SIMULTANEOUS GESTURE AND LANGUAGE PRODUCTION IN
SCHOOL AGE CHILDREN WITH PERINATAL STROKE

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This thesis is dedicated to my dear family and friends who have given me the strength and perseverance through their love, encouragement, and inspiration to pursue my endeavors.
ABSTRACT OF THE THESIS

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In naturalistic settings, children and adults complement speech with gestures when engaging in conversations. McNeill hypothesized that language and gesture form an integrated system. Developmental research in preschool and younger children has supported this hypothesis, as gestures play a predictive role in later language development. During early language development, deictic (i.e., pointing) gestures are frequent and have a primary role in communication. Children undergo rapid morpho-syntactic and lexical development, and with the ability to produce multi-word utterances, come a preference for verbal utterances over gesture as the primary communicative channel. However, during the school age period, the role of gestures remains largely unknown, and we know little about the transition from the use of pointing in infants to adult gesture use.

Children with Perinatal Stroke (PS) provide an opportunity to chronicle gestural growth, and the early neural damage allows us to evaluate assumptions regarding neural plasticity: that the developing brain will develop alternative pathways and thus children are less likely to be affected from an early insult than adults with comparable lesions. With respect to language, adults with right hemisphere injury (RHI) are characterized by cognitive and pragmatic impairments that are different from language impairments, or aphasias, as seen in adults with left hemisphere injury (LHI). However, studies of early language development literature in children with PS has found expressive language delays in children with either RHI or LHI, whereas receptive language is relatively spared in those with LHI. By school age, lesion site differences in the children with PS resolve and these children’s spontaneous language ability is roughly comparable to their typically-developing (TD) peers. However, there is scant research in school age TD children and none in children with PS regarding gestural development, nor is there research regarding the relation between language and gesture in spontaneous social discourse in these groups.

Thus, the present study will address (1) gesture–speech development in school age TD children and (2) their brain-bases by examining speech and gesture in children with unilateral PS.

To address these issues, we explored three research questions to study gesture and language production in school age TD children and those with unilateral PS in a semi-structured biographical interview, in which language samples and gestures are recorded. Data at two time points are collected for each participant. Data at time point 1 were collected between ages five and six and data at time point 2 were collected between ages seven through nine. Findings from gestural and language measures will address McNeill’s language-gesture integration hypothesis and the nature and extent neural plasticity for gesture.
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CHAPTER 1

INTRODUCTION


Children with early neural damage as a result of unilateral Perinatal Stroke (PS) offer a unique opportunity to test McNeill’s hypothesis and to understand the neural bases for gesture and language in the developing brain. The PS literature so far has investigated language and gesture development in toddlers, in addition to children’s language performance beyond preschool; however, there is no research regarding gesture in school age children with PS. The evidence supporting a gesture-language link in toddlers with early brain injury is mixed. In the context of language delay in toddlers with either right hemisphere (RH) or left hemisphere (LH) injury, Bates and colleagues (1997) found right hemisphere injury (RHI) corresponding to impairment in gesture production. However in a longitudinal study, Sauer and colleagues (2010) found no hemispheric differences in gesture production. During school age, children with unilateral PS do not display laterality effects for language performance, and their performance on spontaneous discourse is within low-normal range (Bates et al., 2001; Demir, Levine, & Goldin-Meadow, 2009; Reilly & Appelbaum, 2011; Reilly, Bates, & Marchman, 1998; Reilly, Losh, Bellugi, & Wulfeck, 2004). Our study will address the nature of the gesture-language relation by examining language, gesture, and their integration in school age children with unilateral PS.
Thus, McNeill’s hypothesis can be tested in two ways in school age children during conversational discourse: (1) comparing gestural and language development in TD school age children; (2) examining the neural bases for gesture and language in school age children with unilateral PS. The primary goal of the current study is to understand whether language and gesture are related during development, in both the PS and TD populations; our findings will help us to understand brain-behavior relations in the developing brain and gesture-language relations in development. The following literature review first presents an overview of gesture definition, coding systems, and methodologies to examine gestures, and McNeill’s Growth Point Hypothesis. Subsequent sections review pertinent literature in TD and PS language and gesture development, as well as the neural bases for gesture and language.

**GESTURES: DEFINITION AND McNEILL’S HYPOTHESIS**

Before presenting the literature on gesture and language performance in children and adults, it is important to discuss and understand what a gesture is. One major hypothesis regarding gestures in support of a gesture-language link by McNeill will also be discussed.

**Gestures: An Operational Definition**

In order to measure gesture as a construct, an interpretable definition is mandatory. For example, gestures can be communicative, e.g., to convey a message, or primitive, as in self-grooming. Historically, there is considerable discussion about an operational definition in the gesture literature (Goldin-Meadow, 2003; Scharp, Tomkins, & Iverson, 2007). In an effort to promote consistency within this literature, Scharp and colleagues (2007) suggested the following working definition specifically for communicative gestures: “a communicative gesture includes spontaneous movements of the hands, arms, and fingers that are typically co-verbal and provide information that is consistent with the content of the verbal message, but can also provide additional information not contained in the verbal expression” (p. 722). We will use this definition for a communicative gesture in the current study.

**McNeill’s Hypothesis of Gesture-Language Integration**

Growth Point Hypothesis (McNeill, 2005) proposes a closely-knit relation between gestures and language. The theory proposes uninterrupted interaction between gesture and speech. It stems from the perspective of “thinking-for-speaking” that thinking uses both imagery and language, and hence gestures and language are inseparable and integrated. Cross-sectional studies in young TD children and adults provide evidence for this integrated relation during co-speech gestural production. In fact, the evidence supporting this relationship was found in infancy and toddlerhood in children with PS that will be discussed later on. The present study will determine whether the hypothesis is or is not supported in school age TD children and those with unilateral PS. Initial support and
conceptualization of this hypothesis comes from not only neurologically-intact adults, but also from adults with brain injury.

**Adult Neural Organization for Language and Gestures**

Previous studies in neurologically intact adults support McNeill’s hypothesis that gesture and language are integrated at the conceptual-semantic pre-verbal level (Bates & Dick, 2002). A series of studies have shown that co-speech gestures during narrative production are closely related to the information given in speech and correspond to concepts; moreover, congruent gestures improve speed while incongruent gestures decrease speed in verbal responses (Colletta et al., 2010; Goldin-Meadow, 1998; Goldin-Meadow, Wein, & Chang, 1992; Klatzkey, Pellegrino, McCloskey, & Doherty 1989; McCloskey, Klatzkey, & Pellegrino, 1992; McNeill, 1998; McNeill, Cassell, & McCullough, 1994). What happens when language impairments result from acquired brain injury in the mature system and how is gesture ability affected?

**Language and Gesture in Adults with Unilateral Left or Right Hemisphere Lesion**

Aphasia is defined as an impairment of symbolic functions or representation related to language that can manifest in multiple modalities (e.g., written expression, reading comprehension) (Dronkers, Baldo, & Larry, 2009). The concept of aphasia emerged with Paul Broca’s and Carl Wernicke’s post-mortem examinations of brains undertaken to correlate specific neuro-anatomical structures with the patient’s observed language behaviors (Broca, 1861; Wernicke, 1874). Current aphasia literature generally agrees that the LH is the mediator for the formal aspects of language: phonology, morphology, syntax, and semantics. Broca’s area is located in the third convolution of the LH anterior frontal lobe, mediating functions such as speech production and morpho-syntactic processing (Goodglass, 1993). Wernicke’s area is located in the posterior portion of the LH superior temporal gyrus, implicated in related functions such as auditory comprehension and semantic processing (Goodglass, 1993). Left hemisphere injury (LHI) in either Broca’s or Wernicke’s areas is likely to result in aphasia with corresponding impairments. To date, aphasia research has identified two primary areas of deficits in eight types of aphasia: fluency and comprehension. Within these dimensions, Broca’s aphasia is generally characterized by telegraphic speech (non-fluent) and relatively intact comprehension. Wernicke’s aphasia is generally characterized by fluent but incomprehensible or “empty” speech, and poor comprehension and repetition abilities (Dronkers et al., 2009). These language impairments are demonstrated by common errors committed in spontaneous discourse (Bates et al., 2001).

In contrast, for adults who survive a RHI, language abilities in the domains of morphology, phonology, and semantics are relatively spared. However, these individuals typically present with visuo-spatial impairments, and non-verbal communicative impairments at the discourse level, such as reduced affect and prosody, as well as impairments in pragmatics of language (Joanette & Goulet,
For example, during a conversation, they often demonstrate impulsive and tangential responses; violate turn-taking rules; exhibit topic circumlocution, and often lack cohesion and overall coherence in expressing main ideas (Bates et al., 2001; Campbell & Keith 2006; Lundgren, Brownell, & Keith, 2006). In narrative discourse, they produce disorganized narratives compared to the control group, characterized by lack of cohesion with missing information (Bates et al., 2001). However, regardless of side of lesion, there is high group variability with some participants performing like the normal adult controls, as reflected by varying degree in the severity of these deficits (Bates et al., 2001; Joanette & Goulet, 1990, 1994).

Using a semi-structured conversation, Bates and colleagues (2001) examined morphological, syntactic, and lexical error patterns in adults with RHI and LHI and TD adults who are neurologically intact. The adult LHI group consisted of fluent Wernicke’s aphasics and non-fluent Broca’s aphasics. In a biographical interview, adults with RHI showed overproduction of utterances compared to those with LHI and the TD adults, but the nature of this overproduction differed. Non-aphasic LHI and RHI adults exhibited difficulty with inhibition and disorganized discourse, while the aphasic LHI adults demonstrated word-finding related problems such as paraphasias, circumlocutions, and perseverations. Lexical, syntactic, and morphological findings showed that the RHI group performed comparably with TD adults. Fluent aphasics did not differ from non-fluent aphasic adults in syntactic token, or lexical and syntactic type measures. However, fluent aphasics produced more words, which reflected the ‘empty speech’ nature in fluent aphasic production. The next question pertinent to our investigation is: how are gestures affected in adults with lesions? Do they follow McNeill’s hypothesis, such that impairments in gesture ability align with language impairments?

**Adults with RH and LH Stroke: A Gesture-Language Link**

Gestural performance in patients with RHI or LHI is not as extensively studied as language. In fact, there are few studies looking at gesture in a naturalistic context in stroke patients; most research has used imitation of gestures and elicited contexts (Goldenberg, 1996, 2001; Haaland, Harrington, & Knight, 2000; Halsband et al., 2001; Wang & Goodglass, 1992). However, studies in spontaneous gestural production find that gesture ability is affected differentially depending on site and side of lesion, suggesting a gesture-language link. The strongest support for gesture-language integration comes from the few studies in adults with aphasia (Cocks et al., 2009; McNeill, 2005; Pedelty, 1987). These studies show gestural impairments that parallel language deficits in adults with LH lesions (McNeill & Pedelty, 1995). Specifically, non-fluent aphasia (LH anterior lesion) was correlated with short, abrupt, impaired iconic co-speech gestures that were comprehensible, whereas fluent aphasia (LH posterior lesion) was correlated with fluid, yet vague and meaningless gestures (Cocks et al., 2009, Pedelty, 1987).

Blonder and colleagues (1995) is, to our knowledge, the only study that compared RHI and LHI groups’ spontaneous gestures in a naturalistic situation, a semi-structured interview. She hypothesized decreased gestures in the RHI group, specifically reduced “linguistic” gestures (e.g.,
iconic, metaphoric, beat, and deictic gestures). Her hypothesis was based on evidence from other findings in non-verbal communication, i.e., reduction of prosody and affect in patients with RHI. However, she found the opposite – the RHI group produced more total gestures than the LHI group and the TD adult controls, with enhanced self-grooming and “fidgeting” gestures. The overabundance of gestures in RHI group also aligns with the overproduction of language in the RH group from Bates and colleagues (2001). Blonder and colleagues did not find a laterality effect as RHI and LHI groups appeared to be just as expressive in communicative gestures as the normal controls, suggesting instead, a dissociation between language and gesture. Additionally, self-grooming gestures do not have communicative intent as compared to communicative gestures. It is possible that the outcome measure of all gestures in general (e.g., self-grooming, communicative gestures) – rather than a fine-grained analysis of communicative gestures – resulted in these inconsistent findings.

