DEVELOPMENT OF SPEECH MOTOR CONTROL FOR LANGUAGE:

MOTOR ANALYSIS FROM PHONETIC TRANSCRIPTS

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ABSTRACT OF THE DISSERTATION

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The developmental sequence of speech motor control has yet to be directly examined in the emergence of spoken language. Contemporary accounts of the emergence of spoken language traditionally address speech motor control as part of the maturational process. The present study investigates the developmental sequence of speech motor control in the transition from babble to word productions.

Speech motor control of the jaw, lips, and tongue was observed longitudinally from nine to 16 months of age in five English speaking children. Predictions of speech motor control were evaluated for spontaneous vocalizations from the production of babble to referential words.

Results confirmed that speech sound productions in babble and words at the onset of spoken language are controlled with the child's available motor skills. As predicted, the jaw was the first of the three articulators to have independent graded control in the emergence of word productions. Lip control was observed second as the child began producing referential words. At 16 months there was no evidence of independent tongue control in the production of babble, words, or referential words.

These findings indicate that speech production at the onset of spoken language is enabled by the motor control available to the child. The results of this study add an additional variable to be considered in theoretical perspectives that attempt to explain the onset of spoken language.

Early developmental milestones of the speech motor system have yet to be identified in the emergence of spoken language. The results of this study identify the motor milestones for the jaw and the lip at the onset of word productions. These findings provide a first step in investigation of speech motor control and a basis for investigating therapeutic approaches that consider these skills.

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A special thanks to two colleagues I am lucky enough to call my friends for their support. Jennifer Tonelli, your unconditional friendship and common-sense guidance is always welcomed. Dr. Jennifer Preston, I cannot thank you enough for your knowledge and guidance in understanding motor development.

Dedication

This dissertation is dedicated to my children, you are my greatest inspiration.

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Chapter I Introduction and Background

1.1 Nature of the Problem

There are many questions that surround how speech production emerges. Is the process innate with some biological predisposition needing to be evoked? Is the emergence of a speech just one part of a more complex dynamic process? There are theoretical positions in support of these and other processes, however, the one thing that remains constant is the lack of understanding of the developmental sequence of the motor control necessary to produce speech.

Speech production is one of the most highly refined motor skills performed by humans requiring the activation and coordination of many muscles and body parts. The developmental sequence of how the muscles and body parts needed for speech production have yet to investigated. Contemporary theories of language acquisition consider the development of the speech motor system as a part of more general biological process that occurs with growth and maturation (Kent & Miolo, 1995). The emergence of spoken language is considered rule-based with the assumption of underlying representation of words and other language elements (Menn, Schmidt, & Nicholas, 2009; Stoel-Gammon, 2011; Vihman & Croft, 2007;). A rigorous theory of the emergence of spoken language should include how the motor system necessary for producing the sounds of a language develops.

Rule based theories of speech production present a problem in developing treatment for children that do not develop speech production typically. Typical treatment plans for improving speech production skills emphasize the imitation of target sounds as the frame from which acquisition and generalization of production are built. Depending on the severity of the production delay, therapy can address a set of speech sounds or therapy can focus on one sound a time, with treatment based on a look, listen, do model. In children who cannot produce any speech and lack imitation skills, current treatment models based on phonological acquisition (Hodson, 2010) and speech sound imitation (Van Riper, 1954) are ineffective. When children lack imitation skills, therapeutic interventions include improving child's communication skills (Weitzman, 2017) and alternative communicative systems (gestures, signs) (DeThorne, Johnson, Walder, & Mahurin-Smith, 2009) rather than focusing on the possible underlying cause of their inability to imitate.

Imitation is a neurologically based skill allowing the child to mimic the movements of the target model and is considered a crucial step in lexical development (Stoel-Gammon, 2011). Imitation requires the child to activate and coordinate the body systems necessary to produce action. Since speech models of the emergence of spoken language are rooted in the acquisition of representation and other linguistic elements, they do not typically consider the developing speech motor system except as a maturational process. Treatment based on auditory-visual cueing along with verbal instruction on how to produce target speech sounds does not help the nonverbal child to develop the underlying motor skills necessary for imitating and producing speech sounds. A critical distinction between linguistic and speech motor control issues is necessary to development treatments for children where there are more complex considerations then phonetic and phonological impairments to production.

When a child does not produce speech sounds and cannot imitate the movements necessary for speech, the question is what happens when look, listen, do does not work?

The use of oral motor organization (Beckman, 2007), moto-kinestic prompts (Hayden, 2007) and tactile-proprioceptive oral placement techniques (Bahr & Rosenfeld-Johnson, 2009) may help children with disordered speech sound production develop the oral motor skills necessary to produce speech sounds. Currently the use of such therapeutic interventions to improve oral motor skills necessary for a child's ability to produce speech have little empirical support and their use is extremely controversial (Alhaidary, 2019; Lee & Gibbon, 2015; Lof, 2015) with their application as treatment model considered a pseudoscience (Volkers, 2019). The use of oral motor-based therapy strategies to improve the motor skills necessary for speech production is a highly debated topic in the remediation of speech sound disorders (Lee & Gibbon, 2015; Lof, 2015). The main issue with the use of oral motor-based strategies as an intervention technique is the lack of either theory or empirical evidence to support or disconfirm them. Phonological theories of the emergence of spoken language, based on linguistic principles, overlook the developing speech motor system and the physiological processes necessary for production. Speech motor control has been presumed to be based on a general maturational process with the specific development of the functioning of body parts necessary for sound production not specifically examined or understood (Kent, 1984; Kent & Miolo, 1995; Kent & Murray, 1982).

