VERBAL AND NONVERBAL SEQUENCING IN CHILDREN WITH
SPECIFIC LANGUAGE IMPAIRMENT

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This thesis is dedicated to the members of Impact Young Adults for believing that we have the power not only to survive life's challenges but to reach beyond them and thrive and to my parents whose love and support made it all possible.
ABSTRACT OF THE THESIS

Verbal and Nonverbal Sequencing in Children with Specific Language Impairment
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Specific Language Impairment (SLI) is a neurodevelopmental disorder which interferes with language expression and processing, but children with SLI show no obvious physical or neurological basis for such deficits. Numerous hypotheses have been proposed to explain its origins. One recent approach proposes that individuals with SLI have a deficit to procedural learning. Ullman's Procedural Deficit Hypothesis (PDH) is based on anatomical differences between individuals with SLI and typically developing controls in the subcortical-cortical circuit underlying procedural learning and memory. The PDH predicts that individuals with SLI will have difficulty with any task recruiting this circuit. Previous studies have focused on difficulties that children with SLI have with learning target sequences. Based on this hypothesis and on the functions associated with the procedural learning circuit, children with SLI can be expected to also have difficulty generating new sequences. This study compares the sequence production abilities of 6-7 year olds with SLI to that of age-matched typically developing (TD) peers. Three tasks are used (picture arrangement, scripts, and biographic interviews) to explore how event sequencing, syllable sequences, and intonation may be impacted in SLI. Overall, children with SLI perform more poorly than TD children on all three tasks. They are less able to generate sequences of events, both nonverbally and verbally. They speak in shorter segments and at a slower rate in the biographic interviews. Finally, they do not use intonation comparably to TD children when communicating the end of a turn. The procedural deficit hypothesis may be able to account for the event and syllable sequencing results of this study, but cannot fully explain the intonation results. Further research is recommended to explore the relationships between sequence learning and sequence production and between verbal and nonverbal domains.
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CHAPTER 1

INTRODUCTION

Specific Language Impairment (SLI) is a neurodevelopmental disorder in which individuals have difficulty with spoken language without any obvious cause. Numerous hypotheses have been put forward which attempt to explain its origins. The procedural deficit hypothesis (PDH, Ullman & Pierpont, 2005) is based on anatomical differences between individuals with SLI and typically developing controls in the brain circuit which underlies procedural learning and memory. The PDH proposes that individuals with SLI will have difficulty with any task which uses this circuit. Previous studies have focused on difficulties that children with SLI have with learning target sequences, such as the locations of a series of images. Based on this hypothesis and on the deficits associated with the procedural learning circuit, the current study explores whether children with SLI also have difficulty generating new sequences, both verbally and nonverbally, in tasks which involve sequencing of events, syllables, and intonation.

SLI is a disorder in which children have difficulties learning and using language but do not have physical, developmental, or neurological abnormalities. To be diagnosed with SLI, a child must have language test scores of at least 1.25 SDs below the mean, for example on the CELF (Semel, Wiig, & Secord, 1987) and a nonverbal IQ greater than or equal to 85 (L. Leonard, 1998). There is some variability between studies in the chosen criteria, however; this study uses previously collected data from a project which set criteria of (a) language test scores 1.5 SDs below the mean on standardized language tests and (b) a nonverbal IQ greater than or equal to 80. The child must also have normal hearing, oral structures, and oral motor function. They cannot have had recent episodes of otitis media with effusion or any neurological dysfunction (e.g., seizure disorders, cerebral palsy, or brain lesions). And they must have normal physical and social interactions and cannot be diagnosable with autism spectrum disorders or pervasive developmental delay (L. Leonard, 1998).
Tomblin et al. (1997) performed the most thorough study of the prevalence of SLI and found that 7.4% of all 5 year olds meet the criteria for this diagnosis. It is more prevalent in males than females. Across studies, the male to female ratio is approximately 2.8:1 (Robinson, 1987). It occurs across countries and ethnicities. There is a high co-morbidity with dyslexia, ADHD, and other learning disabilities (Flax et al., 2003; L. Leonard, 1998; Willinger et al., 2003).

Children with SLI frequently have difficulty with both expressive and receptive language tasks. They are slow to learn to talk (Trauner, Wulfeck, Tallal, & Hesselink, 2000) and typically remain at least 1-2 grade levels behind their chronological peers at language tasks. They speak more slowly (Smith, Hall, Tan, & Farrell, 2011) and use shorter utterances than their peers (Redmond, 2004). And they have particular difficulty with grammatical tasks such as inflections and phonological tasks such as nonword repetition (Estes, Evans, & Else-Quest, 2007; L. Leonard, 1998). They also have non-linguistic impairments to domains such as motor skills (Powell & Bishop, 1992; Trauner et al., 2000), dynamic mental imagery (Johnston & Weismer, 1983; Savich, 1984), working memory (Archibald & Gathercole, 2006), and rapid temporal processing (Tallal & Piercy, 1975).

Of the children diagnosed with SLI as preschoolers, between 40% and 60% will show normal language abilities by age 5 or 6. However, if SLI is still present at age 5, it is frequently a lifelong condition. In a longitudinal study of individuals with speech and language impairments, 73% of the individuals with SLI at age 5 continued to have language impairment at age 19 (Bishop & Edmundson, 1987; Johnson et al., 1999).

There are numerous hypotheses about the underlying causes of SLI. It was originally thought to be specific to the domain of language (Gopnik & Crago, 1991; Rice, Wexler, & Cleave, 1995). However, nonlinguistic impairments have forced researchers to consider broader explanations. SLI could be the result of a general processing deficit such as limits to processing speed (L. Leonard et al., 2007), working memory (Archibald & Gathercole, 2006), or executive function (Finneran, Francis, & Leonard, 2009; Henry, Messer, & Nash, 2012; Hughes, Turkstra, & Wulfeck, 2009). A general processing deficit could explain the non-linguistic deficits found in individuals with SLI but cannot account for their uneven profile of preserved and impaired abilities (Conti-Ramsden & Windfuhr, 2002; Kamhi & Koenig, 1985). Alternatively, SLI has been explained as a processing deficit specific to rapid
auditory stimuli (Benasich, Thomas, Choudhury, & Leppänen, 2002; Corriveau, Pasquini, & Goswami, 2007; Gaab, Gabrieli, Deutsch, Tallal, & Temple, 2007; Tallal & Piercy, 1975). Finally, advances in imaging technology have shown that the leftward asymmetry in several language-processing regions of the brain in typical adults is often not found in individuals with SLI (De Fosse et al., 2004; Gauger, Lombardino, & Leonard, 1997; Plante, Swisher, Vance, & Rapcsak, 1991), and this difference has been associated with differences in language ability (C. Leonard et al., 2002; C. Leonard, Eckert, Given, Virginia, & Eden, 2006). Such findings suggest atypical brain development early on.

One promising new approach to explaining SLI proposes that it is caused by deficits to implicit learning and memory. Although no precise definition of implicit learning has been agreed upon by all researchers, it has frequently been described as unconscious, unintentional, and incremental, and is evaluated through behavioral response tasks (Butler & Berry, 2001; Evans, Saffran, & Robe-Torres, 2009; Schacter, 1987). Implicit learning is contrasted with explicit learning which is thought to be conscious, intentional, and based on hypothesis-testing; it can be evaluated through recall or recognition tasks. Two complementary hypotheses have emerged from this approach: (1) the procedural deficit hypothesis (PDH, Ullman & Pierpont, 2005) which is based on anatomical differences between individuals with SLI and typically developing controls in the brain circuit which underlies procedural learning and memory. The PDH proposes that individuals with SLI will have difficulty with any task which uses this circuit; and (2) the statistical learning hypothesis that proposes that individuals with SLI have difficulty with learning patterns based on their occurrence in the environment (Evans et al., 2009; Tomblin, Mainela-Arnold, & Zhang, 2007). This study focuses on the procedural deficit hypothesis.

**Procedural Deficit Hypothesis**

The procedural deficit hypothesis (PDH, Ullman & Pierpont, 2005) suggests that people with SLI have difficulty with procedural learning and memory. Similar to the imaging studies mentioned above, it provides a biological explanation for behavioral characteristics observed in children with SLI explaining both their verbal and nonverbal difficulties. Further, enough is known from other lines of research about the structures implicated by this hypothesis to enable one to make predictions about domains which have
not been well explored in SLI. Thus, the current study focuses on the domain of sequence production in both verbal and nonverbal contexts.

The procedural deficit hypothesis is based on two assumptions: memory can be divided into two systems, explicit and implicit (Schacter, 1987), and the two systems have distinct but complementary roles in the production of language. The explicit or declarative memory system holds factual (semantic) and event (episodic) knowledge. In the domain of language, Ullman (2001) hypothesizes that it is the home of the mental lexicon. The explicit memory system is associated with the ventral stream and the medial temporal lobe (Hickok & Poeppel, 2004).