Despite the limited research, language and gesture performance in the mature system in TD adults provides general support for McNeill’s gesture-language hypothesis — yet the scant literature on brain-injured adults is inconsistent. Our question is whether McNeil’s hypothesis will apply to language and gesture development in children with Perinatal Stroke (PS). The source of conceptualizing gesture-language as an integrated system comes not only from the literature regarding adult normal control and lesion groups, but also from studies in TD children.

**TYPICALLY DEVELOPING LANGUAGE AND GESTURE PERFORMANCE**

Language is but one communicative system. Language consists of arbitrary symbols that convey concrete (e.g., apple) and abstract (e.g., truth) concepts (e.g., manzana and ringo also mean apple [Spanish and Japanese]). A competent language user can use language to comprehend and express the “here and now” (contextualized language), as well as to understand and convey information regarding non-present contexts, including the past and the future (decontextualized language). Children progress through a series of language milestones acquiring this symbolic system that include the ability to express and comprehend information present or absent in the environment.

Gesture is another means of communication, and in children and adults, it often co-occurs with speech. Interestingly, gesture studies of young children acquiring language report that gesture predicts subsequent language milestones (Capirici et al., 1996; Folven & Bonvillian, 1991; Iverson & Goldin-Meadow, 1998; O’Reilly, 1995; Ozcaliskan & Goldin-Meadow, 2005, 2009; Pizzuto & Capobianco, 2005; Sauer et al., 2010; Shore et al., 1984; Thal & Bates, 1988; Thal & Tobias, 1994; Thal, Tobias, & Morrison, 1991; Tomasello, Striano, & Rochat, 1999). Such findings provide insight into the nature of gestures and their role in language and conceptual development. For example, canonical babbling correlates with the onset of rhythmic hand banging and clapping, and these early hand movements were also found to correlate with the onset of first words and communicative gestures (Ejiri & Masataka, 2001; Locke, et al., 1995).
Gestation’s Predictive Role in Early Language Development

Thal & Bates (1988) detailed a four-stage framework to capture the development of symbolic communication. The Pre-symbolic Communication Stage (approximately 9-to-12 months) is when children vocalize as they use deictic or pre-linguistic gestures (i.e., pointing, showing, and giving) with the intent to request or to declare. These gestures start to emerge as early as 10 months of age (Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Folven & Bonvillian, 1991; Pizzuto & Capobianco, 2005). The Symbolic Stage (approximately 13 to 20 months) marks the emergence of one-word utterances, and children in this stage begin to supplement their utterances with iconic gestures (e.g., motion of drinking from a cup) (Capirci, Contaldo, Caselli, & Volterra, 2005; Capirci et al., 1996; Iverson & Goldin-Meadow, 1998; Sauer et al., 2010; Shore et al., 1984; Thal & Bates, 1988; Thal & Tobias, 1994; Thal et al., 1991). Iverson, Capirci, & Caselli (1994) found that 16-month-old children rely on gestures more than speech during this stage of communication. However, by 20 months, a preference for speech was observed, marking the transition into the Symbol Combinations stage (approximately 20 to 24 months). During this time, children produce two-word utterances and engage in cross-modal communication using both gestures and content words. Ozcaliskan & Goldin-Meadow (2005, 2009) described the role of gestures as predicting the onset of the syntactic relations in speech. They evaluated noun arguments (e.g., subject, direct object) and predicates (i.e., verbs) produced in speech and gestures during spontaneous parent-child interactions. They found that these children produced argument+argument (e.g., pointing to the couch + uttered “mommy”), predicate+argument (e.g., pointing to the car + uttered “drive”), and predicate+predicate (e.g., picking up toys + uttered “all-done”) in gesture-speech combinations before these same constructions were produced uniquely with speech. By 22-months old, these children began to produce speech-only predicate+predicate combinations. Symbol Sequencing Stage (28 months and beyond) marks rapid morphological and syntactic growth as well as the development of symbolic gestures. Tomasello and colleagues (1999) and O’Reilly (1995) found that in preschoolers (3 to 5 years), four-year-olds either did not respond to the test item or were likely to produce gestures that consist of body part as an object (BPO; e.g., using a fist to comb hair, with the fist acting as the brush/comb) than gestures using imaginary object (IO; e.g., drinking from a non-existent cup). A shift occurred with five year-olds: they were more likely to produce IO gestures similar to the adults. The authors interpreted this shift as the emergence of maturing gesture ability. The emergence of an adult-like preference to gesture with an imaginary object may be related to an expanding repertoire of semantic-conceptual knowledge.

As the literature has shown, deictic gestures play a primary role in early communication in TD children before children develop linguistic competency in producing similar messages entirely within speech. Preference for the spoken word over gesture is noted once syntax emerges, that is, with the onset of the multi-word utterances. With this onset, iconic-like gesture emerges and gesture overall
takes a complementary role. As far as the early stage of development is concerned, gesture has a predictive role in advancements in language performance, and both gestures and speech are windows to understanding symbolic communication. These findings in TD children generally support McNeill’s hypothesis that language and gesture co-develop. Yet we know little about how gestures are used once children are competent speakers.

Simultaneous Speech and Gestures in School Age TD Children

The predictive nature of gesture in early language development suggests gesture’s facilitative role in scaffolding symbolic and decontextualized information conveyed through language. Unlike the toddler studies, school age gesture development studies instead focus on the relation between gesture and language development. School age children continue to produce gestures spontaneously during speech production. Specifically, these studies have explored gesture-speech mismatch phenomenon that occurs as early as 5 years of age (Church, 1999; Evans et al., 2001; Goldin-Meadow, Alibali, & Church, 1993; Perry et al., 1988). Gesture-speech mismatch is when the gesture and speech content conflict, such as when gestures provide correct solutions to conceptual problems but speech does not. For example, during a Piagetian conservation task of explaining how the same volume of liquid can be contained in a dish and a tall glass, some children give the incorrect verbal response (e.g., “the glass is tall and the dish is short”), yet the accompanying gesture indicates the short height and the thick width of the dish (Church, 1999; Church & Goldin-Meadow, 1986). This cross-modal mismatch is the only known behavioral phenomenon that permits researchers to observe simultaneous access of mental representations regarding a single concept (Church, 1999).

However, these mismatches may be specific to explaining mathematical and conceptual problems since there are no reported findings of mismatch in other discourse contexts. Ergo, we are still left with the question of when the patterns of co-speech gesture become more adult-like. In order to understand simultaneous speech and gesture production in school age children, we must find a natural, social context to observe the interaction of these two modalities, as in the study in French by Colletta et al. (2010). They used a narrative task to investigate linguistic, narrative, and gestural production in six and ten year-old TD children and neurologically intact adults. Adults produced the most complex narratives (i.e., multiple narrative components and episodes) that are linguistically complex (i.e., produced the most subordination), although these narratives were shorter in length and had fewer cohesive devices (i.e., anaphors [he, the baby, a boy] and connectives [so, because]) than the ten year-old group. Within the school age children performance, the ten year-old group showed a positive shift toward increased syntactic and narrative complexity as compared to the six year-old group. Integrating these results, children by ten years of age can produce adult-like narratives, and adult narratives contain highly compacted information telling the story more succinctly and concisely than school age children. Overall, the amount of gestures increased with each age group. In fact, the ten year-old group and the adults used integrative (new, optional information) co-speech gestures the
most and fewer gestures to supplement (facial expression) or reinforce (redundant information) speech. Discursive (rhythmic beats) gestures increased with each age group, which suggested increased pragmatic competence over time in using gestures to mark important speech content. Gestures that were contradictory to speech content were produced only sparingly in all age groups.

In summary, gesture and language use increases with age; children as young as ten years-old produce narratives that resemble adult-like linguistic and gestural patterns. Colletta and colleagues’ results support McNeill’s hypothesis that language and gesture competency develop similarly. Yet, cross-sectional studies (e.g., Colletta et al., 2010) oblige us to infer the developmental path. Colletta and colleagues (2010) also employed a narrative context in which gestures are more likely to be produced (i.e., visuo-spatial elements in a cartoon). Thus, the present study will obtain data from school age TD children and those with unilateral PS in a biographical interview context, at two data points between 5 to 9 years of age, to track gestural and language trajectories in order to test the hypothesis of gesture-language integration.

**PERINATAL STROKES (PS): AN OVERVIEW**

Although stroke can occur in all age groups with varying prevalence and extent of lesions (e.g., size, bilateral or unilateral), the current longitudinal study focuses on children with unilateral PS. Perinatal Stroke occurs during the last trimester of gestation up through the first month post-natally. Compared to the prevalence of approximately three strokes in every 100 adults (20 years old and above), the prevalence of PS is estimated to be 1 in 4,000 children, which may be underestimated as there are variations of diagnostic criteria (American Heart Association, 2010; Lynch, 2009; Lynch, Hirtz, DeVeber, & Nelson, 2002).

Stroke is a cerebrovascular event of decreased blood flow or hemorrhage in a restricted neural region due to an infarct or tearing of a cerebral artery, resulting in neural damage (Davis, 2007). The right and the left middle cerebral arteries are large branched arteries commonly involved in PS and adult strokes that result in right- or left-hemispheric cortical lesions. These arteries supply nutrients to the lateral surfaces of the cortex in each hemisphere, covering primarily the frontal, parietal, and temporal lobes (Lynch et al., 2002). Subsequent lesions can affect speech and language, motor, and sensory function as in adult lesion studies. One major difference between PS and adult strokes is age and the status of the developing brain. Children who survive a PS are confronted with different challenges than adults, because the timing of brain injury occurs prior to motor, cognitive, and behavioral maturity. Prospective studies in children with PS are recent as the tools to diagnose lesions at birth only became available in the later part of the 20th century. As such, much less is known about the nature and the extent of the brain’s alternative organization due to an early insult. To date, studies on language development in the PS group have confirmed the neuroplasticity of the developing brain; unilateral perinatal stroke is less likely to affect language ability as severely as in adults (Basser, 1962; Bates et al., 2001; Chilosi et al., 2008; Feldman, 2005; Lenneberg, 1967; Libzda, Wilke, Staudt, Krägeloh-Mann, & Grodd, 2008; Reilly, Levine, Nass,
Stiles, 2008; Staudt et al., 2002; Stiles, Nass, Levine, Moses, & Reilly, 2009; Stiles, Reilly, Paul, & Moses, 2005). As such, children with PS offer a unique opportunity to better understand brain behavior relations and the developing brain; specifically, communicative development in children with PS can extend our understanding regarding the nature and extent of neural plasticity for language and gesture.

**LANGUAGE DEVELOPMENT AND GESTURES IN UNILATERAL PS**

We will first chronicle gestural and language development starting with infants and young toddlers with unilateral PS.

**Early Development: Scant Research and Mixed Evidence for Mcneill’s Hypothesis**

The existing literature has found very different language deficits when comparing children with unilateral PS to adults with focal lesion due to stroke despite similar neuro-anatomical lesions. Before age five, there is an overall delayed communicative ability in children with unilateral lesions, including delayed onset of babbling, communicative gestures, word comprehension and first words (Bates et al., 1997; Marchman, Miller, & Bates, 1991; Sauer et al., 2010; Thal et al., 1991; Vicari et al., 2000). Additionally, high variability has been noted within the unilateral PS group’s language performance compared to TD performance (Feldman, Holland, Kemp, & Janosky, 1992; Thal, Reilly, Seibert, Jeffries, & Fenson, 2004).