Theoretical attempts to describe the relationship between language development and speech motor skills have found improvements in articulatory speed and range of movement by comparing word productions from children and adults (Goffman & Smith, 2004) and longitudinally children during the emergence of spoken language (Nip, Green, & Marx, 2011). The Nip et al findings are weak because they compare reported language frequency and production variables rather than investigating motor control during actual productions. Stronger findings may be possible if motor activity is compared with actual productions. There currently are no empirical studies that investigate the relationship between the developing speech motor system and phonetic and phonological skills in the emergence of spoken language. The lack of understanding of the speech motor system in the emergence of spoken language hinders a robust understanding of language acquisition and prevents empirical studies aimed at improving oral motor function in the remediation of complex speech production disorders. Investigations are needed to provide specific accounts of speech motor skill acquisition in the emergence of spoken language.

Thus far, theories of the emergence of spoken language have been predominately based on phonological theory. This preference has resulted from the influence of the assumption of underlying representation that include both meaning and production potential derived from rule-based theories (Menn, Schmidt, & Nicholas, 2009; Stoel-Gammon, 2011; Vihman & Croft, 2007) and explain motor development as a more general part of the maturation including anatomical changes observed in the first year (e.g., Kent & Murray, 1982).

1.2 Purpose of the Study

The purpose of this research is to begin to investigate the sequence of speech motor development in the emergence of words. This research investigates a hierarchy of speech motor control from babble to words guided by the PROMPT treatment hierarchy (Hayden, 1986) as well as current knowledge of speech sound production. My hypothesis is that during the early stages of speech sound production, the child gains control of the articulators beginning with the jaw, followed by the lips, and finally the tongue. As the child dissociates each articulator from the others and integrates their actions, speech production will follow a developmental pathway of movement from oscillations to fixed patterns of movement, to finally graded controlled movements. Sequenced movements of the three articulators will occur when the child can integrate the movements of the three articulators.

1.3 Speech Production

Speech production is one of the many variables contributing to language acquisition. Language acquisition requires development of cognition, linguistic knowledge, the sensory system, social skills, and speech motor control. In the emergence of spoken language, research has provided stages of observable speech sound development (Locke, 1983; McCune & Vihman, 1987; Oller, 1980; Stark, 1980; Stoel-Gammon, 1985) and advances in lexical development (Stoel-Gammon, 2011; Storkel & Morrisette, 2002; Thal, Oroz & McCaw, 1995) with little focus on the sequence of speech motor control required for the emergence of these skills.

Speech production is a highly refined process that requires the activation and coordination of many subsystems from the diaphragm to the oral cavity in order to articulate the sounds of language. Thelen (1991) notes that it takes up to 70 body parts to produce a one-syllable word. To produce speech sounds, air is exhaled and then the air is perturbed by the vocal folds as it passes through the larynx; the sound that is created is then shaped with the rapid movement of the articulators as they change the shape of the oral cavity (Kent & Hustard, 2009). The modification of the shape of the oral cavity created by the moveable articulators (jaw, lip, and tongue) creates speech sounds. When speech sounds combine to form words articulation skills emerge. Articulation skills take years to achieve a level that matches the adult form. It has long been known (Sanders, 1972) that children do not master the sounds of their language until 8 years of age and Walsh and Smith (2002) report that children do not develop the highly refined articulatory control seen in adult speech until after 16 years of age. Although the relationship between the development of articulatory skills and speech motor development have not been studied directly, changes in speech motor control can be hypothesized based on accepted stages of sound development from birth to the production of words.

1.4 The Emergence of Spoken Language in Children

The study of the emergence of spoken language has focused on sound productions (specifically consonants), production rules, and lexical development (Ferguson & Farewell, 1975; Macken, 1979; Menn, 1971;). The first studies of babble and word productions reported there was no relationship between the sounds produced in each (Jakobson, 1968). More recent studies demonstrate that the same sounds from babble are those used to produce first words (Locke, 1989; McCune & Vihman, 2001; Stoel-Gammon, 1985; Vihman, Macken, Miller, Simmons, & Miller, 1985;).

Before children begin using words, models of emerging spoken language identify levels of vocal development. Stark (1980) describes six levels of vocal development that are separated by increases in production complexity from the reflexive sounds heard from birth to the production of words. The six levels of production are reflexive (0-6 weeks), cooing and laughter (6-16 weeks), vocal play (16-30 weeks), reduplicated babble (31-50 weeks), non-reduplicated babble (10-14 months), and first words (varied onset). Changes in vocal development are considered part of the greater maturational process of the speech motor system. Notably, the motoric foundation of the levels of speech motor control is not addressed.