The implicit, procedural memory system enables an individual to learn and reproduce cognitive and motor sequences such as grammar, sounds, and physical skills. It is managed by a series of parallel cortical-subcortical circuits (Alexander & Crutcher, 1990; Lichter & Cummings, 2000). These circuits allow information to travel from key areas in the frontal cortex to the basal ganglia to the thalamus and back to the originating frontal cortex region. Each circuit is responsible for a different process, including motor control, personality/emotion, and executive function; the process of an individual circuit depends on the originating frontal lobe structure. Each circuit involves a unique portion of the same brain structures, suggesting that similar operations are applied in all cases.

The procedural deficit hypothesis (PDH) suggests that people with SLI have impairments in the structures of the procedural memory system. Key structures in this system which are thought to impact individuals with SLI include Broca’s area, the caudate nucleus of the basal ganglia, the premotor cortex, the supplementary motor area, and the cerebellum (Jernigan, Hesselink, Sowell, & Tallal, 1991; Ullman & Pierpont, 2005; Watkins et al., 2002). The PDH predicts that the most commonly impaired structures should be similar between all individuals with this diagnosis. These similarities would cause this population to consistently have difficulty with specific language tasks involving grammar but not vocabulary, some motor tasks, tasks involving rapid sequencing, and a variety of other tasks governed by procedural memory. However, not all individuals with SLI are assumed to have abnormalities in precisely the same areas of the brain. This would lead to variability within the SLI population; individual performance could be expected to vary based on where the abnormalities are found (Ullman & Pierpont, 2005).
Because the procedural memory system has been well studied, it is possible to make numerous testable predictions about people with SLI. Some of the predictions made by the PDH are specific to language use and understanding; they are implied by the hypothesized discrepancy between an impaired procedural/grammatical system and relatively spared lexical system. For example, people with SLI are particularly poor with grammatical tasks such as word order, use of inflectional morphemes, and judging syntactic acceptability (Hansson, Nettelbladt, & Leonard, 2000; Kamhi & Koenig, 1985; L. Leonard, Wong, Deevy, Stokes, & Fletcher, 2006; Wulfeck, Bates, Krupa-Kwiatkowski, & Saltzman, 2004). They also have significant difficulty with phonological sequencing tasks such as nonword repetition, but they do not have difficulty repeating words that they know (Estes et al., 2007).

They are less impaired at lexical tasks such as word recognition and comprehension when they are performed with sufficient frequency or contextual support (Mainela-Arnold, Evans, & Coady, 2010); they have more difficulty using verbs than nouns (Conti-Ramsden & Windfuhr, 2002); and they are better at judging the acceptability of semantics than syntax (Kamhi & Koenig, 1985).

Other predictions of the PDH are nonlinguistic. There are four common nonlinguistic categories of impairment commonly found in those with SLI that can be predicted by the PDH: motor skills, dynamic mental imagery, working memory, and rapid temporal processing. Motor skills which are typically impaired are those involving sequencing, speed, timing, and balance (Bishop, 2002; Powell & Bishop, 1992; Webster et al., 2006). For example, rapid oral movements (Tallal, Stark, & Mellitis, 1985) and complex sequencing tasks such as bead stringing or peg moving are slower and often less accurate in people with SLI than in control groups (Bishop, 2002; Powell & Bishop, 1992). Dynamic imagery tasks include mental rotation of images (Johnston & Weismer, 1983) and anticipation of movement along a path (Savich, 1984). These abilities are impaired; in contrast, tasks involving static figures and no mental manipulation are spared. Individuals with SLI also have difficulty with working memory tasks involving serial ordering and nonword repetition (Archibald & Gathercole, 2006; Baird, Dworzynski, Slonims, & Simonoff, 2010; Estes et al., 2007; L. Leonard, 1998). Finally, they have difficulty with processing stimuli which are presented rapidly or have short duration (Tallal & Piercy, 1975). The specificity of their difficulties in these areas is consistent with the PDH.
SEQUENCING

Learning and producing sequential information and behaviors are processes which recruit the procedural system. Previous studies have found that children with SLI have difficulty with sequence-learning tasks. The structures involved in the procedural system which are implicated in SLI also have been found to play a direct role in sequence production. This study explores whether children with SLI have difficulty with generating new sequences, both verbally and nonverbally.

Sequence Learning

The procedural deficit hypothesis has been tested directly by using sequence-learning tasks such as serial reaction time (SRT) tasks. In most studies, individuals with SLI have been found to have deficits in procedural learning (Kemény & Lukács, 2010; Lum, Gelgic, & Conti-Ramsden, 2010; Tomblin et al., 2007). In others, there were no differences between the typically developing and SLI groups (Gabriel, Maillart, Guillaume, Stefaniak, & Meulemans, 2011; Hedenius et al., 2011). However, when the groups were split based on grammar ability, children with grammar deficits were slower to learn sequences than those with normal grammatical ability (Hedenius et al., 2011; Tomblin et al., 2007). This difference was not seen when the groups were compared based on vocabulary (Tomblin et al., 2007). The putative dissociation between grammar and vocabulary provides further evidence for a link between procedural learning and grammatical ability.

The PDH continues to be refined as more is learned about where in the learning process the deficits occur. For example, Hedenius et al. (2011) found that the differences in the sequence-learning process are specific to the process of consolidation – the stabilization, enhancement, and integration of memories. Children with grammar deficits did not show any improvement between their initial SRT testing and a second SRT session three days later. Children without grammar deficits showed improvements both during the first day of testing and between the final round of tests on the first day and the session three days later.

Sequence Production: Anatomical Bases

Sequence production tasks are not generally used to evaluate Ullman's PDH. However, under the PDH, deficits should also be seen in any task which requires the use of procedural circuits in the brain, particularly the ones in which abnormalities have been found.
The basal ganglia (caudate head) and Broca’s area are two of the areas which have been implicated in SLI (Jernigan et al., 1991; Watkins et al., 2002). The current study addresses generating sequences of events and speech behaviors, both of which have been specifically associated with the head of the caudate nucleus and with Broca’s area (Allain et al., 2011; Carota & Sirigu, 2008; Gelfand & Bookheimer, 2003). Further, differences in activity in these areas have been directly linked to sequencing requirements and not just to working memory or cognitive load (Gelfand & Bookheimer, 2003; Grewe et al., 2005).

Schank and Abelson (1977) proposed that people represent frequently experienced events in the form of scripts -- stereotyped sequences of actions that occur in well-known situations. Neuroimaging studies suggest that script-based knowledge has both semantic (object and event knowledge) and procedural components (sequencing of actions and events) (Allain et al., 2011; Gallo, 2006). Sequencing deficits are associated with both frontal lobe (generally, prefrontal cortex and inferior frontal gyrus) and basal ganglia activity (Allain et al., 2011; Carota & Sirigu, 2008; Gallo, 2006; Tinaz, Schendan, Schon, & Stern, 2006). For example, Tinaz et al. (2006) found greater activity in the basal ganglia and dorsolateral prefrontal cortex during a task which required the participants to place pictures in the correct temporal sequence than during a similar task which did not involve sequencing. Though the precise nature of frontal versus subcortical involvement remains unclear, both appear to play a role in event sequencing.

Broca’s area has also been found to play a role in the sequencing of syllables and phonemes (Bohland & Guenther, 2006). This role can also be differentiated from working memory and rapid acoustic processing (Gelfand & Bookheimer, 2003). Gelfand and Bookheimer (2003) looked at the activity of the pars opercularis during sequencing of syllables and hummed notes. They found that it was more active during a reordering task (change the order of 3 items) and a deletion task (omit a specific item) than in a matching task (identify whether the sequence of tones or syllables matches the original). The sequences in all three conditions were the same length, so the differences in activity level cannot be explained solely by working memory. Further, there was an equivalent amount of activation of Broca’s area in both the linguistic and nonlinguistic tasks.

Finally, evidence for the role of basal ganglia circuits in speech motor planning, can be found in the symptoms of Parkinson’s disease (Skodda, Rinsche, & Schlegel, 2009).
Parkinson’s disease is caused by dysregulation of dopamine in the basal ganglia. In Parkinson’s disease, Skodda et al. (2009) found a gradual decrease in speech rate as the disease progressed.

Anatomical differences have been found in children with SLI in the areas which are activated during specific sequence generation tasks in typical adults. This study investigates whether children with SLI have difficulty with similar sequence generation tasks, including generating sequences of events, producing syllable sequences, or speaking at the same rate as typically developing peers.

**Intonation**

The autosegmental-metrical (AM) approach to intonation, first described by Pierrehumbert in 1980, is now one of the most common ways of describing the production and perception of intonation. It describes the intonational contour of a phrase as a series of high and low landmarks which occur on stressed syllables or at the ends of phrases. The contour in between these points can be interpolated based on the exact frequencies of the high and low tones (Pierrehumbert, 1980).

The landmarks can be categorized into pitch accents (stressed syllables) and edge tones (phrase accents and boundary tones). A pitch accent can be a high tone (H*), a low tone (L*), or a combination of both a high and a low (eg: L+H*). An edge tone at the end of an intermediate phrase is called a phrase accent and, in English, is a single high (H-) or low (L-) tone. An edge tone at the end of an intonational phrase is composed of a phrase accent (H- or L-) and a boundary tone (H% or L%), each of which could be either a high or a low tone (Pierrehumbert, 1980).