Within this overall delay, there are laterality effects that do not mirror the adult profile. For example, Bates and colleagues (1997) found children ages 10-44 months with LHI or RHI displayed expressive language delays in the lexicon and morpho-syntax. However, expressive language deficits were more severe in those with LH temporal injury, but receptive language and gesture production were relatively spared. The LH temporal injury profile in children with PS contrasts with that in the adults with LH temporal lesion, who instead have comprehension deficits. In contrast to the RH deficits associated in adults, toddlers with RHI showed mild delays in overall language, but a severe delay in gestures. These results have implications for lateralization of function, neural plasticity, and the gesture-language relationship. RH involvement in early language development contradicts adult RHI profiles and calls into question the notion of a mostly LH bias for language. Receptive vocabulary and gesture production highly correlated, which mirrors the initial findings in late bloomers by Thal and Bates (1988) mentioned earlier. These findings also suggest an early bilateral recruitment for language acquisition. Other studies of young children with unilateral lesions have also reported delay for the group as a whole with the LH group further behind for language production (e.g., Chilosi et al., 2008; Vicari et al., 2000).

Unlike Bates and colleagues (1997) findings, Sauer and colleagues (2010)’s longitudinal study did not find a significant laterality effect within language (receptive and expressive) and gesture abilities. Though children were similar in age (18-32 months) for both studies, Bates and colleagues
(1997)’s findings were based on parental report. Instead, lesion size and type (cortical compared to sub-cortical) were critical variables in performance in Sauer and colleagues (2010). Specifically, children with a small peri-ventricular (sub-cortical) lesion were more likely to use gestures typically and to subsequently develop typical language than those with cortical and larger sized lesions. Cortical lesions were associated with decreased gestures and the predicted atypical lexical development. The cross-sectional study (Bates et al., 1997) using the MBCDI reports different findings from a longitudinal experimental study in a play context (Sauer et al., 2010).

Also, Sauer and colleagues (2010) found that gestures predicted subsequent overall language abilities in both the PS and TD groups. Gestures types (e.g., point to a cup and point to a ball are counted as two types) and speech production were measured during parent-child play. In both TD and PS groups, gesture ability at 18 months positively correlated with receptive and expressive vocabulary growth at 22, 26, and 30 months: the children with PS who produced gestures comparably to TD controls predicted typical expressive lexical development at 22 and 26 months, as well as a typical receptive vocabulary at 30 months. In contrast, the children with PS who produced gestures less frequently than the TD controls at 18 months did not display typical lexical development at 22 and 26 months like the controls. TD and PS groups produced primarily deictic gestures.

The scant PS literature has yet to provide consistent findings in toddlers regarding the nature of language and gesture development in PS, raising questions regarding McNeill’s hypothesis. Moving into school age, there are no other studies that address gesture development. A pertinent question is the following: what is the relation between gesture and language in school age children with unilateral PS?

**Language in School Age Children with Unilateral PS: Varying Strengths**

The gesture-language studies in the unilateral PS group are limited to toddlers; there are currently no known gesture/language studies during school age. However, many have examined narrative and morpho-syntactic performance amongst school age children with PS in cross-sectional studies. Beyond the preschool years, children with PS generally make gains and have functional language ability comparable to that of their TD peers. Findings have consistently found no RHI or LHI differences in language performance in school age children with PS in spontaneous discourse contexts. In these tasks, children with PS demonstrate either comparable or slightly poorer performance than TD children depending upon the specific linguistic measures examined (Bates et al., 2001; Demir et al., 2009; Reilly et al., 1998, 2004; Reilly & Appelbaum, 2011).

Besides TD adults and adults with RH and LH lesion, the aforementioned Bates and colleagues (2001) study also included TD children, and those with LHI and RHI (ages 5-8) in a biographical interview. Results for the children with unilateral PS revealed no left-right differences and found comparable functional language ability on many grammatical measures, including
morphological errors and frequency of complex syntax. Overall, from a functional perspective in morpho-syntactic performance, children with PS were as competent as their TD age peers.

Several cross-sectional studies (Demir et al., 2009; Reilly et al., 1998, 2004; Reilly & Appelbaum, 2011) have examined spontaneous discourse in both PS and TD groups through narrative performance. Reilly and colleagues (1998, 2004) and Reilly & Appelbaum (2011) elicited narratives from PS and TD children. In these three studies, morpho-syntactic results in children ranging approximately 3-16 years indicated decreased gaps between PS and TD groups over time, but children with PS continued to lag behind TD peers in specific measures (e.g., morphological errors, syntactic complexity) during early teenage years. Similar to the control group, narrative ability in the PS group improved with age; however, the PS group produced shorter and simpler narratives compared to their TD peers. Similarly, Demir and colleagues (2009) found that children with PS (5-8 years) performed within the normal range in both vocabulary and syntax, but lower in narrative performance than TD peers, although not statistically different. Within the spontaneous contexts, narrative discourse poses a bigger challenge for children with PS, suggesting that their language performance varies in contexts with varying degrees of language demands.

**Overall Development in Children with PS: Near-Normal Performance Over Time**

As opposed to presenting with prolonged and persistent language impairments as in the adult stroke population, children with RHI or LHI demonstrate initial delays at the onset of language development, and delays while transitioning through steps of acquiring language. However, in spontaneous speech, they eventually display language skills comparable to that of their TD peers. These children’s profiles did not mirror the deficits in adults with comparable injuries, which may suggest that the neural mechanisms for language and communicative development begin with recruiting the cortex more diffusely and transition into a more focalized network that is more lateralized as they develop (Reilly & Appelbaum, 2011).

Considering early development and school age studies on language in the PS group, there is general support of the neural plasticity hypothesis, where differences in performance between PS and TD groups decrease with age. Moreover, after age five there were no language differences between those with right or left lesions. Comparisons with adult stroke patients also reveal an advantage: children with PS produced proportionally fewer errors than adults with homologous lesions. Although there are no significant differences between unilateral PS and TD children in spontaneous speech, children with unilateral PS showed more varying rates of acquiring specific linguistic knowledge as compared to TD children: some performed within the normal range, but others lagged behind. Discourse context also affects their language performance (i.e., biographical interview vs. narratives). The protracted trajectory in language acquisition may suggest the limitations of neural plasticity from an early neural injury. The present study is a longitudinal study of school age children with unilateral
PS between the ages 5 through 9 that explores the nature and extent of language and gesture development and their relations with neural plasticity.

THEORETICAL ASSUMPTIONS: COMMUNICATIVE GESTURE-SPEECH INTEGRATION

One missing piece of the puzzle regarding communication in the PS group is the gestural development during school age. Does school age gesture development in the PS population support McNeill’s hypothesis, that is, does gesture use and development parallel development in language? Most of the aforementioned findings in the adult and children literature have supported the hypothesis that communicative gestures are related to speech at the conceptual level as they convey additional content in the speaker’s message. Specifically, in addition to language, communicative gesture may be a critical participant during the conceptual and planning levels of communication. Therefore, the overall assumption is that to truly evaluate the speaker’s ability to communicate, both must be examined together during spontaneous production (Bates & Dick, 2002; Goldin-Meadow, 2003; McNeill, 1992, 2005; Sauer et al., 2010). It is in this context, where speech and gestures co-occur in a multi-dimensional fashion and convey unique information in each modality (visual and auditory modalities and their timing), that the speaker produces a semantically-rich message (Caselli & Vicari, 1998; Colletta et al., 2010; Goldin-Meadow, 2003; McNeill, 2005; Ozcaliskan & Goldin-Meadow, 2005; Scharp et al., 2007). The present study seeks to understand this interaction and its development in school age children through gesture’s function with regards to the content of speech.

PURPOSE OF THE STUDY

During the prelinguistic stages of development, gesture use is the primary means for communication in young toddlers. However, the gesture-language literature has not yet fully addressed gestures’ roles or functions beyond two-word productions, as the communicative preference shifts toward language in older children. This study is designed to examine school age TD children and children with PS in both language and gesture development and how both modalities co-occur. With respect to children with PS, significant language differences between TD and children with PS in spontaneous speech are generally resolved by school age. Yet, questions still remain whether gesture development would be similar to that of language. If the gestural development does not indicate lesion side differences in children with unilateral PS, and they display TD-like gesture use by school age, this would suggest gesture-language integration. Hence, McNeill’s hypothesis would predict that gesture development in TD and PS groups will follow a similar profile to each of their respective language trajectories.

In consideration of the limited gestural developmental research in school age children, the current study will chronicle gesture performance in a quasi-naturalistic setting in school age children with PS (ages 5 through 6 and ages 7 through 9) compared to their TD age matched peers to evaluate this cross-modal development communication of gesture and speech. In addition to gesture
frequency, diversity and type, the present study will address gesture complexity, and importantly, the relations between gesture and speech in TD children and in those with PS.

The subsequent findings will allow us to address the following questions:

1. What are the gestural trajectories in TD children and those with PS?
2. Do children with PS show similar gestural laterality profiles to those of the adults with homologous lesions?
3. What is the relation of gesture to language in the PS group and will it support the McNeill hypothesis?
4. What is the extent of neural plasticity in terms of gesture development?
5. What are the some clinical implications of these findings?

HYPOTHESES

In the present study, the outcome measures address the issues of laterality, neuroplasticity, as well as the relation of language and gesture from both cross-sectional and longitudinal perspectives.

Question One: Laterality at Time 1 and Time 2

Are there laterality differences in language and gesture use in children with RHI and those with LHI? Our first question tests McNeill’s proposal that language and gesture are integrated and represent one communicative system.

1. No laterality differences: If McNeill’s hypothesis is correct that language and gesture are an integrated system, then there will be no differences in performance for children with right versus left hemisphere injury in language measures on morphological errors, as seen in previous school age PS literature for language (e.g., Bates et al., 2001), or in gesture diversity and gestural function within the PS group (LHI vs. RHI) at ages 5 through 6 years and at 7 through 9 years.

2. Laterality differences between RHI and LHI groups: Recall that in the PS literature for spontaneous language performance that laterality differences resolve by early school age. Contrary to McNeill’s hypothesis and previous language findings in children with PS, laterality differences in both lesion groups will suggest that gesture and language are not parallel in development.

Question Two: The Relations between Gestural and Language Productivity

Question 2A (Cross-sectional): Are gesture and language productivity correlated for the TD and PS groups? In the context of the PS group’s near-normal language performance in spontaneous speech, McNeill’s hypothesis would predict that gestural production in the PS group will also be comparable to that of the TD group performance:

1. No delay: The PS group at Time 1 and Time 2 will be comparable to the TD group on gestural productivity.

2. Gesture delay in PS: Since the PS group is delayed for the initial acquisition of each linguistic milestone (Reilly et al., 2008)
Question 2B (Longitudinal): Does the rate of gesture to language production change over time?

1. No group or age differences: The McNeill’s hypothesis would predict that gesture and language would co-develop. To test this possibility we compared the productivity across time in both modalities. Consistent with TD and PS school age literature, productivity in language and gesture increase between Time 1 and Time 2 for both PS and TD groups.

Question Three: Development in Gestural and Language Performance

How do language and gestural performance change over time in both PS and TD groups? There are no known studies for the gestural development. However, these are the possible predictions:

1. No group or age differences: Consistent with McNeill’s hypothesis and previous language findings, language performance measures will reveal no TD-PS group differences over time. If gestural development co-develops with language, gestural measures will also reveal that TD and PS groups have comparable performance.
CHAPTER 2

METHOD

PARTICIPANTS

Participants included 20 school age children with unilateral PS (10 with RHI and 10 with LHI), and 20 age-matched TD children at 5 and 6 years of age (Time 1). A subset of these same children (n=28) at Time 1 – 15 children with PS (5 with RHI and 10 with LHI) and 13 TD children were examined at 7 and 9 years of age (Time 2). Longitudinal comparisons included only the 28 children at 5 and 6 years of age to observe within-subject developmental changes. Each research question consisted of different participant contribution of gestural and language performance. Thus, participant data will be discussed for each question.