Early anatomical adjustments of the speech motor system have been used to explain changes in sound production in infancy. The developing child's vocal tract is visually smaller than the adult (Kent, 1992). Sound production in an infant is altered due to broader oral cavity, anterior tongue mass, a high larynx, and an approximating velum and epiglottis. Between two and four months, the infant's vocal tract changes and becomes more adult like. Anatomical changes to the vocal tract have been used to explain changes in sounds production from the reflexive and cooing and laughter to speech sound production. From four to eight months, the developing infant begins to spend more time in the upright position, this advance in motor development allows for greater movement of the jaw. The first movement of the jaw are explained as "rhythmical stereotypies" or repetitive or rhythmic movements patterns that occur about the same time as other body parts like limbs, neck and trunk (Thelen, 1981). Movements of the lip and tongue are said to follow the repetitive movements of the jaw.

The first speech like sounds produced by the infant are described as babble. Babble unlike earlier sound productions consist of well-formed syllables that have acoustic characteristics of adult speech production (Locke & Pearson, 1992). Cross-linguistic studies of babble have found that babble production consists of a limited number of consonant sounds, in particular the p,b,t,d,n,k,g,h,w sounds (e.g., de Boysson-Bardies, Vihman, Roug-Hellichius, Durand, Landberg, & Aroa, 1992; Locke, 1983, 1989; Stoel-Gammon & Cooper, 1984;). The "frame then content" theory (MacNeilage & Davis, 1990) proposed that the initial frames of speech are produced by oscillations of the mandible and that later content appears with increases in motor control. The onset of babbling may be due to a combination of maturation and anatomical changes or control of the speech motor system (Oller, Eilers, Neal, & Schwartz, 1999; Stark, 1980) combined with stereotypical rhythmical oscillations of the mandible (MacNeilage & Davis, 1990; Thelen, 1979). Babble initially appears as rhythmical productions of limited set of speech sounds and becomes mature as syllabic forms become increasing like speech (Oller & Lynch, 1992; Vihman, 2014). It seems likely that changes in babble occur as the child gains control of the articulators.

Once babble begins, children's production of consonant sounds tends to increase in frequency (Stoel-Gammon, 1985). Consistent production of a small number of consonants (p,b,t,d,n,k,g,h,w) characterize babble production in a variety of world languages (Locke, 1983; Vihman, 1992) and it is these sounds that provide the motor patterns for the onset of word production (McCune & Vihman, 2001). In the study of sounds produced in babble, McCune and Vihman examined consonant-based productions. This work examined the difference between "well-practiced and longitudinally stable vocal productions (Vocal Motor Schemes: VMS) and more infrequent sporadic and possibly accidental occurrences" (McCune, 2008, p. 158). This work established that during the course of babble a child gains the longitudinally stable motor capacity to 'intentionally' produce specific speech sounds (VMS). The increase in the repertoire of consonant sounds produced in babble has its roots in stable motor capacity, however, these motor capacities have yet to be directly investigated.

The VMS provide stable patterns of sound production that promote word learning (DePaolis, Vihman, & Naki, 2013). There is general agreement that a small subset of sounds is produced in the transition from babble to word productions (Stoel-Gammon, 2011). Early word productions are primarily dependent on the same sounds that are produced during babble (Locke, 1989; McCune & Vihman, 2001; Stoel-Gammon, 1985). In the emergence of words, the repertoire of babbled sounds becomes the repertoire of sounds used in words, with the child using their own specific sound production skills to produce early words (Vihman, Macken, Miller, Simmons, & Miller, 1985). McCune (2008) distinguished *context limited words*, those that do not generalize from the initial context of use from *referential words*, those that extend their meaning to new situations the child encounters. The production of two VMS was predictive of onset of referential word production (McCune & Vihman, 2001). Following the Piagetian notion of action schemes, VMS act as a motor foundation for the goal of stable vocal production of referential words (McCune, 2008). Again, the motor foundation has yet to be directly studied.

In the identification of VMS in the transition to referential word production, stable patterns of production were identified without attention to the speech motor skills being utilized for their productions. More recent work suggests that stable motor patterns in the production of babble improve the perceptual-motor relationship necessary for the development of a phonological system (Vihman & Nakai, 2003; Westmann & Miranda, 2004). There is yet to be a study that directly investigated the development of speech motor skills in relationship to babble, VMS, or word productions.

The word learning processes is initially based on a small subset of sounds, most notably the child’s own repertoire of VMS. The first words produced by a child are often context limited words (Vihman & McCune, 1994). These words are produced with a recognizable adult form and are rooted in the context in which they are produced. Referential words occur when the child uses a word for joint attention and conversation with relatively stable meaning (McCune & Vihman, 1994). Both context limited and referential word productions have recognizable adult production forms, however, their production may take a variety of vocal forms, perhaps due to the child's limited control of the motor system for speech production (Ferguson & Farewell, 1975; Vihman & McCune, 1994). There is no question that the first attempts a child makes to produce sounds and words are far less complex in production skill than the adult target. Limitations in the variety and complexity of speech sound productions within and across children in the beginning stages of word learning may be best explained with an improved understanding of the developing speech motor system.