Adults use intonational boundaries to communicate multiple functions such as whether the utterance is a statement or a question, their degree of certainty about what they said, and whether or not they are done speaking. Wennerstrom and Siegel (2003) studied the odds of turns shifting in a conversation between speakers of American English following specific events in conversation: boundary intonation, pausing, and syntactic completion. They found that at times when an utterance was syntactically complete, the turn was most likely to shift if the speaker concluded with a H-H% (high rising) or L-L% (falling) boundary
sequence. It was much less likely to shift following H-L\% (level or slightly falling) and L-H\% (low rising) boundaries.

The functional neuroanatomy of the sequencing of tones into intonational contours has not been well studied. However, MacPherson, Huber, and Snow (2011) found that patients with Parkinson's disease do not use boundary intonation in the same way as healthy controls. Specifically, they used more falling intonation than controls at the ends of non-final phrases of a read passage and more level intonation at the final boundary.

Based on the autosegmental-metrical theory that tones occur in sequences, the pattern of anatomical abnormalities in children with SLI, and the findings that patients with a basal ganglia disorder use intonation differently than healthy adults, it is possible that children with SLI have difficulty producing tonal sequences correctly or using them to accurately communicate their intentions. This investigation focuses on the use of boundary intonation and its function in signaling turn-taking intentions.

**THE CURRENT STUDY**

The current study uses archival data to explore the extent to which sequencing is impacted in children with SLI in both linguistic and non-linguistic domains. Specifically, we investigate the sequencing of events into scripts, syllables into sentences, and tones into intonational contours. Based on the functions of the brain regions implicated by the PDH, and those found to be atypical in SLI, children with SLI are expected to have more difficulty with these sequencing tasks. Specifically, they are expected to produce shorter sequences at slower speeds and with more sequencing mistakes than their typically developing peers.

**Nonverbal Sequencing of Events**

The ability to organize events into the correct temporal order can be assessed both verbally and nonverbally. Because children with SLI have more difficulty with language tasks, this ability was assessed first through a nonverbal picture sequencing task, the picture arrangement subtest from the WISC-R and WISC-III (Wechsler, 1991). Nonverbal IQ must be within normal limits in order to diagnose a child with SLI. However, if they have difficulty with sequencing, this subtest may be a weakness in children with SLI relative to typically developing children.
Verbal Sequencing of Events

Scripts, the internal representations of a series of actions which occur in well-known situations, have been used as a means for exploring the mental representations that people have for events. Nelson (1986) extended Schank and Abelson's (1977) concept of a script to the context of child development, proposing that this internal representation of events develops with age and experience and that variability in internal representations of events can explain the variability in children's performances across different contexts. Children's ability to demonstrate script-based knowledge nonverbally and verbally emerges at about 3:6 and improves with age; specifically, scripts become longer, and children are able to identify more complex relationships between events (Gruendel, 1980; Nelson and Gruendel, 1986).

Few studies have been done on the scripts of children with SLI, and those have mixed results. Visconti (1999) found that 4 year olds with SLI performed comparably to mental age and language-matched peers on script length and correct temporal sequencing in script production tasks such as describing a bath time routine. In contrast, Hayward, Gillam, and Lien (2007) found that 7 year old children with SLI named fewer events and made sequencing errors when retelling a script-based restaurant story. These findings are consistent with those on narrative production. For example, Miranda, McCabe, and Bliss (1998), found that the narratives of children with SLI (ages 8-9) were more likely to include disordered discourse segments, add off-topic information, and refer implicitly to information which had not been expressed explicitly in the discourse.

The present analyses explore whether six year old children with SLI have difficulty producing verbal scripts about what to do at McDonalds. The procedural deficit hypothesis suggests that they should have more difficulty with this task, resulting in fewer events named and mistakes in sequencing the events in the correct temporal order.

Syllable Sequences

There is some evidence that children with SLI also have difficulties with assembling syllables into words and sentences, resulting in a slower rate of speech (Redmond, 2004; Smith et al., 2011). Rate of speech is evaluated in two ways: speech rate and articulation rate (typically in syllables or phones per second). Speech rate includes pauses and, typically, disfluencies in a person’s speech. Pauses may be present for linguistic reasons such as
between phrases or for cognitive reasons such as searching for the right word or planning what to say next (Levelt, 1989). Speech rate therefore captures all three facets of speech production described by Levelt (1989), including conceptualizing an idea, translating it into linguistic code, and then planning and executing the corresponding articulatory movements. Articulation rate excludes pauses and uses only fluent segments of speech (Logan, Byrd, Mazzocchi, & Gillam, 2011); it is therefore considered a measure of speech motor speed (Smith et al., 2011).

Flipsen (2002) analyzed six studies of articulation rate in typically developing children (mostly ages 3-5 years). Four found increases in articulation rate with age (Amster, 1984; Haselager, Slis, & Rietveld, 1991; Kowal, O’Connell, & Sabin, 1975; Walker, Archibald, Cherniak, & Fish, 1992). Despite differences in sample sizes, type of speech, definitions of speech fluency, and data analysis techniques, overlapping confidence intervals for articulation rate were found within each age group through all of these studies. However, most speech rate studies have been done with preschool children; there is relatively little reference data on the speech and articulation rates of typical school-age children in different contexts (Kowal et al., 1975; Haselager et al., 1991; Sturm & Seery, 2007). According to three studies, the mean articulation rate in conversational speech for 5-6 year old children is between 3.34 and 4.01 syllables/second (Amster, 1984; Hall, Amir, & Yairi, 1999; Haselager et al., 1991). In 7-8 year olds, one study found the mean articulation rate in conversational speech to be 4.51 syllables/second (Haselager et al., 1991); a second study found the mean articulation rate in narratives to be 4.45 syllables/second (Sturm & Seery, 2007).

Several studies have directly investigated speech and/or articulation rate in children with SLI. Tomblin et al. (1992) found that the speaking rates of young adults with a history of SLI were slower than those of children without a history of language impairment. Smith and colleagues (2011) studied preschool children with SLI and found differences in articulation rate but not speech rate between those with SLI and MLU-matched typically developing peers. Redmond (2004) found that six year olds with SLI spoke fewer words per minute than age-matched peers.

Based on these results and the predictions of the PDH, children with SLI are expected to have a slower articulation rate and possibly a slower speech rate than age-matched typically developing peers. They are also expected to speak in shorter phrases.
Further, typically developing children tend to speak faster during longer utterances (Haselager et al., 1991); children with SLI are not expected to show this pattern.

**Intonation**

Typically developing children gradually develop the ability to use intonation in a linguistic context. The falling contour (H* L-L%) is acquired first over the course of the single-word period of development (by 24 months). The rising contour (L* H-H%) continues to develop in range and breadth through the preschool years. With longer utterances, children begin to incorporate more complex combinations of high and low tones (Snow & Balog, 2002).

Development of the ability to use tonal sequences in elicited speech continues through middle childhood (Wells, Peppé, & Goulandris, 2004). Patel and Grigos (2006) compared how children (ages 4, 7, and 11) and adults contrast simple yes-no questions and statements. Adults and eleven year olds primarily used pitch to indicate that they were asking a question (where intonation of a question is described as a rise in pitch and that of a statement as a fall or constant pitch). Four year olds primarily used the duration of the final syllable to differentiate between questions and statements (with longer durations found in questions). Seven year olds used pitch, duration, and intensity.

Wells and Peppé (2003) explored the differences between 8 year old children with SLI and language and age-matched controls in their use of intonation at the ends of utterances. They divided intonation of single syllable utterances into four categories (AM equivalents added): high onset followed by a rise (H*H%); low onset followed by a rise (L*H%); high onset followed by a fall (H*L%); and low onset followed by a fall (L*L%). They then looked at four aspects of the children’s abilities: (1) differentiation between tonal patterns based on onset and direction; (2) determination whether a given intonation implies affirmation (L* L%) or a question (H*H%) and therefore whether the tester wants the child to go on to the next item or repeat the current item; (3) imitation of monosyllabic patterns in each of the four categories; and (4) repetition of monosyllabic words, modifying the intonation to sound as if they are checking versus confirming understanding.

They found that the children with SLI were able to perform at the same level as language-matched controls on all of the tasks. However, when compared to chronological
age-matched peers, they performed more poorly on all but the first of the four tasks. Further, on a test with 16 tasks, the SLI group consistently performed the poorest on the tasks with a pragmatic component (such as the second and fourth tasks listed above).

Little is known about typically developing children’s use of intonation in conversational speech to signal whether or not they have finished speaking. Less is known about this pragmatic use of intonation by children with SLI.

Based on the performance of typically developing children relative to those with SLI on other tasks, typically developing children are predicted to be better than children with SLI at using intonation to communicate whether or not they have more to say. When telling a story, typical children are expected to primarily use level intonation within the story and to use falling intonation at the end of their final phrase.