For Question One in assessing laterality differences, only children with RHI and LHI were compared. At Time 1, there were two groups (n=20), RHI (n=10) with 6 males and 4 females (average age 5.5 years; range: 5.0 years – 6.5 years), and LHI (n=10) with 4 males and 6 females (average age 5.75 years; range: 5.0 years – 6.33 years). At Time 2, participants with PS (n=15) were RHI (n=5) with 4 males and 1 females (average age 7.83 years; range: 7.08 – 9.5 years), and LHI (n=10) with 4 males and 6 females (average age 8.08 years; range: 7.0 – 9.33 years).

For Question Two, cross-sectional and longitudinal perspectives of gestural and language productivity were examined. For the cross-sectional question (2A), 40 participants at Time 1 included the RHI group (n=10) with 6 males and 4 females (average age 5.5 years; range: 5.0 years – 6.5 years), the LHI group (n=10) with 4 males and 6 females (average age 5.75 years; range: 5.0 years – 6.33 years), and TD control (n=20) with 10 males and 10 females (average age 5.83 years; range: 5.08 – 6.67 years). 28 participants at Time 2 included the RHI group (n=5) with 4 males and 1 females (average age 7.83; range: 7.08 – 9.5 years), the LHI group (n=10) with 4 males and 6 females (average age 8.08 years; range: 7.0 – 9.33 years), and the TD control (n=13) with 7 males and 6 females (average age 8.08 years; range: 7.08 – 9.75 years).

Question 2B (longitudinal perspective for gestural and language productivity) and Question 3 consisted of analyzing within-subject performance in 28 participants. At Time 1 (5-6 years), the RHI (n=5) group's average age was 5.5 years (range: 5.0-6.5 years); the LHI (n=10) group’s average age was 5.75 years (range: 5.0-6.3 years); and TD control (n=13) group's average age was 5.92 years (range: 5:1-6.5 years).

All participants participated in a longitudinal study in the Project of Cognitive and Neural Development in San Diego, California. Inclusion criteria for all participants include: monolingual English speakers, normal hearing, normal or assisted vision, and an IQ within the normal range.
The inclusion criteria for the PS group include: one unilateral focal lesion in the absence of other or more diffuse pathology. All participants’ dominant hands are ipsilateral to the lesion side. The focal lesion occurred within the last trimester of gestation or within the first four weeks after birth as indicated by *Magnetic Resonance Imaging* (MRI) or *Computed Tomography* (CT) scan (see Appendix). The TD group had no history of developmental delay and was neurologically intact, as confirmed by *Wechsler Intelligence Scale for Children* (WISC-R) (Wechsler, 1974), *Clinical Evaluations of Language Fundamentals, Revised or 3rd edition* (CELF-R or CELF-3) and neurological assessments (Semel, Wiig, & Secord, 1995). Table 1 listed the standardized language performance for all forty participants.

**PROCEDURES**

In the beginning of each experimental session, the child participant first engaged in a semi-structured biographical interview. The child was asked a set of opened-ended questions (e.g., “tell me about your hobbies”), and the experimenter subsequently followed up with questions and comments specific to the child’s responses. The interviews were audio and video recorded. Table 2 contains the total and mean length of biographical interview for TD and both lesion groups at both time points.

Language data were recorded on audio cassettes and were transcribed using the Codes of Human Analysis of Transcripts (CHAT) system from the Child Language Data Exchange System database (CHILDES; MacWhinney & Snow, 1985). Video cassettes were transformed into digital format to allow for analysis using the Eudico Linguistic Annotator (ELAN; Lausbery & Sloetjes, 2009). ELAN is a software platform that is used to create multi-tier annotations using audio and video data. This permits real-time integration and ELAN computes information regarding duration, frequency, and latency. For the purpose of this study, tiers were created for both child and experimenter utterances; the child’s utterances are timed for word onset and offset; gestures within a gesture sequence were also timed for onset and offset.

For Question One, the mean length per interview obtained for each participant at Time 1 were as follow: 6 minutes 38 seconds (total: 66 minutes 29 seconds) in the RHI group, and 5 minutes 41 seconds (total: 56 minutes 52 seconds) in the LHI group. At Time 2, the mean length was 7 minutes 53 seconds (total: 35 minutes 36 seconds) in the RHI group, and 6 minutes 20 seconds (total: 63 minutes 21 seconds) in the LHI group.

For Question 2A, the mean length per interview obtained for each participant at Time 1 were as follow: 6 minutes 38 seconds (total: 66 minutes 29 seconds) in the RHI group, 5 minutes 41 seconds (total: 56 minutes 52 seconds) in the LHI group, and 6 minutes 43 seconds (total: 134 minutes 23 seconds) in the TD group. At Time 2, the mean length was 7 minutes 53 seconds (total: 35 minutes 36 seconds) in the RHI group, 6 minutes 20 seconds (total: 63 minutes 21 seconds) in the LHI group, and 7 minutes 24 seconds (total: 96 minutes 20 seconds) in the TD group.
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Table 2. Summary of Biographical Interview Length by Group and Time

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<td>Time 2: 7-9 years</td>
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<td>96 min 20 sec</td>
<td>N = 5 (7 min 53 sec)</td>
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For Question 2B (longitudinal) and Question 3, the average length per interview obtained per participant at Time 1 was 6 minutes 24 seconds (total: 32 minutes 2 seconds) in the RHI group, 5 minutes 41 seconds (total: 56 minutes 52 seconds) in the LHI group, and 6 minutes 20 seconds (total: 82 minutes 27 seconds) in the TD group. At Time 2, the mean length was 7 minutes 53 seconds (total: 35 minutes 36 seconds) in the RHI group, 6 minutes 20 seconds (total: 63 minutes 21 seconds) in the LHI group, and 7 minutes 24 seconds (total: 96 minutes 20 seconds) in the TD group.

**OUTCOME MEASURES AND OPERATIONAL DEFINITIONS:**

**GESTURAL CODING CONVENTIONS**

In order to avoid the influence of speech in gestural coding, all gestural coding, except for functions of gestures to speech, were completed without audio.

**Gestural Frequency:** *Gesture:* In addition to Scharp and colleagues (2007)’s formal definition for communicative gestures, the present study adapted McNeill’s phases of gestures to define the beginning and the end of a single gesture (McNeill, 2005). The optional pre-stroke phase or the stroke phase mark a gesture onset, and post-stroke phase marks the end of a gesture.

**Gestural Rate** is the ratio of Gestures Total and Productivity Index to control for interview length (see Productivity Index). Due to varying degrees of hemiparesis in the non-dominant hand contralateral to the lesion side in the PS group, all gestures produced with the dominant hand are coded in both PS and TD groups, but gestures produced uniquely by the non-dominant hand are excluded from the study.
**Gestural sequence**: It is a series of communicative gestures produced continuously. A gestural sequence begins with hand or arm movements (including the shoulders) beginning to leave rest position and ends when limbs come to a resting position or there is an extended pause in movement. Thus, during a spontaneous discourse, the onset of a gesture sequence can occur before, co-terminus, or after an utterance. The sequence may also overlap two or more utterances. Single gestures and components are identified for more detailed analyses.

**Gesture complexity**: Changes at the featural level: The number of M-O-S markers per gesture (movement (M), orientation (O), and shape (S)). A *gestural component* consists of M, O, and S aspects. Transitioning from one component to the next is marked by at least one change in M, O, or S, or a combination of those (i.e., M, O, S, M+S, O+S, M+O, M+O+S). This measure will evaluate the internal changes within a gesture. The total number of featural changes will be divided by gesture total to yield an index of Gesture Complexity. At minimum, a gesture contains one component with zero featural changes.

**Language Measures**

These measures were adapted from Reilly et al. (1998).

**Productivity Index**: Total number of propositions is obtained to control for varying lengths in the language samples. It also serves as the denominator for gesture frequency measures. A proposition contains a verb/copula and its obligatory arguments; a proposition can be considered one semantic event. Morphological errors or omissions are not part of the criterion so they are included as long as the verb/copula and all obligatory arguments are present and intelligible. Hence, the utterance, "a boy who taked the book running away", contains two propositions; one verb (*running*) and its argument (*a boy*) in the main clause, and another verb (*taked*) and its arguments (*a boy*, *the book*) in the subordinate clause. Additionally, filler statements (e.g., "Maybe he didn’t want to go, I dunno," "I really didn’t want to go, you know?") were excluded. The variable reporting the number of propositions is Propositions Total for the number of propositions derived from the biographical interview. Since children’s language samples vary in length, the number of propositions also serves as a denominator to create the variables Rate of Morphological Errors and Rate of Complex Syntax (see below).

**Morphosyntactic Errors**: As a measure of the child’s mastery of English morphosyntax, all uncorrected errors were tallied. Error types included both errors and omitted obligatory morphemes, as in the following:

1. copula or auxiliary errors: as in *He (0) walking, He (0) happy about it*
2. agreement errors: *He were sleeping, they was coming; those boy (0) kicked…*
3. errors in verb form: *I haved a cat; He got aten*
4. errors on word order: *She is very a smart girl.*
5. pronominal errors: *Him was hitten’ me.*
determiner errors: and (0) boy ran away

The total number of errors was divided by the total number of propositions to create a proportion, Rate of Morphological Errors which is coded into the variable MorphErr.

**Syntactic Complexity:** The number of complex sentences was counted to determine the frequency of complex syntax. All coordinate sentences, verb complements, relative clauses, passive sentences, and dependent clauses were included. To derive a frequency measure that is controlled for story length, the total number of complex constructions was divided by the number of propositions in the child’s story to yield Rate of Complex Syntax as CompSyn.

**Co-Speech Gesture Combinations**

The relations between gesture and speech is analyzed by specific roles of gesture and language. Adapting the coding system from Colletta et al. (2010), Ozcalıskan, & Goldin-Meadow (2006), and Capirci & Volterra (2008), the index of Gestural Functions is the ratio of each function category and Gestures Total, which will be coded according to the following categories:

1. **Reinforcement:** gestures that repeat information that is also conveyed in the utterance. For example, “I don’t know” accompanied by a shrug.

2. **Integration:** gestures that provide new and optional details regarding the referent in the utterance. For example, “you can take the exit by the restroom”, gesture with an “open five” hand moving right to left (indication direction).

3. **Supplemental:** gestures that provide new and obligatory information different from the utterance. For example, “you can take this exit” while pointing to the door.

**Inter-Rater Reliability**

A second coder who was blind to the group status coded 25% of the language samples for all language, gestural, and co-speech gestural measures for reliability; agreement for all measures should exceed 85%.
CHAPTER 3

RESULTS

The relationship between gesture and language development in school age children with PS and their TD peers was explored through a semi-structured biographical interview. Figure 1 provides a snapshot of ELAN software program platform where language and gestural coding were integrated. In consideration of both McNeill’s hypothesis that language and gesture form an integrated system and the adult lesion model for language and gestural performance, three research questions were addressed regarding the relationship between gesture and language in development. We used data from three groups of children at two time points—TD, RHI, and LHI groups at Time 1 (5 to 6 years) and Time 2 (7 to 9).

Figure 1. Screenshot of the ELAN software program. Tiers of various linguistic and gestural behaviors are integrated at the bottom display. The upper right hand display shows tier-specific onset, offset, and duration of each annotation.
To summarize our findings, the overall results indicate no laterality differences in either
gesture or language performance between children with RHI and those with LHI. These findings
suggest that language and gesture develop similarly over time for children with PS. In addition, we
found that language and gesture performance also develop in parallel in the TD group. Finally, the
use of gesture with respect to language in children with PS is comparable to that of their TD peers.
Table 3, Table 4, and Table 5 present mean values and standard deviations for all linguistic and
gestural measures.