First words initially appear in the context of babble, which continues for an extended period in the early stages of language acquisition. The sounds and sound combinations used to produce first words typically contain production errors that commonly follow patterns (McIntosh & Dodd, 2008) and are attributed to rules, known as phonological processes. Phonological processes occur frequently as children learn the sounds of their language, e.g. consonant harmony, velar fronting, and stopping (Bauman-Waengler, 2012). A common phonological process in children's speech is consonant harmony (Grunwell, 1997). Saying "baba" for "bottle" is one example of consonant harmony, where the child repeats the initial sound in the word. Phonological processes are said occur because the child creates rules due to their limited production capacity as compared to their representation of the language. However, in the example of "baba" for "bottle" a lack of speech motor control seems more likely than a production rule. Child specific production patterns may be better explained with biological consequences of the developing speech motor system (Tessier, 2015) and requires a more fully developed theory.

There are many theoretical positions that attempt to explain how a child comes to produce adult phonology and over several decades have seen considerable change since the original assumptions of universal grammar (Chomsky, 1965). Changes in theoretical perspective have progressed from the child being born with a universal knowledge of language to perspectives that consider the emergence of spoken language as a more dynamic process considering the many elements involved. A brief historical review of the changes in theoretical frameworks of phonological theory will introduce the theoretical foundation of this work.

1.5 Theories of Phonological Development

Early developmental theories of the emergence of spoken language assumed a Universal framework (Chomsky,1965). This framework did not consider the variability of sound productions across children and it assumed that the sounds produced in babble had nothing to do with the sounds produced in words (Jakobson, 1968). Generative phonology introduced by Chomsky and Halle in 1968 proposed that children are born with a universal knowledge base for language and have the same linguistic capacities as adults. The capacity for spoken language were described as emerging with maturation and exposure to the ambient language. The emergence of spoken language was believed to be constrained in production capacity as the result of innate universal rules that are modified given the child's exposure to language (Smith, 1973; Stampe, 1979). Generative phonology did not consider the speech motor system in the emergence of language or the range of differences in children beginning to use language.

Cognitive phonological theory saw the child as a more active participant in the emergence of language questioning the innate universals described by generative phonology. Cognitive phonology says that constraints in speech production in the emergence of language occur because the child's simplified output does not match the representation stored from perceived language input (Macken & Ferguson, 1983). Limitations in speech output are the result of rules created given the child's production abilities. The problem-solving method proposed by the cognitive theory suggested that the child used cognitive processes like hypothesis testing to create a sound system and did not consider the developing speech motor system as a constraint in production skills in the emergence of spoken language (Macken & Ferguson, 1983).

Optimality theory focuses on constraints of output (Gleason & Ratner, 2009). For production of words in early language acquisition, optimality theory suggests a set of universal constraints identified as markedness and faithfulness. Faithfulness constraints ensure that the productions closely resemble the adult form. Markedness constraints result in productions that contain preferred characteristics of the adult form. Constraints are based on a hierarchy of the child's native language and based on the child's production needs at the time of production. The use of markedness and faithfulness are re-ranked as production improves and output more closely resemble that of the adult. The lack of complexity at the onset of word use is not believed to be the result changes in control of the speech motor system, they are presumed to be the result of universal production constraints for determining ease of production.

The biological theoretical framework of speech production differs from previously described theories in that it places an emphasis on physiological processes of the biological system and the observable production limitations of the developing child. Kent (1992) suggests that “speech is a coordinated action, and the learning of its coordination is one part of phonological development” (p.77). Biological theories argue that changes in vocal production in the emergence of spoken language are the result of growth of the phonatory apparatus, the shape of the vocal tract, and the timing and coordination of articulation (Kent, 1999; Kent & Miolo, 1995). Biological theories of phonological development theorize that the motor skills necessary to produce speech occur in the same fashion as the motor skills needed for other body movements. The oral motor movements necessary for speech output are the result of the biological functioning and maturation of the system, combined with the child’s interactions with the environment. Early vocalizations provide the foundation for later speech motor movements as the infant interacts with its environment and receives feedback that allows the continuation or termination of motor movements for speech production (Kent, 1992). Biological theories support the importance of the development of the speech motor system as a basis for production in the emergence of speech, but the developmental sequence of the speech motor system from babble to words has yet to be investigated, nor does this framework call for such investigation.

Vihman and her colleagues (Ferguson, Menn, & Stoel-Gammon, 1992; Vihman, 1996, 2014; Vihman & Croft, 2007; Vihman, DePaolis, & Keren-Portnoy, 2009; Vihman & Keren-Portnoy, 2013; Vihman & McCune, 2001) have recently presented a theory of the emergence of spoken language that incorporates the biological, representational, and perceptual components in the development of spoken language. The research labeled a "radical" templatic theory (Vihman & Croft, 2007) recognizes the importance of early motor skills for both the pre-verbal and early word production periods without addressing the processes or steps in speech motor development. Motor skills are identified in the production of vocal motor schemes and templates which allow for production patterns that encourage phonological and lexical development by providing stable motor movement patterns (Vihman, DePaolis, & Keren-Portnoy, 2009). Vocal motor schemes are defined as voluntary production of a consonant (McCune & Vihman, 2001), however, in the identification of VMS little attention was given to the speech motor skill necessary to produce the consonant sounds. Similarly, word templates were initially identified as common phonetic frameworks characterizing a large number of a given child's words, without reference to underlying motor production skills. This is the first research I have found that has linked phonetic and phonological development with speech motor development in the emergence of spoken language.