Based on the procedural deficit hypothesis and the autosegmental-metrical theory of intonation, children with SLI may neglect to use the sequencing of tones to communicate turn-taking intentions at the ends of longer phrases or during longer stories where they have had to struggle more with other sequencing requirements. If so, then children with SLI should look similar to their TD peers during shorter stories but differ from them during longer ones.

**SUMMARY OF HYPOTHESES**

The current project explores the role of sequencing in the speech of six year olds with SLI compared to age-matched typically developing (TD) peers in three contexts: nonverbal picture arrangement, scripts, and naturalistic conversation. In general, children with SLI are expected to perform more poorly than TD children at all sequencing tasks. Further, the greater the sequencing requirements, the poorer children with SLI will perform relative to TD peers.

1. *Nonverbal event sequencing*: Children with SLI will have more difficulty putting a series of pictures in order than their typically developing peers.

2. *Verbal event sequencing*: Children with SLI will have more difficulty naming a series of events in the correct temporal order.

3. *Syllable sequences*: Children with SLI will speak more slowly and in shorter segments than TD children. They will show less of an increase in rate of speech than TD children during longer phrases.
4. *Sequencing of tones in intonation:* Children with SLI will be less effective at using intonation to communicate turn-taking intentions than typically developing peers. They will not alter their intonation use based on whether they have more to say.
CHAPTER 2

METHOD

This chapter discusses the method used in this project, including the participants, tasks, and procedures.

PARTICIPANTS

The participants included 34 six and seven year old children, 17 typically developing (TD) and 17 with Specific Language Impairment (SLI). All of the children had participated in the Project on Cognitive and Neural Development (PCND) in San Diego, California between 1995 and 2005. The typically developing children all had IQs within the normal range (>85) and had no history of developmental delay. The SLI group was recruited from area schools and clinics and had a documented language impairment. Prior to inclusion in the present analysis, the data were screened to ensure that they met the following selection criteria: (1) performance IQ (PIQ) of 80 or higher on the WISC-R, WPPSI or Leiter non-verbal measures; (2) no major neurological abnormalities (determined by a neurological examination); (3) expressive language composite score 1.5 or more standard deviations below the mean for expressive language on the CELF-R (Semel et al., 1987); and (4) absence of known developmental disorders such as mental retardation or autism. Available test scores for the selected sample are shown in Table 1.

Table 1. Participant Ages, IQs, and CELF Scores

<table>
<thead>
<tr>
<th></th>
<th>TD</th>
<th>SLI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (months)</td>
<td>M 79.06</td>
<td>M 79.24</td>
</tr>
<tr>
<td></td>
<td>n 17</td>
<td>n 17</td>
</tr>
<tr>
<td>IQ</td>
<td>M 119.82</td>
<td>M 95.76</td>
</tr>
<tr>
<td></td>
<td>n 17</td>
<td>n 17</td>
</tr>
<tr>
<td>- Verbal</td>
<td>M 120.50</td>
<td>M 85.19</td>
</tr>
<tr>
<td></td>
<td>n 16</td>
<td>n 16</td>
</tr>
<tr>
<td>- Performance</td>
<td>M 114.88</td>
<td>M 102.82</td>
</tr>
<tr>
<td></td>
<td>n 17</td>
<td>n 17</td>
</tr>
<tr>
<td>CELF</td>
<td>M 110.08</td>
<td>M 72.86</td>
</tr>
<tr>
<td></td>
<td>n 13</td>
<td>n 14</td>
</tr>
<tr>
<td>- Expressive</td>
<td>M 105.23</td>
<td>M 66.20</td>
</tr>
<tr>
<td></td>
<td>n 13</td>
<td>n 15</td>
</tr>
<tr>
<td>- Receptive</td>
<td>M 107.23</td>
<td>M 81.79</td>
</tr>
<tr>
<td></td>
<td>n 13</td>
<td>n 14</td>
</tr>
</tbody>
</table>

The data are archival from the PCND; for the SLI group, analyses include all available data from six and seven year old children. The data for the TD group were selected
to match to the SLI group first on gender (11 male, 6 female) and then on age (TD M=79.06, SD=6.20; SLI M=79.24, SD=7.05). The gender match used all of the data from available TD boys. Due to a disproportionate number of six year olds with SLI, the TD girls included all of the available six year olds; the seven year old girls were then chosen at random from the available pool. The uneven gender distribution resulted from the unequal prevalence of SLI in males and females (2.8:1, Robinson, 1987).

**PROCEDURES**

The analyses of the current project used three tasks from a longer experimental and screening battery. For a child’s data to be included in these analyses, data had to available for that child from all three tasks. The tasks were administered over two testing sessions. The children had first participated in a testing session which included the picture arrangement subtest from either the WISC-III (Wechsler, 1991) or WISC-R (Wechsler, 1974). In it, the children were given a set of pictures which, when sequenced correctly, tell a story. They were asked to place the pictures in the correct order.

Later, in a second session, functioning as both as a warm up activity and as a language sample, children had answered questions about themselves (their school, friends, family, etc.) in semi-structured biographical interviews. Finally, immediately after the interview, scripts were elicited: children were asked to describe everything someone from another planet would need to know in order to go to McDonalds.

The sessions were video and audio taped. The video or audio tape, whichever had the better sound quality, was digitized at a sampling rate of 44.1kHz with 16-bit resolution. The sessions were transcribed using CHAT from CHILDES (MacWhinney, 2000). Acoustic coding and analysis was performed using Praat (Boersma & Weenink, 2011). All language data, scripts and the biographical interviews were transcribed using CHAT from CHILDES (MacWhinney, 2000).

**MEASURES**

Children's sequence production was characterized based on three tasks. Picture arrangement scores and McDonald's script measures were used to evaluate nonverbal and verbal event sequencing, respectively. The semi-structured biographical interviews were used to evaluate both syllable sequences and intonation.
**Picture Arrangement**

The picture arrangement subtest of the WISC-R is a series of black and white pictures which the child must put in logical order and or chronological order. The task is scored based on accuracy and speed as designated in the WISC manual.

**Scripts**

The transcripts from McDonald's scripts were scored on three measures: number of essential events, completion of task, and correct ordering.

*Number of essential events:* Four component activities were considered essential for a trip to McDonalds: getting to the restaurant, ordering/paying for food, receiving food, and eating food. At least eight typically developing children named each of these events. Each essential activity is given one point, up to a total of 4 points.

*Completion of task:* Task completion was rated as 0 or 1. A score of 1 indicated that the child produced two or more essential events with minimal prompting between the events named (ie, they received only neutral prompts such as, "Is there anything else I need to know?"). A score of 0 was assigned when the child produced only one event. All children produced at least one event. All children who responded to prompts provided two or more events.

*Correct ordering:* Children who completed the task by producing multiple events were evaluated on whether they put the events in the correct temporal order. This was scored as correct (1) and incorrect (0). When children did not use language such as "next" or "and then" to indicate the order of events, it was assumed that the events were stated in chronological order.

**Biographic Interviews**

The biographic interviews were used to evaluate syllable sequences (length and rate of speech) and intonation.

**Length of Speech**

Length of speech was measured in fluent syllables on three domains: total speech, narrative segments, and runs of speech.
Total Child Speech

Total speech measured the length of the interview based on the total number of fluent syllables spoken by the child in the conversation. Nonfluent speech was defined as repeated sounds or words, filled pauses, repetitions, and revisions. The nonfluent attempt was excluded; the fluent repair was included (Savova, 2003). This was deemed important since disfluencies may be more common in the speech of individuals with language impairment (Miranda et al., 1998), and their prosodic characteristics could skew the analysis if included. Though there is evidence to suggest that the inclusion of normal non-fluencies would not result in statistically significant differences in articulation rate (Flipsen, 2002), there is also evidence of significant prosodic differences in disfluent speech (Savova, 2003; Shriberg, Bates, & Stolcke, 1997).

All turns composed of a single word response or a segment of nonfluent speech followed by a single word response were excluded from the analysis. The first and last multi-word turns were also excluded to avoid any effects of getting used to a new situation or getting tired of the activity. Within each turn, sound effects, imitations of other speakers, and statements such as "uhhuh" and "oh" were also excluded.

Syllable counts were obtained perceptually from the digitized audio signal. A syllable was defined as a peak of sonority within a word due to the presence of a vowel, diphthong, or syllabic consonant.

Narrative Segments

In the interviews, narrative segments were identified from the transcripts as the child’s utterances in response to an experimenter question introducing a topic or request for elaboration. (see the example below). A narrative segment ended when the experimenter asked another question or commented on what the child said. Experimenter utterances such as "mhmhm," "I see," or "alright" did not begin a new narrative segment.

Narrative segment example:

EXP:  Who’s your favorite character in GI Joes?
CHI:  it one bad guy and one my friend and NAME got that guy.
EXP:  hmmmm.
CHI:  and and I don’t know what to name him j- j- just he looks like
like have the gear like he look like him Cobramander.
EXP:  hmmmm.
CHI: just him not Cobramander.
just him in a cobra and him just look like gold.
no no I mean silver.
EXP: hmhm.
CHI: and him costume and his gear look is it is is in metal.
EXP: that's all?