Table 3. Question 1: Descriptive Statistics for RHI and LHI Groups at Time 1 and Time 2

<table>
<thead>
<tr>
<th>Measures</th>
<th>Time 1 (5-6 years)</th>
<th>Time 2 (7-9 Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RHI</td>
<td>LHI</td>
</tr>
<tr>
<td></td>
<td>n = 9</td>
<td>n = 10</td>
</tr>
<tr>
<td>Propositions Total</td>
<td>30.3 (20.6)</td>
<td>42 (28.9)</td>
</tr>
<tr>
<td>Gestures Total</td>
<td>15.3 (7.57)</td>
<td>9.6 (9.06)</td>
</tr>
<tr>
<td>MorphErr¹</td>
<td>0.14 (0.17)</td>
<td>0.10 (0.12)</td>
</tr>
<tr>
<td>Gestural Complexity²</td>
<td>1.26 (1.06)</td>
<td>1.07 (1.20)</td>
</tr>
<tr>
<td>Reinforcement³</td>
<td>35.2% (17.3)</td>
<td>23.8% (20.1)</td>
</tr>
<tr>
<td>Integration³</td>
<td>42.0% (17.0)</td>
<td>55.2% (27.2)</td>
</tr>
<tr>
<td>Supplemental³</td>
<td>21.8% (19.8)</td>
<td>10.9% (10.6)</td>
</tr>
</tbody>
</table>

¹ Number of Morphological Errors per Proposition.
² Number of Featural Changes per gesture.
³ Percentage of this Gestural Function to Gestures Total.
⁴ All parenthesized values represent standard deviations.

Table 4. Question 2A: Cross-Sectional Descriptive Statistics for TD and PS Groups at Time 1 and Time 2

<table>
<thead>
<tr>
<th>Measures</th>
<th>Time 1, 5-6 years</th>
<th>Time 2, 7-9 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TD</td>
<td>PS</td>
</tr>
<tr>
<td></td>
<td>n = 20</td>
<td>n = 19</td>
</tr>
<tr>
<td>Propositions Total</td>
<td>64.9 (24.9)</td>
<td>36.5 (25.4)</td>
</tr>
<tr>
<td>Gestures Total</td>
<td>16.35 (11.7)</td>
<td>12.3 (8.71)</td>
</tr>
</tbody>
</table>

Note: All parenthesized values represent standard deviations.

Subject Analysis for Outliers

Prior to hypothesis testing, influence statistics and leverage were completed to identify
potential outliers at Time 1 and Time 2. One participant (Child no. 8 [RHI]) was detected as a
potential outlier. At time 1, this participant produced high amounts of language and gestures during
the biographical interview, with 67 gestures (2.61 standard deviations above the RHI group mean of
17.83) and 123 propositions (2.37 standard deviations above the RHI group mean of 39.6
propositions). All analyses were run initially with and without the data of this participant, and the
overall results were the same. However, his inclusion inflated some of the statistics (e.g., $R^2$ dropped
by approximately 0.10 when he was excluded).
Table 5. Questions 2B & 3: Longitudinal Descriptive Statistics for TD and PS Groups at Time 1 and Time 2

<table>
<thead>
<tr>
<th>Measures</th>
<th>Time 1, 5-6 years</th>
<th>Time 2, 7-9 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TD</td>
<td>PS</td>
</tr>
<tr>
<td></td>
<td>n = 13</td>
<td>n = 15</td>
</tr>
<tr>
<td>Propositions Total</td>
<td>66.0 (17.3)</td>
<td>42.2 (25.4)</td>
</tr>
<tr>
<td>Gestures Total</td>
<td>16.0 (9.45)</td>
<td>12.0 (9.16)</td>
</tr>
<tr>
<td>Gestural Rate 1</td>
<td>0.25 (0.18)</td>
<td>0.34 (0.28)</td>
</tr>
<tr>
<td>MorphErr 2</td>
<td>0.05 (0.04)</td>
<td>0.10 (0.10)</td>
</tr>
<tr>
<td>CompSyn 3</td>
<td>0.54 (0.12)</td>
<td>0.46 (0.18)</td>
</tr>
<tr>
<td>Gestural Complexity 4</td>
<td>1.29 (1.00)</td>
<td>1.20 (1.15)</td>
</tr>
<tr>
<td>Reinforcement 5</td>
<td>32.3% (19.6)</td>
<td>28.2% (20.0)</td>
</tr>
<tr>
<td>Integration 5</td>
<td>55.5% (22.4)</td>
<td>50.6% (24.9)</td>
</tr>
<tr>
<td>Supplemental 5</td>
<td>12.2% (13.9)</td>
<td>14.4% (12.1)</td>
</tr>
</tbody>
</table>

*Within-participant group means for longitudinal comparisons.
1. Number of Gestures per Proposition.
2. Number of Morphological Errors per Proposition.
3. Number of Dependent Clause per Proposition.
4. Number of Featural Changes per gesture.
5. Percentage of Gestural Function to Gestures Total.
All parenthesized values represent standard deviations.

There is no good solution to this problem. We have no evidence that this participant’s data were poorly collected or analyzed, and we cannot discard the data on those grounds. But, we also do not wish to present statistics that are highly influenced by a single participant. Because the main results were unchanged when he was excluded, we conclude that his data impact only the size, not the direction or significance, of the statistics. Therefore, we take the conservative approach of excluding this child from the statistical analyses and exploring his gesture and language performance separately in the Discussion section.

**INTER-RATER RELIABILITY: GESTURAL AND LINGUISTIC MEASURES**

Inter-rater reliability was measured in 25% of total data (both gesture and language coding). For gestural measures, the overall inter-rater reliability was 94.42%; 93.65% for the total of gestural type; 92.10% for the total of gestural function; 89.86% for the total of gestural components; and 88.97% for the total of featural changes. For linguistic measures, the overall inter-rater reliability was 96.21%; 98.2% for propositions total; 97.65% for the total of morphological errors; and 92.08% for the total of complex syntax.

Question One: Are there laterality differences in language and gesture use in children with RHI and those with LHI?
RESULTS: LATERALITY DIFFERENCES AT TIME 1 AND TIME 2

This question focused on the laterality differences between children with RHI and those with LHI in gesture and language performance. Gestural measures were Gestural Function (Reinforcement, Integration, and Supplemental) and Gestural Complexity (Featural Changes per gesture). The linguistic outcome measure was MorphErr (morphological errors per Proposition). Independent sample T-tests were completed for each condition of Gestural Functions (Reinforcement, Integration, Supplemental) at Time 1 as well as for MorphErr and Gestural Complexity. Similar tests were carried out on the same outcome measures for performance at Time 2. There were no significant differences in language or gesture performance between children with RHI and children with LHI at Time 1, indicating that there are no lesion group differences for gesture and language performance. Similar to the findings in Time 1, no measures revealed significant differences at Time 2. Overall, lesion group differences were not present at Time 1 or Time 2 for either gesture or language production. Mean values for these measures are presented in Table 1.

Given comparable performances between both lesion groups in language and gesture, the RHI and LHI groups were combined to form the PS group. As such, the remaining two questions compared gesture and language productivity and performance between the PS as a whole and their typically developing controls (TD).

Question Two: (2A) Are gesture and language productivity correlated for the TD and PS groups?

RESULTS (2A): CROSS-SECTIONAL GESTURAL AND LANGUAGE PRODUCTIVITY

This two-part question investigates gesture and language productivity utilizing both cross-sectional and longitudinal methods. In the cross-sectional data, the relation between gesture and language productivity (total number of Gestures and Total number of Propositions) were examined in the TD and PS groups. Mean values for Total Propositions and Total Gestures are in Table 2. Individual hierarchical regression models were run separately for Time 1 and Time 2, regressing Gestures on Group and Propositions. Group information was dummy-coded, using the TD group as the reference group (i.e., coded zero on the dependent variable). Group was always entered alone in the first step as the first variable to determine whether there are group differences on the dependent variable, Gestures Total, followed by Propositions entered on the second step, and lastly the interaction between group and Propositions on the third step.

Both regression analyses yielded significant R² values, indicating a strong relationship between Number of Propositions and Number of Gestures Total at Time 1 and Time 2. At step one of the analyses at Time 1, we did not find a correlation between Group and Gestures Total. At step two of the analysis at Time 1 the model containing Group and Propositions accounted for 28.6% of the variance of Gestures Total (R² = .286 with adjusted R² = .246), F (1, 36) = 12.417, p = .001. The
additions of Group and Group by Propositions were not significant. Time 1 $R^2$ and coefficient values are listed in Table 6.

**Table 6. Cross-Sectional: Time 1 (TD, n = 20; PS, n = 19). Time 1 Summary of Separate Hierarchical Regression Analyses for Variables Predicting Gestural Productivity**

<table>
<thead>
<tr>
<th>Model</th>
<th>$R^2$</th>
<th>$B$</th>
<th>Std. Error</th>
<th>Beta</th>
<th>$t$</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1 Group (PS)</td>
<td>.039</td>
<td>-4.087</td>
<td>3.317</td>
<td>-.199</td>
<td>-1.232</td>
<td>.226</td>
</tr>
<tr>
<td>Step 2 Group (PS)</td>
<td>.286*</td>
<td>1.840</td>
<td>3.352</td>
<td>.089</td>
<td>.549</td>
<td>.586</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.209</td>
<td>.059</td>
<td>.574</td>
<td>3.524</td>
<td>.001</td>
</tr>
<tr>
<td>Step 3 Group (PS)</td>
<td>.039</td>
<td>5.823</td>
<td>6.914</td>
<td>.283</td>
<td>.842</td>
<td>.405</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.248</td>
<td>.084</td>
<td>.681</td>
<td>2.947</td>
<td>.006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-.079</td>
<td>.119</td>
<td>-.192</td>
<td>-.660</td>
<td>.513</td>
</tr>
</tbody>
</table>

Similar results were found for Time 2; we did not find a correlation between Group and Gestures Total at step one. At step two, entering both Group and Propositions independent variables accounted for 32.6% of the variance in Gestures Total ($R^2 = .326$ with adjusted $R^2 = .272$), $F(1, 25) = 11.373, p < .05$. The additions of Group and Group by Propositions were not significant. Time 1 $R^2$ and coefficient values are listed in Table 7. This indicates that Number of Propositions and Number of Gestures Total were significantly correlated at both time points; that is, children who talked more used more gestures regardless of group.

**Table 7. Cross-Sectional: (TD, n = 13; PS, n = 15). Time 2 Summary of Two Hierarchical Regression Analyses for Variables Predicting Gestural Productivity**

<table>
<thead>
<tr>
<th>Model</th>
<th>$R^2$</th>
<th>$B$</th>
<th>Std. Error</th>
<th>Beta</th>
<th>$t$</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1 Group (PS)</td>
<td>.019</td>
<td>5.179</td>
<td>7.218</td>
<td>.139</td>
<td>.718</td>
<td>.479</td>
</tr>
<tr>
<td>Step 2 Group (PS)</td>
<td>.326*</td>
<td>10.124</td>
<td>6.277</td>
<td>.272</td>
<td>1.613</td>
<td>.119</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.257</td>
<td>.076</td>
<td>.569</td>
<td>3.372</td>
<td>.002</td>
</tr>
<tr>
<td>Step 3 Group (PS)</td>
<td>.366</td>
<td>-6.026</td>
<td>14.484</td>
<td>-.162</td>
<td>-.416</td>
<td>.681</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.206</td>
<td>.086</td>
<td>.457</td>
<td>2.397</td>
<td>.025</td>
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<tr>
<td></td>
<td></td>
<td>.221</td>
<td>.179</td>
<td>.468</td>
<td>1.234</td>
<td>.229</td>
</tr>
</tbody>
</table>

Question (2B): Does the rate of gesture to language production change over time?
RESULTS (2B): LONGITUDINAL GESTURAL AND LANGUAGE PRODUCTIVITY

Using the longitudinal data from Time 1 and time 2, we explored how the relationship between gesture and language production changed over time in the TD and PS groups. Our longitudinal data included 28 of the 40 cross-sectional subjects. We analyzed participants' proportions of gesture to language within-subjects to assess developmental changes in Gesture Rate (Gesture/proposition) between Time 1 and Time 2. Mean values for Gestural Rate are listed in Table 3. A 2x2 (Group x Age) ANOVA of Gestural Rate with the repeated measures on the second factor was carried out. There were no main effects for Group or Age, and there was no interaction between Group and Age, which indicates that the proportion of gesture to propositions, or more broadly the frequency of gesture to utterance, remains stable within-participant for both TD and PS groups over the two time points.