Redford (2019) explains a developmentally sensitive speech production process in her recent theoretical proposal. The process of developing speech production is presented in developmental stages, with each stage building on the previous. The stages of this approach include: the perceptual-motor map, perceptual word forms and action schemas, onset of perceptually based control, and self-monitoring. The production of words becomes possible when the child has "reasonably stable perceptual lexicon and a perceptual motor map" (p. 2955) that results from the child's desire to communicate. Word productions from this perspective are described as vocal actions, or schemas, that are produced to communicate a referential meaning for communication. Schemas are defined as the phonological representation and speech plan for a meaningful communication. In the transition from child-like to adult-like forms, the schemas update until a single motor routine generalizes for all attempts of a word. The generalized production of the word is then integrated into the perceptual map. Constraints in production from this perspective are the result of the child's best motoric approximation of the word they are attempting to produce given the child's representation of the word in the perceived perceptual-motor map. This theory identifies the necessary importance of speech motor control, but again, does not offer a specific means of understanding the aspects of the development of speech motor control beyond motor routines for words.

Theories that attempt to explain the lack of complexity in production in the emergence of spoken language provide little if any understanding of the changes in control of the speech motor system beyond the notion of being a maturational process. As discussed previously, this lack of explanation of speech motor development in current theories of the emergence of spoken language is evident in the treatment of complex speech production disorders that do not respond to traditional treatments. Speech production has been considered a linguistic skill and as described in the above, little attention is given to the speech motor system. Without an understanding of speech motor development from babble to words, no developmental theory will be complete. No such theory can provide the basis for treatment of children who do not produce words and whose lack of speech motor skills prevents them from following verbal instruction or models for imitation. In the following section, a dynamic systems approach to language acquisition is reviewed as a more complex theory that provides a framework for addressing the many complex variables involved in the language acquisition process, including the importance of developing speech motor skills.

1.6 A Dynamic Systems Approach in the Emergence of Spoken Language

Skill acquisition from a dynamic systems approach occurs through the cooperative interaction of the subsystems necessary for specific developmental outcomes. In the emergence of developmental milestone, like reaching and walking, outcomes are recognized as dependent upon the child's motivation to perform motor activities combined with contextual support and necessary underlying skills (Abraham & Shaw, 1982). Phase shifts in development are the result of changes in stability of the skills within one or more subsystems. In the emergence of spoken language outcomes are dependent upon the child's attraction to use verbal language combined with cognitive, social, biological, linguistic, and motor behaviors (McCune, 1992). Evidence supporting the dynamic systems view of language development form the foundation of this research.

McCune (1992) proposed a dynamic system of skills as contributors to the complexity of language during initial word acquisition. The developmental domains that contribute to language acquisition discussed are cognitive, psychosocial, biological, and motor development. Prior to the onset of first words, control parameters were identified as the development of mental representation, VMS, and communicative grunts. For verbal communication, the child must integrate the desire to communicate given their unique level of mastery of the underlying skills within the subsystems involved. In the transition from prelinguistic communication to the production of words, the interaction of the subsystems of language cooperatively interact for the goal of verbal language.

McCune (2008) extended her original interpretation of language as a dynamic system in her book “How Children Learn to Learn Language.” The book expands on her initial explanation of the dynamic interaction of social factors, cognitive development including mental representation, pre-linguistic development, and speech motor skills. McCune identifies dynamic variables that emerge prior to the onset of referential word use. She presents data that suggest a child must control respiration, communicative intent through vocalization (communicative grunts), and have stable motor control for at least two vocal motor schemes prior to the production of reference. From nine to 16 months of age, the children she studied had increased articulatory control, first exhibited as the production of glides and glottal sounds, to finally producing referential words in the month after they had production control of two or more suprasegmental consonant sounds. At any point in the developmental process, language production is the result of the dynamic interaction of the child’s cognitive, perceptual, communicative, and production skills. McCune’s theory does not consider a development course of speech motor skills in the emergence of language.

From a dynamic systems perspective, the emergence of spoken language is considered a continuous, self-organizing process that emerges over time within the context of real time processing (Evans, 2007). The assumption is that “novel, complex forms of behavior emerge from the interactions of the components of each system and the environment” (Evan, 2007, p.131). Spoken language develops from the dynamic interaction of a socially supportive environment, cognitive advancement, linguistic skill development, and speech motor control (McCune, 2008).

Speech production is one variable in the emergence of spoken language. The development of articulatory control requires the activation and coordination of respiration, phonation, and articulation. Thelen (1991) described the capacity for spoken language considering the motor components necessary in the emergence of spoken language using principles of dynamic systems theory. The emergence of speech can be considered as similar to the emergence of other motor skills, like walking. The development of motor skills is “dynamically assembled from subsystems that themselves change over time rather than being scripted from a maturational or cognitive device” (p. 358). Speech production emerges with the onset of new skills interacting with stable existing skills. There are no studies to date that have investigated the changes in speech motor control in the transition from babble to words.

Vihman, DePaolis, and Keren-Portnoy (2009) have investigated speech production from a dynamic systems approach by describing the function of babble in relation to the development of first words and the origins of grammar. Their position is that there is a “powerful learning mechanism-coupled with the speech motor system-rather than innate knowledge of linguistic principles that can be identified as the source of the remarkable human capacity for language” (p. 164). Babble production supports attention to sounds, initially to sounds that the child can already produce and then to new sounds. The child’s first evidence in motor performance for sound production is vocal motor scheme development (VMS). VMS development offers routinized production strategies in support of the production, which provide the child voluntary motor control over specific consonant sounds.