Length of narrative segment was defined as the number of fluent syllables spoken by the child during the narrative segment.

 Runs and Phonetic Phrases

A phonetic phrase was defined as a section of child speech bounded on either side by a pause of 250ms or longer (Flipsen, 2002; Logan et al., 2011; Smith et al., 2011; Walker & Archibald, 2006). Pauses were identified using the waveform and spectrogram and confirmed by the analyst’s perceptual judgment. Based on the guidelines set by Flipsen (2002) and Logan et al. (2011), the following criteria were used to identify the beginning of a phrase: for vowels and resonant consonants, the onset of F1 energy; for fricative consonants, the onset of broadband noise; and for stop and affricative consonants, the onset of the burst release. The reverse of each were used to identify the end of a phrase. When background noise or recording quality made it impossible to determine the precise onset or offset of a phrase, that section was marked as ambiguous, and the first word for which the onset or offset could be identified was used instead. These times were indicated in an interval tier in Praat (Boersma & Weenink, 2011), as shown in Figure 1.

A phonetic phrase could be composed of one or more runs of speech, defined as sections of uninterrupted fluent speech within a phonetic phrase which were at least three syllables long and did not contain any excluded or ambiguous material. The length of each run was measured in syllables.

 Rate of Speech

Articulation rate was measured by adding the total time of all of the runs of speech and dividing it by the total number of syllables.

Speech rate was measured by adding the total pause time to the time of all the runs and dividing by the total number of syllables. Pause time only included the length of pauses
Figure 1. Screenshot of Praat coding. Runs (s followed by the number of syllables in the run), pauses (+ or +d), disfluencies (d), and the pause following a disfluency (d+) have been labeled in the tier below the spectrogram.

within an utterance. It also included any pause which occurred following a fluent speech segment before a nonfluent one. Pause time did not include pauses within nonfluent speech or between nonfluent speech and subsequent fluent speech (Savova, 2003).

A length-rate correlation measure was created by correlating the length of the child's runs with the articulation rate of each run.

INTONATION

Phrase accents and boundary tones at the end of each intonational phrase (IP) were labeled using the ToBI system (Beckman & Ayers, 1997) and then categorized as falling intonation (L-L%), level intonation (H-L%), or rising intonation (L-H% or H-H%).

Frequencies for falling and level intonation were calculated over the whole interview by dividing the number of phrases ending in a given intonation category by the total number of measurable IPs. A measurable IP was any IP which was not a question, did not end in disfluent speech, and did not contain excluded or ambiguous segments. For each group (TD and SLI), approximately 86% of the IPs met these criteria.

Intonational phrases were divided into two categories based on their position within a narrative segment: non-final and final. The last IP of each narrative segment was labeled as final; all other IPs were considered non-final. The frequencies of non-final and final, falling and level intonation were calculated over the whole interview (eg: number of final IPs ending in falling intonation divided by total number of final IPs).
Rising intonation was not evaluated in this study. The high rise is primarily associated with yes-no questions, which are very seldom used by children in the context of the biographic interviews. The low rise has multiple uses (Levis, 2002) and is therefore not readily interpretable.

Two *length-frequency correlation* measures were created, one for falling intonation (*length-falling correlation*) and one for level intonation (*length-level correlation*) based on the child's intonation use over the course of each narrative segment. For each narrative segment the frequencies of both falling and level intonation were calculated by dividing the number of IPs ending with a given type of intonation by the total number of measurable IPs in that narrative segment. This proportion was then correlated with the length of the narrative segment in syllables.

**Reliability**

Two individuals independently coded the McDonald's scripts. Percent agreement was 96% ($\kappa = .91$) for identification of events, 94% ($\kappa = .97$) for task completion, and 96% ($\kappa = .83$) for correct ordering. Disagreements were resolved by consensus.

For the interviews, portions of the recordings for 16 of the subjects (8 from each group) were coded by two coders. To test for reliability on run length, articulation rate, and speech rate coding, 60 seconds of each Praat file (starting 30 seconds into the file) was coded. Inter-rater correlations (Pearson) were used on articulation rate ($r = .99$) and speech rate ($r = .99$) over the whole interview. The number of syllables in each run was compared using percent agreement and Cohen's kappa. For the 163 runs evaluated by both coders, percent agreement was 91%. The identification of narrative segments was also coded on these 16 subjects; percent agreement was 97% ($\kappa = .92$).

For ToBI coding, two narrative segments were chosen at random from each of 16 subjects (8 from each group). Reliability was measured using percent agreement and Cohen's kappa. For location of IP boundaries, percent agreement was 99% ($\kappa = .95$). When both coders agreed that a boundary was present, percent agreement on which intonational category (falling, level, or rising) was used was 80% ($\kappa = .69$). This is consistent with prior reliability studies on the ToBI system (Pitrelli, Beckman, & Hirschberg, 1994; Yoon, Chavarria, Cole, & Hasegawa-Johnson, 2004).
CHAPTER 3

RESULTS

The ability of children with SLI to produce sequences was analyzed using three different tasks (picture arrangement, verbal scripts, and interviews), focusing on nonverbal and verbal event sequencing, syllable sequences, and intonation. Analyses of syllable sequences and intonation in the interviews are exploratory, and t-tests are used to show the degree of difference between the groups. Correlations between the nonverbal and verbal event sequencing tasks are also described.

NONVERBAL EVENT SEQUENCING

Raw scores on the picture arrangement subtest of the WISC were compared between typically developing (TD) children and children with SLI. As illustrated in Figure 2, TD children obtained significantly higher scores than children with SLI, $F(1,32) = 18.18, p < .001$. Mean scores for the TD and SLI groups were 14.41 (SD = 3.04) and 9.85 (SD = 3.19) respectively.

Figure 2. Mean raw scores on picture arrangement subtest of the WISC. Error bars +/-1 SE.
**VERBAL EVENT SEQUENCING**

The groups were compared on each of the essential events used in their scripts about going to McDonald's. In general, more TD children named each event than children with SLI (see Figure 3). In the TD group, the events of driving there and ordering/paying were both named by 77% of the children, followed by getting food (71%) and eating the food (47%). In the SLI group, ordering/paying was named the most frequently (59%), followed by eating (53%), followed by driving and getting food (41% each). More typically developing children than children with SLI mentioned driving and getting food.

![Figure 3. Proportion of each group which named each essential event involved in going to McDonald's. Error bars +/- 1 SE.](image)

Typically developing children also named more total events (M = 2.71, SD = 0.92) than children with SLI (M = 1.94, SD = 1.09), $t(32) = 2.21$, $p = .017$ (see Figure 4). More TD children (82%) than children with SLI (47%) completed the task by independently naming two or more events (see Figure 5). The subset of the sample (both TD and SLI) who named more than two events was compared on their ability to order the events correctly. As illustrated in Figure 6, 100% of the TD children (n=14) correctly ordered the events they named, compared with 75% of the children with SLI (n=8); this was not a statistically significant difference, $t(7) = -1.53$, $p = .170$. 
Figure 4. Total events named in McDonald's scripts.

Figure 5. Proportion of each group that completed the McDonald's script task by naming more than one event.

Figure 6. Subjects who correctly ordered the events in the McDonald's script task as a proportion of subjects who completed the task.
SYLLABLE SEQUENCES

During the biographic interviews, children with SLI spoke less and in shorter segments than typically developing children. Their total fluent speech was measured both in time (seconds) and in number of syllables. TD children spoke fluently for 126.58 seconds (SD 32.80) while children with SLI only spoke for 97.40 seconds (SD 38.49). TD children also produced significantly more syllables than children with SLI (see Table 2).

Also, children with SLI also spoke in shorter segments than TD children (see Table 2). Their runs of speech (the segments of fluent speech between pauses) were significantly shorter, $t(32) = 4.37$, $p < .001$, and they produced shorter narrative segments (the speech between questions or comments from the experimenter).

Table 2. Mean Length of Speech in Syllables

<table>
<thead>
<tr>
<th></th>
<th>TD</th>
<th>SD</th>
<th>SLI</th>
<th>SD</th>
<th>Comparison of means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total speech</td>
<td>492.77</td>
<td>136.53</td>
<td>350.29</td>
<td>167.00</td>
<td>2.72, &lt;.011</td>
</tr>
<tr>
<td>Runs</td>
<td>7.05</td>
<td>.87</td>
<td>5.87</td>
<td>.69</td>
<td>4.37, &lt;.001</td>
</tr>
<tr>
<td>Narrative segments</td>
<td>20.47</td>
<td>9.47</td>
<td>13.35</td>
<td>5.25</td>
<td>2.71, .006</td>
</tr>
</tbody>
</table>

Children with SLI also spoke more slowly than typically developing children (see Figure 7). This was true of both their articulation rate, the rate of speech excluding pauses (TD M = 3.90, SD = 0.57; SLI M = 3.53, SD = 0.47; $t(32) = 2.11$, $p = .022$), and their speech rate, the rate of speech including pauses (TD M = 3.45, SD = 0.63; SLI M = 3.06, SD = 0.51; $t(32) = 1.99$, $p = .028$).