Question 3: How do language and gestural performance change over time?

RESULTS: DEVELOPMENTAL CHANGES IN GESTURAL AND LANGUAGE PERFORMANCE

To observe the individual developmental patterns for language and gestural performance, Question Three explored developmental changes in gestural and language performance in TD and PS groups. Mean values for all linguistic and gestural measures are in Table 3.

For gestural performance, four 2x2 (Group x Age) ANOVAs with repeated measures on the second factor were completed using Gestural Complexity and each condition of Gestural Function (Reinforcement, Integration, and Supplemental) as the dependent variables. There were no main effects found for Group or Age, and there was no interaction between Group and Age. For each Gestural Function condition (Reinforcement, Integration, and Supplemental), there were no main effects of Group or Age, and there was no interaction between Group and Age. The results for gestural measures indicated that there are no group or age differences in the distribution of functions and complexity of gestures.

Similar tests were carried out for the linguistic measures of MorphErr and CompSyn. Separate 2x2 (Group x Age) ANOVAs were carried out with repeated measures on the second factor. For MorphErr, there was a main effect for group, $F(1,26) = .6.223$, $p < .05$, but not for age, in which the PS group produce higher rate of morphological errors than the TD groups at both time points. Figure 2 illustrates the relatively low rate of morphological errors in both TD and PS group. There was no interaction between Group and Age.

For CompSyn, there was an interaction between Group and Age, $F(1,26) = .018$, $p < .05$, but there were no main effects for Group or Age. Simple effects tests (two separate T-Tests) for TD and PS groups were completed post-hoc to interpret the interaction. We found a significant change across age in the use of complex syntax for the PS group, $F(1,28) = 4.081$, $p = .05$ but not for the TD group. Figure 3 illustrates the interaction between both groups.
Figure 2. Group means of MorphErr over time between TD and PS groups. Main effect for group is found, but not for age. There was no interaction between group and age. The PS group consistently produces higher error rates in morphology than the TD group.

Figure 3. Group means of CompSyn over time between TD and PS groups. An interaction between group and age was found. There were no main effect for group and age. Simple effects test revealed that the rate of complex syntax significantly increases from Time 1 to Time 2 in the PS group, but not in the TD group.
CHAPTER 4

DISCUSSION, CLINICAL RAMIFICATIONS, AND CONCLUSION

The current study explores the relationship between gesture and language production and performance in children with PS and their TD peers. Children with PS provide an opportunity to examine the relationship between gesture and language development in the context of an earlier language delay. Previous literature in school age children with PS demonstrate comparable spontaneous language performance as their TD peers (e.g., Bates et al., 2001). The current study also allows us to examine the relationship between verbal and gestural communication, a non-verbal mode. It is in the context of a language delay that we can evaluate whether this relationship is consistent with McNeill's hypothesis that language and gesture form an integrated communicative system. In addition, the current literature is also scant in examining the gestural development in TD school age children. Three primary exploratory questions are formulated from McNeill's hypothesis, as well as from consideration of the language and gesture literature in adults who are neurologically intact and those with lesions.

In response to Question One, there were no laterality differences between RHI and LHI groups. We found no side-specific profiles and thus both groups were combined in the remaining analyses as the PS group. In response to the cross-sectional perspective of Question Two, gesture and language productivity were significantly correlated at Time 1 and Time 2 for both TD and PS groups. From the longitudinal perspective of Question Two examining the changes in the relationship between gesture and language production, there were no main effects for age or for group in Gestural Rate. Both groups' gestural and language productivity remained stable. In response to Question Three, separate language and gestural indices were examined longitudinally. For gestural performance, there were no main effects for age or for group, and there were no interactions in relations of gestural functions to speech and gestural complexity. Both groups were producing complex gestures, and the distribution of gestural functions in relation to speech did not differ. For language measures, a main effect for group was found for morphological error rates, and a statistically significant interaction between group and age was found for complex syntax rates. Both groups exhibited stable performance in morphological rates, but the PS group consistently produced higher rates of errors than the TD group, although the PS group's rate of morphological errors reduced over time. The PS group also exhibited a significant increase in their use of complex syntax when a simple effects test was completed subsequently to evaluate group contribution of the interaction effect.

In summary, the findings of the current study have confirmed McNeill's hypothesis for a gesture-language link and are consistent with previous findings within the school age PS literature.
regarding language performance. Yet, these results also show differences with respect to the
language and gestural profiles in adults with comparable lesions. Therefore, our data suggest a
developmental model for children with PS. Study limitations, variability in the PS population, neural
bases for language and gesture development, and clinical ramifications are discussed, in addition
to future directions.

**DISCUSSION**

Each question is first discussed, followed by the ramifications of McNeill's hypothesis and
the neural bases of gesture and language. Finally, study limitations and future directions are
indicated.

**Question One: Laterality Differences in Gestural and
Language Performance**

In Question One, we explored laterality differences in children with PS with regards to both
language and gestural use. We found that children with RHI and LHI were comparable in
morphological error rates, gestural complexity, and gestural function with respect to speech, at both
early school age (Time 1, 5-6 years of age) as well as at later school age (Time 2, 7-9 years of age).
No side specific profiles were found, as both gesture and language performances were comparable
between those with RHI and LHI. We tested McNeill's hypothesis that gestures and language are an
integrated system, and thus language and gestural production would develop in parallel. In earlier
studies of the PS group, laterality differences were reported in toddler and infant with PS for language
and gestures (e.g., Bates et al., 1997), and so far the literature reported that these laterality
differences are resolved as early as 5 years of age for language (e.g., Bates et al., 2001). If McNeill's
hypothesis holds, we would expect to find laterality differences in gestural performance between RHI
and LHI groups also resolved; that is, no differences for language and gestural performance. Indeed,
our findings for gestural performance are similar to that of language: laterality differences in gestural
and language performance are resolved in between the lesion groups at 5 and 6 years of age.
Moreover, the resolved differences in language and gestures remained stable at 7 to 9 years of age.
These results partially confirm McNeill's hypothesis for children with PS as language and gesture
performance did not vary between children with left and right hemisphere injury.

In chapter one, we also raised the notion of neural plasticity. Through our findings, we
attempted to understand language and gesture relations in children with early neural insult compared
to those of the adults with comparable injuries. Consistent with McNeill's hypothesis, gesture and
language performance are parallel for both adults and children with neural injuries. However, children
with neural injuries, or those with PS in the current study, demonstrate resolved side-specific
differences at 5 to 6 years of age, which suggests neural plasticity for not just language but also for
the gestural domain. For children with PS lesions, comparable spontaneous language and gestural
performance was observed between both lesion groups at 5 to 6 years of age. Initial delays in gesture
and language reported in the literature during toddler and infancy are resolved - as the side-specific delays in gestural and language performances converge between RHI and LHI groups at 5 to 6 years of age. Previous studies reported that toddlers with RHI display severe gestural and overall language delay, and toddlers with LHI display more severe expressive language delays, with intact receptive language and gestures (e.g., Bates et al., 1997). Side-specific differences in spontaneous language production are resolved by as early as 5 years of age (e.g., Bates et al., 2001). The current study found consistent results for gestural and language performance between the two lesion groups - no side-specific differences were found.

While for the adults with comparable lesions, their language and gestural deficits are consistent. For instance, adults with RHI display an overproduction of gestures, corresponding to their overproduction of language; adults with anterior LHI display informative but perseverative gestures, corresponding to their non-fluent but meaningful language; and adults with posterior LHI display fluid but incomprehensible gestures that correspond to their fluent but 'empty' speech. (e.g., Blonder et al., 1995; Cocks et al., 2009; McNeill & Pedelty, 1995). Again, these different characterizations of side-specific impairments in both language and gesture for adults with lesions are not observed in children with PS in the current study. Hence, a developmental model for language and gesture in children with unilateral lesions is suggested.

In this developmental model, toddlers and infants with PS demonstrate language and gestural delays at the onset of language development, as Sauer et al. (2010) found that gestures have a predicting role in expressive language development in toddlers with PS. Bates et al. (2001) found that while toddlers with RHI displayed more severe deficits in gestural productions and mild delays in overall language, and children with LHI displayed more severe expressive language deficits with relatively spared receptive language and gestural productions. By around ages 5 through 6 in kindergarten, these lesion-specific differences are resolved – children with RHI and those with LHI perform similarly in both gestural and language production. Up to 7 through 9 years of age, these school age children with RHI and those with LHI continue to perform similarly in gestures and language production.

**Question Two: The Relations between Gestural and Language Production**

Given comparable performance for language and gesture of those with RHI and LHI, we combined the groups to form the PS group. This is a two-part question that tested McNeill's hypothesis regarding the relationship between gesture and language, within the context of the language and gestural delays found in toddler and infant studies of children with PS. As early as 5 years of age, the PS literature reported comparable spontaneous language skills as their TD peers (e.g, Bates et al., 2001). Within this context, McNeill's hypothesis predicts that comparable gesture skills would be observed between children with PS and their TD peers. Addressing the relationship between gestures and language, we compared TD and PS group performance on gesture and
language productivity through cross-sectional (Question 2A) and a longitudinal perspective (Question 2B).

Through a cross-sectional perspective, we explored whether the productivity of gesture and language correlate at Time 1 and at Time 2. Our findings show that gesture and language productivity significantly correlated for both TD and PS groups at both time points; such that as language productivity increases, gesture also increases in production. McNeill's hypothesis for gesture-language link is thus confirmed in the current study through a cross-sectional perspective.

Question 2B focused on whether this gestural-language developmental pattern holds over time, through a longitudinal analysis of Gestural Rate - a proportion of gestural productivity to language productivity (specifically the number of gestures per spoken proposition). There were no TD-PS group and age differences between Time 1 and Time 2 in the proportion of gestures to speech. Both groups produced a comparable rate of gestures to language, and this rate remained stable from Time 1 to Time 2. In other words, a child with a certain gestural rate at Time 1 did not significantly gesture more or less as a proportion to their language production at Time 2. With development, neither the production of gesture nor language asynchronously fluctuates over time for both TD children and children with PS. So through a longitudinal perspective, a gesture-language link is also confirmed, supporting McNeill's hypothesis for both PS and TD groups; gesture and language co-develop.

Moreover, by school age; we did not observe gestural productivity delays in children with PS, while they continue to make more errors, talk less, and use less complex syntax in spontaneous language production.

Thus, both cross-sectional and longitudinal findings for both of our groups support McNeill's hypothesis that language and gesture form an integrated system. A stable positive correlation between gesture and language is found for both children with PS and TD children at both time points. Both cross-sectional and longitudinal language productivity results in children with PS are also consistent with the current language literature in children with PS, that conversational language performance in children with PS is comparable to that of TD children during school age (e.g., Bates et al., 2001). Similarly, the TD and PS groups have comparable gestural productivity at both time points, which mirrors the pattern in language productivity in our findings and previous studies (e.g., Bates et al., 2001; Demir et al., 2009). Also, our study's results suggest that school age children's gestural-linguistic production pattern is stable, and the development of gestural productivity parallels with that of language productivity. A close-knit relationship between gesture and language production is observed not just in adults who are neurologically intact and those with neural injuries, but also in children both TD and PS through development.