Vihman (1992) proposed that the child selects sounds to attempt to produce in initial word learning through an “articulatory filter” which provides the child a means to select sounds he or she can produce from the sounds heard. There is an increase in word learning when the child has one or more well-practiced production pattern or templates, to produce words (Vihman, DePaolis, & Keren-Portnoy, 2014). Templates “support attention and memory to the form-meaning link” in word learning (Vihman et al, 2014, p. 178). From this perspective, the speech motor system is acknowledged in the form of well-practiced sounds and sound combinations that reduce the learning load and provide the child with phonological patterns for speech production. It is the interaction of what the child can produce, what they perceive, and the cognitive process of word learning that stimulates the emergence of spoken language. The exact course of speech motor skill acquisition is not addressed, although improvements in speech motor skill are identified as a major contributing factor in the transition from babble to word production.

The dynamic systems approach to the emergence of spoken language provides a framework that considers the many accomplishments that occurs prior to the production of words. In the emergence of spoken language, production skill is one of the variables that must be considered. At this point, no theory of the emergence of spoken language demonstrates a sequence of speech motor development. Determining a developmental sequence of speech motor skills in the emergence of spoken language will add a missing piece to theory and provide a starting point to better understand the role of treatment that includes speech motor control.

1.7 Motor Skills in the Emergence of Speech

Control of the speech motor system cannot be ignored in the production of speech. Although the production of speech requires the activation and coordination of many body parts, articulation, or the production of speech sounds, occurs in the oral cavity. Control of the moveable articulators (jaw, lips and tongue) is necessary for the rapid modification of oral cavity for speech sounds to be produced. As discussed previously, early speech sound productions are limited to a small subset of sounds that are the result of the child not having the ability to produce complex speech sounds.

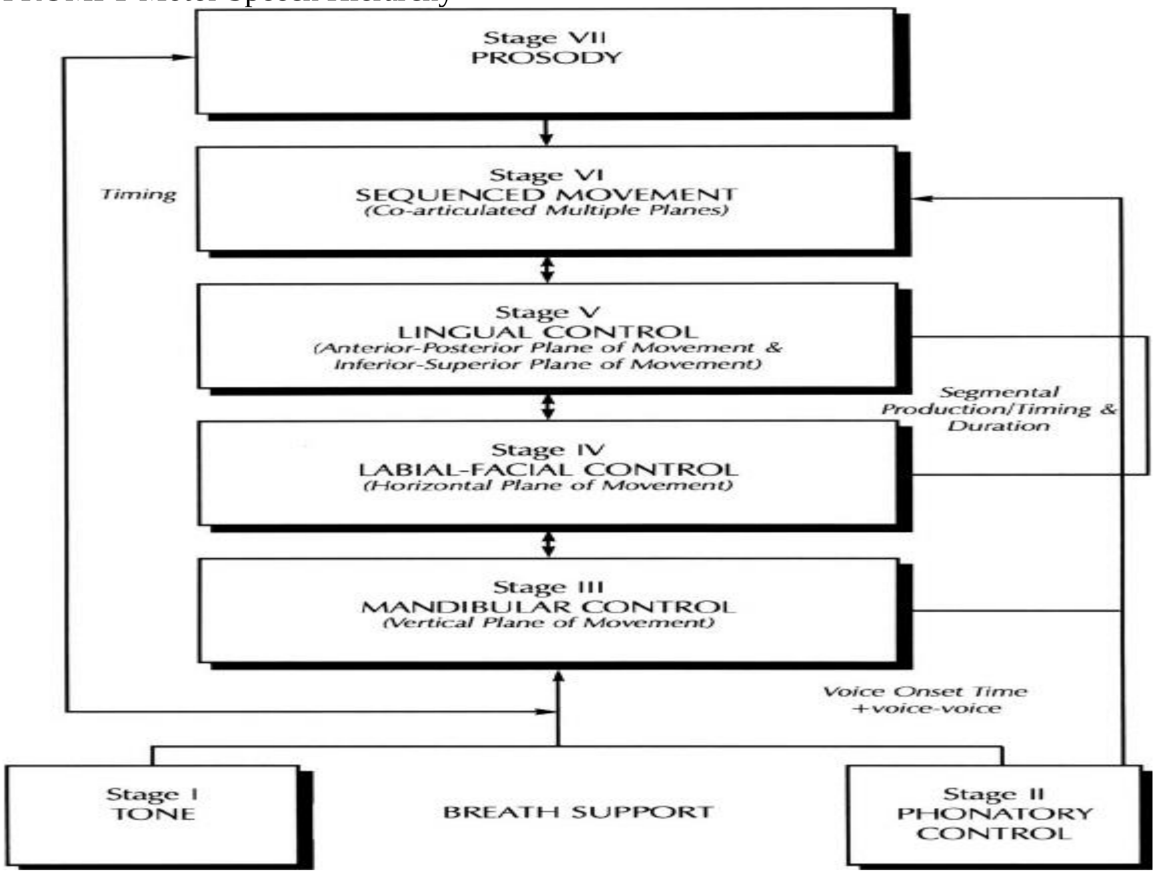
Limitations in control of the jaw, lips, and tongue have been found in cross-sectional studies of speech motor control. The opening and closing of the jaw are identified as primary movements in babble and early speech productions (Green, Moore, Higashikawa, & Steeve, 2000) with the tongue playing a passive role. Lip movements are more disorganized in pre-verbal children when compared to mature speakers (Green, Moore, & Reilly, 2002). The development of lip movement revealed three stages of lip shape control that can be predicted by age and expressive language skills (Iuzzini-Seigel, Hogan, Rong, & Green, 2015). These studies have provided knowledge of speech motor skills without a specific sequence of control in the emergence of spoken language.