Figure 7. Rate of speech in TD and SLI groups. **p<.05.
Mean length-rate correlation scores for both groups were compared to zero and to each other. Length-rate correlation scores were greater than zero in both groups (TD M = .248, SD = 0.07, \( t(16) = 14.45, p < .001 \); SLI M = .173, SD = 0.15, \( t(16) = 4.79, p < .001 \)); however, the correlation was stronger in the TD group, \( t(34) = 1.91, p = .033 \).

**INTONATION**

Overall, the TD group spoke in longer intonational phrases (M = 5.80, SD = 0.99) than the SLI group (M = 4.91, SD = 0.73). Over the entire interview, the two groups used a similar proportion of each category of intonation (falling: TD M = .41, SLI M = .38; level: TD M = .37, SLI M = .40). The groups were then compared on (a) the frequency with which each category of intonation was used over the course of a narrative segment and (b) the relationship between length of narrative segment and intonation use.

The frequency with which each category of their intonation was used differed between the groups when the position of the intonational phrase (IP) within the narrative segment was taken into account (non-final vs final). Two-way within subjects ANOVAs were used to evaluate the effects Position of IP and Group on falling and level intonation use. For both categories of intonation, there was a significant main effect of position (falling: \( F(1,32) = 57.68, p < .001 \); level: \( F(1,32) = 87.41, p < .001 \)). For falling intonation, there was a significant interaction effect between position and group, \( F(1,32) = 5.94, p = .021 \). For level intonation, the position by group interaction almost reached significance, \( F(1,32) = 3.94, p = .056 \).

Simple effects t-tests (one-tail) were used to test specific hypotheses related to the interaction effects (see Figures 8 and 9). There was no difference between the groups on their use of either intonation category at the non-final position (falling: TD M = .31, SLI M = .31, \( t(32) = .025, p = .489 \); level: TD M = .45, SLI M = .47, \( t(32) = .66, p = .285 \)). At the final position, the groups differed for both falling intonation (TD M = .65, SD = .19; SLI M = .49, SD = .15; \( t(32) = 2.73, p = .005 \)) and level intonation (TD M = .19, SD = .12; SLI M = .30, SD = .13; \( t(32) = 2.61, p = .007 \)).

Mean length-falling and length-level correlation scores for both groups were compared to zero and to each other (see Table 3). For the TD group, the mean correlation scores for both categories of intonation differed from zero (falling: \( t(32) = 5.86, p < .001 \); level: \( t(32) = 3.36 \),
Figure 8. Proportion of intonational phrases (IPs) ending with falling intonation by position within the narrative segment (NS). Both groups use falling intonation similarly except at the ends of NSs, at which point children with SLI use significantly less of it than typically developing (TD) children. *p<.01.

Figure 9. Proportion of intonational phrases (IPs) ending with level intonation by position within the narrative segment (NS). Both groups use falling intonation similarly except at the ends of NSs, at which point children with SLI use significantly more of it than typically developing (TD) children. *p<.01.
Table 3. Mean Narrative Segment Length by Intonation Use Correlation Scores

<table>
<thead>
<tr>
<th>Intonation category</th>
<th>TD M</th>
<th>SD</th>
<th>SLI M</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Falling intonation</td>
<td>-.214</td>
<td>.152</td>
<td>-.055</td>
<td>.199</td>
<td>-2.65</td>
<td>.013</td>
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<tr>
<td>Level intonation</td>
<td>.147</td>
<td>.182</td>
<td>.078</td>
<td>.141</td>
<td>1.24</td>
<td>.224</td>
</tr>
</tbody>
</table>

For the SLI group, only the mean correlation scores for level intonation differed from zero, \( t(32) = 2.29, p = .018 \). The groups differed from each other on but not level intonation.

As a follow-up, the groups were compared to determine whether the differences occurred in longer or shorter intonational phrases. The number of syllables was counted for the final intonational phrase of each narrative segment. These IPs were pooled together and were then divided into three groups such that approximately one third of the total IPs were in each category: short (1-4 syllables), medium (5-6 syllables), and long (7 or more syllables). For each length category, the proportion of IPs which ended in each type of intonation was calculated.

As illustrated in Figures 10 and 11, the groups differ far more on short IPs than on long ones for both falling and level intonation. In short IPs, the TD group used falling intonation at the ends of 63% of the phrases and level intonation in 20% of the phrases. The SLI group used falling intonation at the ends of 42% of the phrases and level intonation in 31% of the phrases. (The remainder of the phrases used rising intonation.) In long IPs, the groups were relatively similar in their intonation use. This pattern was found when the narrative segments were separated into short and long categories as well.

Finally, the extent to which the groups differentiate between intonation categories and IP positions was investigated. As a derived measure, difference scores were calculated for each child for the positions of IPs and categories of intonation (specifically, falling intonation in final minus non-final IPs, level intonation in non-final minus final IPs, level minus falling intonation in non-final IPs, and falling minus level intonation in final IPs). The mean difference scores for both groups all differed from zero. However, in general the TD group differentiated more between intonation category and IP position than the SLI group (see Figure 12). The greatest difference between the groups was for intonation in the final position (TD M = .46, SD = .30; SLI M = .19, SD = .25). The groups did not differ for
Figure 10. Frequency of falling intonation by group. For the final intonational phrase (IP) of each narrative segment, proportions were calculated for each group (typically developing and SLI) at each intonational phrase length: short (1-4 syllables), medium (5-6 syllables), and long (7+ syllables).

Figure 11. Frequency of level intonation by group. For the final intonational phrase (IP) of each narrative segment, proportions were calculated for each group (typically developing and SLI) at each intonational phrase length: short (1-4 syllables), medium (5-6 syllables), and long (7+ syllables).
Figure 12. Comparison of the degree of differentiation between intonation categories and positions between groups. Difference scores are the differences between the specified proportions (frequency of intonation over total IPs) calculated for each child.

intonation in the non-final position (TD M = .14, SD = .25; SLI M = .16, SD = .16). TD children adjusted their use of falling intonation based on position to a greater degree than children with SLI (TD M = .34, SD = .19; SLI M = .17, SD = .20). This was also true but to a lesser degree for level intonation (TD M = .27, SD = .14; SLI M = .17, SD = .13).

**Nonverbal and Verbal Event Sequencing**

To explore similarities between nonverbal and verbal performance, correlations (Pearson) were calculated between the nonverbal event sequencing measure (picture arrangement) and the verbal event sequencing measures from the McDonald's scripts. Correlations were performed for the entire sample and for each group individually (see Table 4). Positive correlations were seen for the entire sample and within the TD group. The SLI group showed no correlation between number of events in the scripts or completion of task and picture arrangement scores. In the group of eight children with SLI who could be evaluated on correct ordering, there was a slight negative correlation.
Table 4. Correlations Between Picture Arrangement Score and McDonald's Script Measures

<table>
<thead>
<tr>
<th>Variable</th>
<th>All</th>
<th>TD</th>
<th>SLI</th>
</tr>
</thead>
<tbody>
<tr>
<td>McDonald's scripts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Number of events</td>
<td>.341</td>
<td>.336</td>
<td>.024</td>
</tr>
<tr>
<td>- Completion of task</td>
<td>.310</td>
<td>.326</td>
<td>-.031</td>
</tr>
<tr>
<td>- Correct ordering</td>
<td>.215</td>
<td>-</td>
<td>-.212</td>
</tr>
</tbody>
</table>
CHAPTER 4

DISCUSSION

Children with SLI have difficulty with a variety of tasks, both linguistic and nonlinguistic. The procedural deficit hypothesis (PDH) predicts that based on anatomical abnormalities in portions of the procedural system, the performance of children with SLI on tasks which use this system should be impaired. Two hypotheses which attempt to explain the deficits found in SLI assume that children with SLI have difficulty with aspects of implicit learning – procedural and statistical learning. Previous studies have found that children with SLI have difficulty learning new sequence-based information. Given the procedural system has also been found to underlie the ability to perform sequence production activities, children with SLI may have difficulty with these tasks as well. Specifically, these analyses focused on four forms of sequence production – nonverbal sequencing of events, verbal sequencing of events, syllable sequences, and sequencing of tones in intonational contours.

As predicted, the children with SLI were less successful at all four types of sequencing than the typically developing children. They were poorer at nonverbal event sequencing, as measured by the WISC picture arrangement subtest. They produced shorter verbal sequences of events on the McDonald's script task. They spoke in shorter segments and at a slower rate in the biographic interview task. And they did not use intonation in the same way as TD children when communicating the end of a turn.