Recall from the infant and toddler literature, language and gesture delays are reported in children with PS. Also in the school age literature, language performance in the spontaneous context is comparable between the PS and the TD populations. In the current study, we observed similar findings; that by early school age children with PS were comparable with their TD peers in language
productivity. Gestural productivity was also comparable in rate between both TD and PS groups. This provides cross-sectional and longitudinal support that delays in gesture are not persistent deficits in children with PS — they are as productive in gestures and language as their TD peers by early school age, which suggests support for the notion of neural plasticity. Early insult to an immature system is less likely to impinge on gestural and language production than insult to a mature neural system. We now turn to Question Three, which explores separately development of gestural and language performance.

**Question Three: Developmental Changes in Gestural and Language Performance**

McNeill's hypothesis was tested in Question Two with respect to rate and productivity in language and gesture. Question Three instead examined the development of performances in language and gestural individually, by investigating children’s proficiency and use of linguistic and gestural structures as well as how gestures function with language. With respect to testing McNeill's hypothesis, gestural performance measures would be predicted to be similar in development to language performances. In the context of language delay in toddlers and infants with PS who make gains in acquiring functional language during school age, comparable TD-PS group performances in gesture is also predicted as language performance measures are comparable between TD and PS groups. When the relations between gestural and language productivity were examined (Question Two), both TD and PS groups demonstrated stable rates of production over time. However, when looking at individual aspects of performance, we observed different results.

In gesture performance, there were no TD-PS group or age differences for gesture complexity or how gesture functions in respect to the utterance it accompanies. From these findings, there are three important results: First, on average, both children with PS and their TD peers produced a comparable number of featural changes for each gesture (changes in the orientation, movement, or hand shape). Both groups were also comparable in the distribution of gestural functions to speech; that is whether a gesture reinforces, integrates, or supplements the semantic content in speech. And lastly, there were no within-age differences for both children with PS and their TD peers in gestural function and complexity measures. Together, these findings suggest that in school age, gesture use in spontaneous conversation is relatively stable in both function and complexity. Previous PS literature for spontaneous language performance found that school age performance is comparable between children with PS and their TD peers (e.g., Bates et al., 2001). Our findings for gestural performance then are consistent with language in that children with PS use their gestures comparably to their TD peers. Gestural delays were not observed in our participants with PS, which contrasts to the gestural delays reported in toddlers and infants with PS (e.g., Sauer et al., 2010). Additionally, stable patterns in gesture use for both the PS and TD groups suggest that gestural communication does not become more complex or different in its functions to support speech over school age. This stable pattern of gesture use contrasts with the findings in the adult gesture
literature, in which metaphorical gestures, or abstract gestures, were more likely to be produced. These abstract gestures associate highly imaginable icons to represent intangible representations (e.g., drawing a circle to express "repeating himself over and over") (McNeill, 2005). However, the current study did not analyze gestural types (iconic, beat, deictic, and metaphorical). It is possible that use of gestural types may change with development, or across various contexts (e.g., expository to give instructions, or to explain concepts), but not in the age range studied in this conversational context.

In the language performance measures, we found that the PS group continued to produce higher rates of morphological errors than the TD group. The TD group's rate of errors remained consistently low at both time points. These results are consistent with the school age PS literature on narrative production, in which children with PS produce more morphological errors than their TD peers (Reilly et al., 2004). It should be noted that despite producing more errors than the TD group, the PS group rate of morphological errors decreased between Time 1 and Time 2. One possible explanation may be that children with PS may be "catching up" to their peers in that regard; as this pattern has been reported in previous PS literature during narrative tasks (Reilly et al., 2004).

One issue that has been discussed in the PS literature regarding the language difficulties is whether or not these children are displaying language deviance or delay. Our findings did not provide a clear answer to this question. Table 4 displays examples of morphological errors from children with PS and TD peers at both time points. From our informal TD-PS group comparisons, we found that the children with PS made many similar errors to those of their TD peers. However, they also made errors deviating from developmental errors. For example, number agreement errors were common in both TD and PS groups as in examples 1 through 5 in Table 8. These errors were third person singular, which is determined by the subject pronoun (e.g., "it goes that way"), and plurality of the copula as determined by the predicate nominative (e.g., "there are no lights"). Another error type was tense, as in examples 6 through 12 in Table 8. Both groups made past tense overgeneralizations (adding –ed) and switched between present and past tense across utterances. However, pronoun errors were different from those of the TD peers. Children with PS made not just case errors in 3rd person pronouns (e.g. "him" used in the subject position), but also pronoun omissions, such as those in examples 13 through 15 in Table 8. We did not find TD peers at either time point making similar errors with pronouns. However, sentence pronoun omission is common in younger children. Pronoun omissions may also indicate difficulty with verb arguments. For example, a verb with an obligatory two-place argument requires a subject and a direct object, otherwise the sentence is marked as ungrammatical (e.g., I pushed the table vs. I pushed*). We observed both developmentally similar errors and atypical errors that TD children do not commit.

We also found an interaction between group and age for the frequency of complex syntax. At Time 1, the PS group produced a lower rate of complex syntax than that of the TD group, but at Time 2, this relationship is reversed - the PS group displayed a significant increase in their use of complex syntax. Post-hoc results indicated that the PS group contributed to the effects of the interaction, as
Table 8. TD and PS Morphological Error Examples

<table>
<thead>
<tr>
<th>Example #</th>
<th>Age</th>
<th>Group</th>
<th>Examples (*=errors)</th>
<th>Error Types/Target form</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>TD</td>
<td>If you push the tiller this way it go* that way. (Child 22)</td>
<td>Agreement/goes</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>PS</td>
<td>Him* lick*! (Child 3)</td>
<td>Pronoun/He Agreement/licks</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>TD</td>
<td>There's* Kirby and Oilinks. (Child 28)</td>
<td>Agreement/are</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>PS</td>
<td>You plays* You gets* a prize. (Child 12)</td>
<td>Agreement/play, get</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>PS</td>
<td>When you turn it on low there's* no lights. (Child 1)</td>
<td>Agreement/are</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>PS</td>
<td>I didn't think it was* cost* thirty bucks. (Child 1)</td>
<td>Auxiliary/(nil) Tense/costed</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>TD</td>
<td>And they rebuild* it. (Child 27)</td>
<td>Tense/rebuilt</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>TD</td>
<td>When I letted* Cocoa out of his cage, guess what? (Child 27)</td>
<td>Tense/let</td>
</tr>
<tr>
<td>9</td>
<td>7</td>
<td>TD</td>
<td>The mailman came up to the door and then Charlie's* like all &quot;grrr&quot;! (Child 28)</td>
<td>Tense/was</td>
</tr>
<tr>
<td>10</td>
<td>7</td>
<td>TD</td>
<td>And then he took her home and (they) they say* goodbye. (Child 35)</td>
<td>Tense/said</td>
</tr>
<tr>
<td>11</td>
<td>7</td>
<td>PS</td>
<td>I look* stupid when I was playing with that hat. (Child 10).</td>
<td>Tense/looked</td>
</tr>
<tr>
<td>12</td>
<td>9</td>
<td>PS</td>
<td>The falls were lighted* up and they make* them change colors. (Child 17)</td>
<td>Tense/lit, made</td>
</tr>
<tr>
<td>13</td>
<td>6</td>
<td>PS</td>
<td>___* want a Boxer (Child 19)</td>
<td>Pronoun/I</td>
</tr>
<tr>
<td>14</td>
<td>7</td>
<td>PS</td>
<td>You like shoot all the things and ___* shows you things that you need to get. (Child 13)</td>
<td>Pronoun/it</td>
</tr>
<tr>
<td>15</td>
<td>7</td>
<td>TD</td>
<td>One time me* and my friend Kevin and Michael (Child 31)</td>
<td>Pronoun/l</td>
</tr>
<tr>
<td>16</td>
<td>9</td>
<td>TD</td>
<td>It's* just things about like music and shows on Disney Channel and then they have a bunch of games in them. (Child 32)</td>
<td>Pronoun/They</td>
</tr>
</tbody>
</table>

they demonstrated a significant increase in the rate of complex syntax between Time 1 and Time 2, while the TD group remained relatively stable.

What can be contributing to this significant increase in the use of complex syntax from Time 1 to Time 2 for the PS group? Are they truly caught up to their TD peers? Informal evaluation of the PS group's complex syntax production patterns showed that the proportions of each type to the total number of complex syntax produced were similar between Time 1 and Time 2. However, the PS group means of total number of coordinated sentences and dependent clauses increased two-fold between Time 1 and Time 2, whereas the TD group means for these two structures between Time 1 and Time 2 were comparable. Table 9 listed all the group mean values for syntactic structures.
Table 9. Descriptive Statistics for Complex Syntax Types at Time 1 and Time 2

<table>
<thead>
<tr>
<th>Types</th>
<th>TD Time 1, 5-6 years</th>
<th>TD Time 2, 7-9 Years</th>
<th>PS Time 1, 5-6 Years</th>
<th>PS Time 2, 7-9 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n = 13</td>
<td>n = 13</td>
<td>n = 15</td>
<td>n = 15</td>
</tr>
<tr>
<td>Coordinated Sentences</td>
<td>17.23 (6.72)</td>
<td>24.46 (23.86)</td>
<td>9.47 (6.7)</td>
<td>20.87 (12.83)</td>
</tr>
<tr>
<td>Dependent</td>
<td>10.77 (6.22)</td>
<td>14.92 (16.15)</td>
<td>6.4 (5.96)</td>
<td>11.13 (5.18)</td>
</tr>
<tr>
<td>Verb Complement</td>
<td>5.77 (4.38)</td>
<td>6.38 (5.38)</td>
<td>4.33 (3.6)</td>
<td>5.2 (3.99)</td>
</tr>
<tr>
<td>Relative</td>
<td>1.85 (1.46)</td>
<td>3.0 (4.28)</td>
<td>1.07 (1.48)</td>
<td>2.93 (2.60)</td>
</tr>
<tr>
<td>Passive</td>
<td>0.54 (0.78)</td>
<td>1.23 (1.42)</td>
<td>0.4 (0.63)</td>
<td>0.47 (0.74)</td>
</tr>
</tbody>
</table>

Note: All parenthesized values represent standard deviations.

So what does this indicate? Complex syntactic structures that were examined in the current study included coordinate sentences, verb complements, relative clauses, passive sentences, and dependent clauses. However, not all structures are equally complex. For example, coordinate sentences are a relatively less complex type than the rest because it requires the conjoining of two independent clauses (e.g., "he told me, but no one else knows about it"), while other structures involve independent and dependent clause and the relation is made explicit by the subordinating conjunctions (e.g., because, when, who). For example, 'by' passive (e.g., the cat chased by the boy) involves syntactic movement in which the actor of the verb is not in the subject position. Whereas morphological errors are errors in obligatory contexts, the use of complex syntactical structures is optional, and may vary depending on personal styles of communication. At Time 2, the PS group's increased complex syntax rate from Time 1 is now comparable to their TD peers and this may reflect their ability to embed semantic information using more complicated linguistic structures. Complex syntax production in children with PS is consistent with the literature in which initial delays are observed earlier in language development, and with development, although they appear to increase in complex syntactic production, they continue to show delay transitioning through steps of acquiring language.

Limitation of the Gestural-Language Link – A Semantic Relation?