1.8 A Treatment Model as a Hypothesis for a Developmental Sequence

Hayden's (1994) treatment program, *Prompts for Restructuring Oral Muscular Phonetic Targets (PROMPT)*, was developed to help clinicians working on speech-motor control with patients with complex speech motor dysfunction. The PROMPT treatment hierarchy aims to organize treatment in line with the levels and interactions of the entire speech motor system to facilitate the production of sounds, words, and phrases. Hayden has suggested that the motor speech treatment hierarchy has universal applications as a

Figure 1

PROMPT Motor Speech Hierarchy



guide in the in treatment of motor-speech disorders regardless of the intervention being implemented. It is possible that this hierarchy may provide a model for predicting the developmental sequence for control of the speech motor system in the emergence of spoken language. Although little is known regarding the development of the speech motor system, Hayden's hierarchy combined with generally accepted speech production milestones and dynamic system variables provides a framework for investigating the developmental sequence of speech motor control in the emergence of spoken language. This research will utilize Hayden's treatment hierarchy as a model of sequential speech motor development in the emergence of spoken language.

The PROMPT motor speech hierarchy (see Figure 1) consists of 7 stages. Each stage interacts with the one before and after. To sustain the complex, flexible movement sequences for speech production, each successive stage of the hierarchy is dependent on the next to provide support for its involvement. Voluntary control at each stage will help establish the independent (dissociation) movement in later stages where integrated coordinated control (integration) is necessary for complex production. The following sections describe the of the levels of the hierarchy and any research evidence regarding the proposed level of control involved.

1.8.1 Stage I: Tone

General muscle tone for movement and control is necessary for the body to support itself against gravity and for muscle movements. In a typically developing child, tone provides support necessary respiratory, phonatory, and articulatory development.

1.8.2 Stage II: Phonation Control

Phonation is a supportive speech function for breath, phonation, and voicing. To produce speech, there needs to be a steady flow of air through the larynx. For speech sounds to be produced, the child needs to maintain respiratory control during exhalation as well as subglottic and oral pressure. Activation of the vocal folds during exhalation provides the sound stream for speech. Esling (2012) has demonstrated that the pharynx is the first articulator under the child’s control. The emerging control of grunt communications, defined as laryngeal produced vocalizations, in the first months of sound production have demonstrated a sequence of control of the laryngeal mechanism for communication (McCune, Vihman, Roug-Hellichius, Delery & Gogate, 1996). Grunt production changes with the earliest grunt productions accompanying effort, later they accompany acts of focal attention, and the final use of grunts is communication. Communicative grunts give some evidence of phonatory control as, unlike grunts of effort, they tend to utilize the same vowels favored in a given child's word productions (McCune, 2008). Communicative grunts appear the month before the onset of referential words use in the transition to spoken language for children who have already established VMS.

1.8.3 Stage III: Mandibular Control

Mandibular (jaw) control requires a single motor movement of the jaw combined movement on a single vertical (up and down) plane. Movement at this stage of speech motor development includes the jaw and voice. Jaw movements occur in the vertical plane of movement allowing for the opening and closing of the mouth. When the jaw opens, the mouth opens allowing for vowel production and retraction of the tongue. When the jaw closes, it allows the lips to approximate and causes the tongue tip to elevate. Research provides evidence that control of the jaw is necessary for both the production of babble (McNeilage & Davis, 1998) and early word productions (Green et al, 2000 and 2002). According to Green and collegues (2000, 2002 & 2010) the jaw is the dominant articulator in production of vocalizations in infants from 9 to 21 months.

Jaw movements develop from oscillations, or rhythmical stereotypies (Thelen, 1981) to graded movements (Rosenfeld-Johnson, 2005). Graded control of the articulator allows for the structure to perform the necessary movements to attain mature movement patterns. In theory, control of the jaw begins as rhythmical oscillations from the resting position and become more controlled as the child differentiates the movements of the jaw from other movements of the head and body. Jaw movements become graded when strength and stability improve. During the course of development, abnormal patterns of fixing occur when strength and stability are challenged with increased motor demands. During early stages of speech production control over the jaw becomes similar to adult control earlier than either the lips or tongue (Green et al, 2000). Graded movements of the jaw allow for more mature movement patterns that are flexible and fixed movements reduce the flexibility of movement patterns.