HYPOTHESIS 1: NONVERBAL EVENT SEQUENCING

Children with SLI were expected to have more difficulty with putting a series of pictures in the correct temporal order than their typically developing peers. This hypothesis was supported. The children with SLI performed significantly more poorly on the picture arrangement subtest from the WISC than the typically developing children. This is evidence that the procedural deficit hypothesis extends to the generation of picture sequences.
However, the scoring of this test makes it impossible to eliminate other explanations for SLI. The standard scoring incorporates three factors: processing speed (the test was timed, and response time was a factor in scoring), working memory (sequences increased in length over the course of the test), and sequencing ability (scoring was primarily based on producing the correct order). Also, the test requires the use of social knowledge to identify the correct sequence. Further research is recommended to distinguish between the roles of these four factors.

**HYPOTHESIS 2: VERBAL EVENT SEQUENCING**

Children with SLI were expected to produce fewer events and to have more difficulty putting them in the correct temporal order when describing ‘what to do at McDonald's’. The results mostly support this hypothesis.

The SLI group produced fewer events. Their scripts were compared on whether they mentioned four essential events: drive (or walk) to McDonald's, order and/or pay for food, receive the food, and eat the food. Each of these events was named by at least eight TD children. With the exception of eating, fewer children with SLI named each of the events. The SLI group also, on average, named fewer total events than the TD group. Children with SLI also appeared to have more difficulty completing this task. Fewer of them produced multiple consecutive events without prompting in between.

It was also expected that they would be make more ordering mistakes when naming of the events. The groups did not differ significantly on this measure. However, all of the TD children sequenced the events correctly. In contrast, only 75% of the children with SLI sequenced the events correctly (see below for excerpts from scripts with and without sequencing errors; see Appendix for full scripts). Further, less than half of the SLI group named enough events to evaluate their ability to order them correctly. The limited number of subjects able to complete the task makes it difficult to draw firm conclusions about their ability to order the events they do name correctly.

Well-ordered script (TD child):

```
EXP: and what do I do when I get there?  
CHI: well you get it go and open the doors.  
you... order what you want and when it's ready you come and get it.  
and then...you pay for the money.
```
and then if you have a kid you can let the kid go play in the balls.
and... then you go home an' I... I think that's it.

Poorly ordered script (child with SLI):

EXP:  can you tell me everything that I need to know to go to McDonalds?
CHI:  you eat dere and you after you're done you choose a place but den you
don't ask them...you they just give you and you seeing what they give you.
EXP:  mmhm.
CHI:  and and you go to someone tells you to be nice and bring your friend.
EXP:  mmhm.
CHI:  an' an'...and you gotta get money from the thing.

<Off-topic conversation>
EXP:  is there anything else I need to go know to go to McDonalds?
CHI:  that's all.
EXP:  that's all?
CHI:  but you could order wha' you wan'.
CHI:  there's chicken nudget...hamburger and cheeseburger a' that's all at
McDonalds.

Interestingly, the groups also had a different pattern of which events were named the
most frequently. In the TD group, the children most commonly named events were those
which occurred first in the chronological sequence: 77% of the TD group named getting to
McDonald's and ordering/paying for food, followed by receiving the food, followed by
eating the food. The children with SLI were most likely to name ordering/paying for food,
followed by eating, followed by getting to McDonald's and getting the food. This suggests
that they may represent event knowledge incompletely or differently from TD children.

Neuroimaging studies have found that healthy adults represent scripts both temporally
and hierarchically (Farag et al., 2010; Tinaz et al., 2006). However, damage to the brain can
result in changes in either the internal representation or how it is accessed. For example,
Farag et al. (2010) found that adults with nonfluent aphasia do not appear to represent events
hierarchically but are able to represent them linearly. Specifically, healthy adults responded
faster and more accurately when ordering pairs of events if they were from the same
hierarchical cluster than if they were from different clusters; the performance of the patients
with aphasia did not vary between these two conditions. Given that Broca's area is one of the
regions likely impacted in SLI (Gauger et al., 1997; Watkins et al., 2002), it is possible that
children with SLI also have a different internal representation of scripts.
Together, these results indicate that verbally sequencing events is a difficult task for children with SLI. Similar to the younger children in Gruendel's (1980) study, more children with SLI named only one event. The presence of problems with both verbal and nonverbal sequencing of events suggests that this is not just due to differences in language ability. Instead, it may indicate that the neuroanatomical abnormalities found in the procedural circuits in children with SLI may result in developmental delays in the ability to represent events in scripts, differences in how scripts are represented, and/or differences in how the temporal ordering of scripts is accessed.

Unfortunately, the strength of this finding is weakened by inconsistencies in the testing procedure. Experimenters varied in how much prompting they gave the children and the types of prompts they gave. There was not a significant difference between the groups in the number of prompts they received, but variability in the amount and type of prompting made it difficult to accurately assess the potential level of independent performance of the children.

**HYPOTHESIS 3: SYLLABLE SEQUENCES**

Children with SLI were expected to talk in shorter segments and to speak more slowly than TD children. They were also expected to show less of an increase in rate of speech than TD children during longer speech segments. The results support this hypothesis.

The length of speech was measured in syllables for each child's fluent speech. The mean length was measured for the child's narrative segments (the speech between one comment or request for new information by the experimenter and the next) and runs of speech (the segments of fluent speech between pauses). The children with SLI talked less overall. They also spoke in shorter segments (both narrative segments and runs of speech). The difference in length of runs is particularly striking. It indicates that the children produce shorter segments of speech before pausing to formulate (physically or mentally) what they will say next. It supports the idea that children with SLI have difficulty assembling longer sequences.

As expected the children with SLI spoke more slowly than the TD children, as measured by both articulation (without pauses) and speech (with pauses) rates. This suggests
that the effort to formulate speech on both a motor planning level and a cognitive level is greater for this population.

Consistent with previous studies, typically developing children increased their articulation rate as the length of their runs of speech increased. The children with SLI also showed this correlation between length and rate, but the relationship was significantly stronger in the TD group than the SLI group. Further, the groups were generally the most similar on short runs and differed most on long runs. This suggests that producing longer runs does take more effort for the children with SLI, and they are not able to process them as quickly as TD children.

Previous studies have shown that the pars opercularis and basal ganglia play a role in the production of syllable sequences (Bohland & Guenther, 2006; Gelfand & Bookheimer, 2003; Skodda et al., 2009). It was expected that because abnormalities in these areas have been found in children with SLI, this population would also have difficulty with producing syllable sequences. The results matched this prediction and support the procedural deficit hypothesis as an explanation for SLI.

One limitation of these data is that in the context of a conversation, it is impossible to say whether the children with SLI speak in shorter runs of speech due more to cognitive demands or motor planning demands. Similarly, it is not possible to determine in this context whether the root cause is linked more strongly to sequencing abilities or working memory. Further studies could look at these issues in a more controlled context.

**HYPOTHESIS 4: INTONATION**

Children with SLI were expected to be less effective at using intonation to communicate turn-taking intentions than typically developing peers; specifically, it was predicted that they would not alter the intonation at the ends of intonational phrases based on whether they had more to say.

The overall use of each category of intonation did not differ in frequency between the groups. However, their use of falling and level intonation to signal the ends of narrative segments did differ. TD children used more falling and less level intonation at the ends of these segments than children with SLI.
The correlation between the frequency of each intonation type and length of segment was used as a measure of both whether the groups use intonation in the same way when communicating and a reflection of the impact of length of segment on their use of boundary intonation. As expected, children with SLI showed little or no correlation; TD children did show a significant correlation for both intonation categories in the expected directions. The groups differed from each other on the falling but not the level intonation.

Overall, children with SLI did use intonation to communicate turn-taking intentions. However, they did not do so to the same degree as TD children. This is consistent with the findings of Wells and Peppé (2003) that children with SLI had more difficulty than TD children with intonational tasks involving a pragmatic component.

To further explore the procedural learning hypothesis, the use of intonation was compared at the ends of short and long intonational phrases and narrative segments. If children with SLI have difficulty putting together sequences, then they might be expected to be more similar to TD children when the sequence is shorter than when the sequence is longer. This was not the case. The groups were more similar on longer intonational phrases than on shorter ones.

The statistical learning hypothesis is an alternative implicit learning explanation of SLI. Under this hypothesis, it's possible that children with SLI have an impaired ability to learn from the frequency of a pattern’s occurrence in the environment. Studies have found that children with SLI have difficulty with this type of probabilistic learning in both linguistic and non-linguistic contexts (Evans et al., 2009; Tomblin et al., 2007). Under this hypothesis, children with SLI may have difficulty learning the categories of boundary intonation.

Post hoc analyses were therefore performed to explore the extent to which the SLI group differentiated between intonational categories. If children had no understanding of how to use boundary intonation for communicative purposes, they could be expected to use each intonation category with the same frequency in both the non-final and final positions. This was not the case. However, children with SLI do not differentiate between the non-final and final positions as much as TD children. One possible explanation for this is that children with SLI have a weaker ability to differentiate between the categories of intonation than TD children have.
However, caution must be used when interpreting intonation results in an open-ended task such as the biographic interviews. Several additional factors could be playing a role. Perhaps the children are correctly communicating that they have more to say but also use a contradictory cue (such as a long pause) which leads the experimenter to think that they are done talking or need more assistance to figure out what to say next. Their intonation use could be an expression of uncertainty (such as not being sure whether they answered the question correctly or wondering whether they communicated clearly). It could indicate that they are still thinking and are undecided about whether they are done yet, and it could represent a need to focus on speech production over pragmatics.