For Question Three, the findings for language measures, but not gesture measures, differed between groups. So far, no known studies have compared the form and structure of gestural and language domains. Since no differences were found for gestural form and structure, is the presence of group differences in language form and structural measures inconsistent with McNeill's hypothesis? And also inconsistent with our findings for Question Two regarding the rate of gestural to language productivity? McNeill's hypothesis assumes that gestures play a communicative role in support of verbal communication. The semantic aspect of gesture is thus an integral part of its relationship with speech. Unlike sign languages, gestures produced by hearing communicators do not conform to systematic linguistic rules. This may be a possible explanation in our findings that gestural complexity remained similar between the two time points for the two groups of children. It should be
noted that complexity in gestures is not necessarily comparable to linguistic complexity, such as complex syntax. Complexity in gestures does not necessarily increase over time in this age range, as language has become the primary modality for communication. Communicative gestures are ambiguous without hearing the accompanying speech. The interpretation of these gestures is contextually-based, such that not just the meaning, but the functional role a particular gesture plays is only interpretable given the speech context. For example, a child who raises an index finger may be either integrating an emphasis to highlight a synchronously produced word in speech (e.g., "we ran to the store"), or reinforcing the number 'one'. We cannot know until we hear the speech. It is possible that gestures' relationship to language with respect to development is a semantic one, rather than one of form and structure. This may suggest the notion of gesture functioning as supporting, dependent system to language, rather than an individual or primary modality, during communication. During development, children transition into multi-word productions as they acquire vocabulary rapidly. As they formulate conceptual information verbally, supporting gestures provide additional semantic context. In the current study, we observed that TD children and children with PS between 5 and 6 years of age have the ability to embed information through gestures that provide an additional dimension to the content of their speech.

Examining the productivity and the semantic relatedness in gesture and language expression, we found similarities between PS and TD groups indicating that general gestural and language delays in children with PS do not persist. However, looking beyond the productivity and the semantic relationship between gestures and language, we found that for the PS group, both modalities pattern differently in structure and form. While the children with PS have comparable gestural complexity to their TD peers, they produced more errors in morphology and their use of complex structures increased. McNeill's hypothesis has yet to address whether gesture and language expression are integrated beyond the semantic, conceptual level.

**Variability in Gestural and Language Performance – Support for Neural Plasticity**

Historically, studies with children with PS are confronted with wide variability in children’s performance (e.g., Bates et al., 1997; Reilly et al., 2004; Sauer et al., 2010). For the current study, our data set shows that there is both within-group variability and also between-group variability for language and gestural performance. The standard deviation values of some gestural and linguistic measures for TD and PS groups were nearly as large as the group means. For example, at Time 1 for morphological error rates, the TD group mean was 0.05 and a standard deviation of 0.04, whereas the PS group mean was 0.10 with a standard deviation of 0.10 (See Table 3). In gestures total at Time 2, for instance, the TD group mean was 19.2 with a standard deviation of 20.9, and the PS group mean was 24.6 with a standard deviation of 17.6 (See Table 2). We observed high variability not just in children with PS but also in the TD children, particularly for gesture production. Also, variability is present between the two modalities as well. Particularly, two participants, Child 8, whom
we excluded from our analyses, and Child 12 in the PS group exemplify variable performance for gestural and language productivity.

In the PS group, 17 of 20 participants have sub-cortical as well as cortical involvement. The appendix listed lesion locations for all participants in the PS group. Particularly, both Child 8 (high language and high gestures) and Child 12 (reduced language and average gestures) have comparable sized cortical and sub-cortical lesions within the right hemisphere, in that these lesions are multi-lobule including damages to the frontal, temporal, parietal and occipital lobes, with sub-cortical involvement. However, Child 8 produced high amounts of language and gestures, whereas Child 12 produced below average amount of language (18 propositions), which is 0.61 standard deviations below the PS group mean, but above average amount of gestures (24 gestures), which is 0.20 standard deviation above the PS group mean. Child 12 also produced exceptionally high rate of morphological errors (55.6% of the propositions contained morphological errors, which was 3.2 standard deviations above the PS group mean) and zero complex syntax structures. Not only was the language productivity low, the language produced was simple and included an unusual amount of errors.

**Summary: Neural Bases for Gestural and Language Development**

In our study, we observed both comparable TD-PS language and gestural relations and no laterality differences between children with RHI and LHI. Returning to our questions regarding the neural bases for language and gesture, what are the effects of early neural damage in comparison to the neural damage that occurs in a mature system? Our results provide support for neural plasticity in both language and gesture.

In the two individual cases above, we observed variability not only between modalities for these children, but also differences from the adult model, which may suggest that language development involves the cortex in a more distributed fashion in children than the in adults. Such a claim is supported by the developmental neuro-imaging literature that demonstrates that lateralization for language is a developmental process (e.g., Holland et al., 2007; Ressel, Wilke, Lidzba, Lutzenberger, & Krageloh-Mann, 2008). Within the same side of lesion, we observed variability that is inconsistent with the adult lesion profile. Adults with RHI often demonstrate impairments with pragmatic aspects of communication – overproduction of language and gestures, with relatively intact language form and content abilities (e.g., Bates et. al., 2001). The case of Child 12 (RHI) is a contrasting example with exceptionally low performance of language with frequent errors. We observed more production in gestures than in language, and this child’s language contained the highest rate of morphological errors and the lowest rate of complex syntax. The profile of adults with RHI then, is inconsistent, or inapplicable to this child’s performance. Yet in Child 8 (RHI), we observed exceptionally high performance of language and gestures, which is consistent with the profile in adults with RHI. Even within the same side of lesion, these two exemplars represent
contrasting gestural and language performance. One explanation relating to the aforementioned variability in these participants may be attributed to the individual speed of development and differences in lesions. In addition to the absence of group laterality differences in school age children with PS, the variability in the neural bases for language and gestural development at the individual level also suggest a developmental model to account for these differences.

Although beyond the scope of this study, it may be that the speed of development is correlated with the size, site, and side of lesions. Overall, our findings provide indirect support for neural plasticity for language and gesture in the face of early neural insult, as observed in the context of spontaneous production in school age children with PS.

**Study Limitation and Future Directions**

During the analyses, we found that Gestural Rate for group was tending toward significance, $F(1,26) = 3.148, p = 0.088$, in which the PS group produce higher proportions of gestures to language than the TD group at both time points. This may be the result of insufficient power. The current study analyzed gestural and language production and performance using archival participant data. Since we analyzed data retrospectively, we were limited in the number of available participants with longitudinal data.

Also, it is also worth mentioning that only dominant hand gestures were coded and analyzed, whether these gestures were produced singly or bimanually. This decision was made, to control for variability in children with PS who may or may not present with hemiparesis. This is not to say that children with PS do not utilize their non-dominant hand to gesture. In fact, in this study, both the PS and TD groups were comparable in the number of non-dominant hand gestures produced. For example, the PS group mean was 2.0 gestures with a standard deviation of 4.2 at Time 1, and the TD group mean was 2.1 gestures with a standard deviation of 3.0 at Time 1.

The questions that were explored in the current study can be considered broad. There are various paths for future research in studying the relationship between gestures and language. One would be investigating in gestures’ contribution to overall communication beyond verbal and other non-verbal modalities (e.g., facial expression). Future research may explore dominant and non-dominant hand gestures, or single-handed and bimanual gestures. Another possible direction is to further examine the interaction between various aspects of gestures. Gesture types and functions, or gestures’ temporal relationship with speech would be interesting to pursue, for example, are there specific functions of iconic gestures? Are certain types of gestures produced before speech? Gestural research is still in its infancy and there are multiple paths to further explore its relationship with speech. Replication of the study's results is also important, whether through increasing statistical power by including more participants with PS, or exploring the relationship between gestures and language in other clinical population such as children with language impairments or in other contexts (e.g., narrative task). With the available imaging technology, future research can investigate the
relationship between the site, size, and side of lesions and gesture performance during communication.

Since McNeill's hypothesis has yet to account for the gestural and language relationship with respect to form and structure, future studies may also further replicate these results in children with PS. Also, our participants with PS at Time 2 demonstrated a decrease in morphological errors as compared to their Time 1 performance, and they demonstrated a two-fold increase in complex syntax production. These two trends may provide future direction to studies in adolescents with PS, to assess whether or not their language performance in morphological error rates and use of complex syntax continue to converge with the performance of their TD peers.

**CLINICAL RAMIFICATIONS**

It is a long tradition for speech language pathologists to assess and facilitate communication development in toddlers through gestures and expressive language. Standardized batteries such as the Communication and Symbolic Behavior Scales Developmental Profile (CSBS DP; Wetherby & Prizant) and the MacArthur-Bates Communicative Development Inventories (MBCDI; Fenson, Marchman, Thal, Dale, Reznick, & Bates) recognize the importance of gestures as part of the communicative systems in young toddlers. However, standardized batteries for school age children steer away from examining gestural abilities during communication, and instead focus primarily on speech and language abilities. The current study found co-developing patterns between language and gesture in school age children, both TD and those with PS. There may be a clinical value in assessing school age children's ability to communicate using gestures and speech. During treatment, school age children may also benefit from using gestures to facilitate learning as a means to provide multi-modal cues, or to provide them the skill set in using gestures to enhance communication academically and socially.

**CONCLUSION**

McNeill's hypothesis posits that language and gesture form an integrated communicative system. The initial conceptualization and support of this hypothesis stem from findings in adults who are neurologically intact and adults with lesions. Current literature in gestural communication is scant for school age children who are typically developing, and in children with unilateral lesion secondary to a PS. The current study sought to explore the relations between gesture and language in school age children in both populations through three primary research questions. Overall findings are consistent with McNeill's hypothesis, but differed from the adult model for individuals with unilateral lesions.

Our first question was whether lesion side differences in gestures and language performance continue to persist in children with PS during school age. Our results found that around 5 to 6 years of age these differences are resolved and remain stable. The second question was whether gesture and language productivity were correlated and whether the relationship between these two modalities
changed over time. We found that both modalities significantly correlated at Time 1 around 5 to 6 years of age, and the relationship between the two modalities remains stable over time. Finally, our third question explored whether there are within-subject changes in gestural and language performance over time. Results found that gestural performance continues to remain stable for both PS and TD groups. However, language performance in the PS group suggests gestural-language relationship may be a semantic one, instead of structural. Children with PS in our study continued to make gains in morphological error rates and complex syntax rates, yet they were still producing higher rate of errors, both developmentally typical and atypical, and using less complex syntactic structures than the TD group. These results suggest that children with PS are confronted with intermittent challenges as they transition through the steps acquiring language.

Gestural production, as shown in our findings, co-develops with language production regardless of group or age. A developmental model is suggested by these data, as these profiles differ from those of the adults with comparable lesions. As expected, variability between gesture and language measures was also found in both TD and PS groups, which provide support for the notion of neural plasticity. Children with global cortical and sub-cortical lesions may present with age-appropriate or reduced language and gestural performance, as with Child 8 and Child 12. The variable consequences in gestural and language performance of early neural insult in our participants with PS raise questions for the LH bias for language development. Our results also illustrate that lesions of comparable size do not necessarily predict similar developmental outcomes, since a majority of our participants with PS exhibit large and extensive lesions. We have yet to make direct conclusions regarding how neural injuries correlate with gestural and language performances without direct, imaging experimental evidence. However, that gesture and language co-develop regardless of size and extensiveness of lesion allows for clinical application in assessments and treatment for school age children. Future studies of gestural communication in school age clinical populations and TD children should focus on finding direct evidence between neural substrates and language and gestural abilities, and the treatment efficacy in using gestures to facilitate gains in language development.
REFERENCES


APPENDIX

LESION GROUP SITE(S) OF LESION & SEIZURES
Appendix. Lesion Group Site(s) of Lesion & Seizures.

<table>
<thead>
<tr>
<th>CHILD</th>
<th>Lesion side</th>
<th>Frontal</th>
<th>Temporal</th>
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+. Lesion is present in that region.
-. No lesion present in that region.