliciting Retell for Calculation of Proportion of Whole-Word Variation

It was a beautiful morning. The sun was rising over the **hill**. There was **snow everywhere**. It was **cold**. There was a pretty **red house** on the **hill**. The **old lady** was lying in **bed**. There was a **cat asleep** on the **bed**. A **dog** had **woken** up on the **floor**. The **old lady** had **woken** up too. The **old lady**, whose name was **Gabriella**, got out of **bed**. She went into the **kitchen**. The **cat** and **dog** went into the **kitchen** too. They were still **tired**. **Gabriella thought** that she would like to make **pancakes** for breakfast. The **cat** and **dog** were **happy**. **Gabriella** couldn't stop **thinking** about **pancakes**. She got the **book** from the shelf with the **recipe** in it. **Gabriella opened** the **book** and found the **recipe** for **pancakes**. She looked at the **ingredients**. **Gabriella** put a **big yellow bowl** on the **table**. She picked up the bag of **flour** from the **table**. **Gabriella poured** the **flour** into the **big yellow bowl**.
BREAK
Then, she went to find some **eggs**. She **opened** the cupboard. "**Oh no**", she said. She didn't have any **eggs** left. **Gabriella** had to get some **more eggs** for the **pancakes**. She **walked outside** to the **red shed**, where the **chickens** were. She **dressed** up **warm**. She had a coat on. She took a **basket** for the **eggs**. There was **snow everywhere**. **Gabriella** went **inside** the **red shed**. She got some **eggs** out of the **nests**. The **chickens** had laid **eggs** in the **nests**. The **dog** was **watching** from o**utside**. The **chickens** were **watching** from their **nests**. Gabriella's **basket** was **full** of **eggs**.
BREAK
Gabriella walked back **inside** to cook her **pancakes**. "**Oh no**", she said. There's no **milk**! The **jug** was **empty**. The **dog** was **licking** his **lips**. Maybe he drank all the **milk**. **Gabriella** was not very **happy**. She had to get some **more milk** for the **pancakes**. She **dressed** up **warm** and went **outside** again. She took a **bucket** and a **stool**. She **walked** out the **door**. **Gabriella** and the **cat** went **outside** into the **cold**. This time, they went to see the **cow**. They could get some **milk** from the **cow**. **Gabriella sat** on the **stool** and milked the **cow**. She put the **milk** in the **bucket**. The **cat sat** and watched. The **cow** was **happy**. She was **eating** straw. **Gabriella** and the **cat** returned to the **house**. Their **bucket** was **full** of **milk**. They went **inside** and **poured** the **milk** into the **jug**. The **cat** was **licking** her **lips**.
BREAK
Next, **Gabriella** made some **butter**. She used the spoon to put some **milk** in the **big yellow bowl**. The cat was **watching** from under the **table**. **Gabriella poured** the **milk** into a **barrel**. She **stirred** and **stirred** the **milk**. She was getting **tired**. She had **stirred** for a long time. **Gabriella** was not very **happy**. She finally finished making the **butter**. She took the **butter** from the **barrel**, and put it in a **bowl**. She took the **red bowl** and carried it back to the **kitchen**.
BREAK
"**Oh no**", said **Gabriella**. There's no **syrup**. The **jar** was **empty**. **Gabriella** had to get some **more syrup** for the **pancakes**. She went back **outside** into the **cold**. There was so much **snow**. But she **dressed** up **warm**. **Gabriella walked** next **door** to see her **neighbor**. She bought some **syrup** from him. Her **jar** was **full** of **syrup**. **Gabriella walked** back **home**, **thinking** of her **pancakes**. She **thought** about the **eggs**. She **imagined** stirring the mixture in the **big yellow bowl**. She **imagined** cooking the **pancakes** over the **fire**. She **dreamed** about

flipping the **pancakes** with a spatula. And she **dreamed** about **eating** the **pancakes**, with lots of **butter** and **syrup**.

BREAK

"**Oh no**", she shouted as she **walked** in the **door**. "What happened to the **ingredients**?" She dropped the **jar** of **syrup**. The **dog** was on the **floor eating** the **eggs**. The **cat** was on the **table** drinking the **milk**. **Gabriella** was very sad. Then, a **smell** came in through the **door** and into the **house**. **Gabriella** followed the **smell outside**. She **walked** next **door** to the neighbor's **house**.

Her **neighbor opened** the **door**. "**Hello**", said **Gabriella**. "**Hello**", said the man. "I can **smell pancakes**", said **Gabriella**. Before her **neighbor** knew, she **sat** at the **table**. She was **happy** that she would be **eating** some **pancakes** after all. **Gabriella** went **home**. She **sat** in front of the **warm fire** and **fell asleep**. The **dog** and **cat fell asleep** too.

- Bold = words repeated in script

<u>Words repeated in script</u>

Asleep	Floor	Old
Barrel	Flour	Opened
Basket	Full	Outside
Bed	Gabriella	Pancakes
Big	Happy	Poured
Book	Hello	Recipe
Bowl	Hill	Red
Bucket	Home	Sat
Butter	House	Shed
Cat	Imagined	Smell
Chickens	Ingredients	Snow
Cold	Inside	Stirred
Cow	Jar	Stool
Dog	Jug	Syrup
Door	Kitchen	Table
Dreamed	Lady	Thinking
Dressed	Licking	Thought
Eating	Lips	Tired
Eggs	Milk	Walked
Empty	More	Warm
Everywhere	Neighbor	Watching
Fell	Nests	Woken
Fire	Oh no	Yellow