Further research in a more controlled context would be needed to tease apart these different possibilities. First, although procedural learning and working memory do not appear to have been a factor in the results of this study, it is worth confirming the extent to which either working memory or procedural learning difficulties are interfering with intonation. Varying the length of the phrases both in terms of syllables and pitch accent frequency and complexity on a test where the wording is also constrained would help to establish the degree to which sequencing and/or working memory is a factor.

Second, there is a need to explore the possibility that poor statistical learning is creating a weaker understanding of intonational categories and their uses. Wells and Peppé (2003) tested the ability of children with SLI to differentiate between rising and falling intonation on a listening test and found that they could succeed at this task; to my knowledge, though, no one has tested this population on their ability to differentiate between the more similar level and falling intonations. A similar listening test could also be used to determine whether children with SLI have linked intonational categories to their pragmatic uses.

Similarly, a more simple language elicitation task could be designed to test children's ability to produce or imitate the same categories of intonation appropriately. This would clarify the extent to which the ability to distinguish between categories (statistical learning) is a factor in their understanding of intonation.

Finally, it's important to evaluate the extent to which difficulties with pragmatics may be impacting intonation. Along with testing children's understanding of the pragmatic uses of intonation, intonation use could also be explored by using either read or elicited speech which was more uniform to make possible more direct comparisons between the groups.
This would make it possible to determine if the results of this study would be reproduced in a more controlled context or whether there is something distinctive about spontaneous speech in a conversational context.

**Nonverbal and Verbal Event Sequencing**

Children who were poor at nonverbal event sequencing task were expected to also be poor at verbal event sequencing. If the procedural circuit underlies these tasks and is impaired in children with SLI, then stronger correlations may be seen in the SLI group than the TD group. This pattern was not the case.

There was a small relationship between nonverbal and verbal measures in the TD group and none in the SLI group. It is difficult, however, to interpret this result. It may simply be a consequence of the small sample sizes, or it could be interpreted as evidence against a relationship between nonverbal and verbal performance.

To better test this relationship, a larger sample is needed, and better measures should be used than those which were available for this study. An untimed variation on the picture arrangement test, one in which scores could be divided by sequence length would offer a nonverbal sequence production measure and make it possible to rule out processing speed or working memory factors. Greater consistency in the experimental procedure would strengthen the verbal scripting measure.

Further research might also explore the extent to which sequence learning measures such as serial reaction time tasks can be correlated directly with sequence production measures, both verbal and nonverbal. The relationship between the performance on sequence learning tasks and sequence production tasks would provide valuable insights which might help to refine the procedural deficit hypothesis.

**Conclusions**

Many of these results are consistent with the procedural deficit hypothesis. The PDH predicts that children with SLI will have difficulty with any task which requires the use of the procedural circuit involving Broca's area and the basal ganglia. Event sequencing, both verbally and nonverbally, has been shown to be linked to these structures, as have syllable sequence production and rate of speech. In this study, children with SLI showed
evidence of deficits in each of these domains. They also did not use intonation comparably to their TD peers.

However, the PDH alone cannot explain all of the results. It cannot explain why the intonation of children with SLI was more similar to TD children on long IPs than short ones, and it does not explain why the nonverbal and verbal event sequencing measures are less correlated in the SLI group. These findings may be the result of experimental design limitations due to the use of archival data, or they may be evidence that multiple (or different) theories are needed to explain SLI.

**Limitations**

The primary limitation of this study is that it used archival data which were not collected for the purpose of testing sequence production ability. Therefore, although most of the results of this study support the PDH, the study cannot rule out alternative explanations for the performance of children SLI. Nonverbal picture arrangement was the most direct measure of event sequencing in this study, but the scoring method used does not allow one to disentangle the effects of working memory or processing speed issues from those directly associated with sequencing.

Spontaneous conversational speech has the benefit of being a relatively naturalistic context in which to explore how well children with SLI perform in "real-life" circumstances, but the lack of control over elements such as content, turn-taking, and working memory demands also makes it impossible to conclusively state that sequencing difficulties are at the root of the children's performance. However, the difficulties the SLI group had with performing a series of sequence production tasks indicates that it is worth exploring sequence production abilities in this population in a more controlled context.

**Summary**

SLI is a neurodevelopmental disorder in which children have difficulty with both spoken language and a variety of nonverbal tasks. This study explored the extent to which difficulties with procedural learning may be a factor impacting their sequence production. It used three tasks (arranging pictures sequentially, telling a script, and answering questions in an interview) to explore how event sequencing, syllable sequences, and intonation may be impacted in SLI. The procedural deficit hypothesis may account for many of the results of
the study. However, it is not sufficient to explain all of the results. Further research is recommended both to explore the interactions between sequence learning and sequence production across verbal and nonverbal domains and to investigate the underlying causes of differences in intonation use.
REFERENCES


APPENDIX

MCDONALD'S SCRIPT EXAMPLES
*EXP: I want you to tell me everything I need to know to go to McDonalds.
*EXP: okay [= laughing] ?
*CHI: &um first you +... [+ F]
%flo: um first you...
*CHI: I know the one over by church.
%flo: I know the one over by church.
*CHI: first you &um go straight I think.
%flo: first you um go straight I think.
*CHI: &um then you turn.
%flo: um then you turn.
*CHI: then you go straight -: .
%flo: then you go straight.
*CHI: then you turn left.
%flo: then you turn left.
*CHI: then you turn again.
%flo: then you turn again.
*CHI: then you go straight.
%flo: then you go straight.
*CHI: then you turn right.
%flo: then you turn right.
*CHI: then you're there.
%flo: then you're there.
*CHI: I think that-'is how you do it.
%flo: I think that's how you do it.
*EXP: okay.
*EXP: and what do I do when I get there?
*CHI: well you <get it> [/] go and open the door-s.
%flo: well you get it go and open the doors.
*CHI: you -: # order what you want and when it-'is ready you come and get it.
%flo: you...order what you want and when it's ready you come and get it.
*CHI: and then # you pay for [*] the money.
%flo: and then...you pay for the money.
*CHI: and then if you have a kid you [/] you can let the kid go play in the balls -: .
%flo: and then if you have a kid you can let the kid go play in the balls.
*CHI: and # then you go home and I [/] # I think that-'is it.
%flo: and...then you go home an' I...I think that's it.
MCDONALD'S SCRIPT (SLI)

*EXP: okay so NAME we're going to do something a little different now we're going to be playing a pretend game.

*EXP: can you pretend that I am from another planet and that I don't know how to do anything here on earth but you know how to do everything so I need your help.

*EXP: can you tell me everything that I need to know to go to McDonald's?

*CHI: you eat there and you [//] after you're done you choose a place but then you do'-nt ask them # you [//] they just give 0noun 0prep you and you see-ing [*] what they give you.

%flo: you eat dere and you after you're done you choose a place but den you don't ask them...you they just give you and you seeing what they give you.

*EXP: mmhm.

*CHI: and [/] and <you go to> [/] someone tell-es you and you be [*] nice and bring your friend.

%flo: and and you go to someone tells you to be nice and bring your friend.

*EXP: mmhm.

*CHI: <and -: and - > [/] # and you gotta [: got to] get money from the thing.

%flo: an' an'...and you gotta get money from the thing.

*EXP: mmhm.

*CHI: and -: # you have to go to the doctor to get shot or anything with [/] in [*] the doctor-'s.

%flo: and...you have to go to 'e dotor to ge t shot or anysing with in the doctors.

*CHI: and you could find an [*] home and when you want to move you could find a new house.

%flo: and you could find an home and when you want to move you could find a new house.

*EXP: uhhuh.

*CHI: that old one.

%flo: that old one.

*CHI: &a and -: you gotta [: got to] go to 0det store to get food and you could go to Toys+R+Us to get toy-s.

%flo: a-and you gotta go to store to get food and you could go to Toys R US to get toys.

*EXP: is there anything else I need to go know to go to McDonalds?

*CHI: that-'is all.

%flo: that's all.

*EXP: that's all?

*CHI: but you could order what you want.

%flo: but you could order wha' you wan'.

*CHI: there-'is chicken+nugget [*] # hamburger and cheeseburger and that-'is all at McDonalds.

%flo: there's chicken nudget...hamburger and cheeseburger a' that's all at McDonalds.

*EXP: ah yeah so once I've ordered what I want then what do I do?

*CHI: then when you'-re done you could open your [/] the bag and get your prize.

%flo: then when you're done you could open your the bag and get your prize.

*EXP: oh okay is there anything else I need to know to go to McDonalds?

*CHI: that-'is all.
%flo: that's all.
*EXP: that's all # great.