1.8.4 Stage IV: Labio-Facial Control

Labio-facial control includes the voice, jaw, and facial contraction for lip retraction and rounding. Lip movement occurs in the horizontal plane, consisting of lip contraction and rounding. The use of the lips to produce speech sounds requires the muscles of both the cheeks and the face. Development of speech requires the integration of labial movements into mandibular movement patterns (Green et al, 2002). Early lip movements for the production of bilabials in early speech production are controlled by the jaw with lip closure being a result of jaw closure (Green et al, 2000). Upper and lower lip movements are more variable than jaw movements in one and two-year old children when compared with older children and adults.

Lip movement is controlled by jaw movements in early babble and word productions. When lip movement becomes independent of the jaw, initially both the upper and lower lip perform together. Differentiation of upper and lower lip movements is necessary for the production of sounds like the labio-dentals (f/v) (Green et al, 2002; MacNeilage & Davis, 1998).

1.8.5 Stage V: Lingual Control

Lingual control includes voice, jaw, facial contraction and rounding, and tongue control. Tongue movements occur on the anterior-posterior and inferior-superior planes of movement. The tongue must be able to function separately from the jaw and lips in order to perform the quick, isolated movements necessary for connected speech. The tongue consists of 8 muscles. There are four intrinsic that function to change the shape of the tongue and four extrinsic muscles that change the tongues position. In early speech sound production, the movement of the tongue is thought to be controlled by the movements of both the jaw and lips. The tongue is identified as a hydrostat (Kent, 1992) and is capable of flexible movements in multiple complex patterns. The tongue is the least understood articulator in early speech sound production and its control occurs after the jaw and lips.

1.8.6 Stage VI Sequenced Movements

Sequenced movements include coordinated movements on multiple planes of movement and include voice, jaw, lip control, tongue control, and timing. For sequenced movements to occur, there must be dissociation and integration the parts of the speech motor system. (Kent, 1992). Normal dissociation, or increasingly independent movement, occurs in the following order: head from body, jaw from head, lips from jaw, and jaw from tongue (Rosenfield-Johnson, 2005). The jaw, lips, and tongue must gains strength and stability as they begin to move independently. Differentiation occurs when there is independent control for a specific motor tasks (Green et al, 2000; Kent, 2009). For speech, the jaw, lips, and tongue must each have independent control before sequenced movements can occur. There is integration of new motor movements with stable motor movements at each stage of the motor speech hierarchy.

The productions of words and word combinations at the transition to spoken language lack the precision of adult production. It is not known whether sequenced movements are necessary to produce babble or words at the onset of speech production. The assumption here is that a child's early attempts at word production lack the complexity of the adult target due to both the level of independent control of each articulator as well as the level of integration of the components when the production is attempted. In the development of production skills, refinement of speech motor control continues as the components of the speech motor system improve both independent control and increased flexibility in the integration of components. Given the lack of motor control at the onset of word productions, the lack of complexity may be the result of the production demand exceeding the child's motor control as well as their ability to integrate movements.

1.8.7 Stage VII: Prosody

Prosody includes voice, jaw, facial contraction and rounding, tongue control, timing, and prosody. This involves intonation, stress, juncture, and speech rate in sequenced motor movements. This stage of motor control is beyond the scope of the current study. Prosody occurs at the conversation level and the current study specifically addressed babble and first words in the emergence of spoken language.

1.8.8 Summary

The PROMPT motor treatment hierarchy combined with findings of speech motor research provides the foundation for understanding the sequence of speech motor skills in the emergence of spoken language. There are many variables to consider in the emergence of spoken language and at this point, no theory has fully explored the development of the speech motor system. A comprehensive theory of the emergence of spoken language needs to consider the cognitive, linguistic, and speech motor skills that are necessary for production to occur.

1.9 Theoretical Perspective of Dissertation

McCune and Zlatev (2015) expanded the theory of McCune's (2008) description of language acquisition from the dynamic systems perspective in their discussion of semiotic development in the transition to reference relying on dynamic systems principles. In the individual analysis of 10 children they found that there are measurable abilities necessary for the onset of referential word production and comprehension. Although there was not a sequential order of acquisition of these dynamic variables, without all the abilities in place the transition to reference did not occur.

Speech motor skills from this perspective were addressed with VMS. As mentioned earlier, when a child was credited with VMS, no specific motor skills were identified. The development of speech motor control in the transition to reference as a dynamic variable has yet to be investigated and is the least understood variable in the emergence of spoken language.

This dissertation will add the additional variable of the speech motor system to be considered in the transition to spoken language and will complement the work of McCune as it is one piece of a much larger puzzle.

1.10 Significance of the Study

The questions this research aims to answer are (1) What is the developmental sequence of control of the speech motor system from babble to production of words? and (2) What impact does the hierarchy of speech motor control have on phonetic and phonological development from babble to words? These questions will be answered considering three specific hypothesis and four exploratory questions.

Specific Hypothesis:

1. For each articulator, articulatory skills will begin at level of oscillation, then, to fixed patterns of movement, and finally, to graded controlled movement.
2. Graded movements across articulators will be achieved according to the hierarchy stages: mandibular, labial, lingual, and finally sequenced movements.
3. When the child is credited with referential word productions, all articulators will be at the level of graded control.

Exploratory Questions

1. What are the changes in speech motor control in relation to dynamic system variable (mental representation, play, VMS, communicative grunts, first words, referential words)?
2. Do children demonstrate variegated babble at the level of sequenced movements?
3. What is the motor level for each of the articulators at month of two VMS?
4. What is the motor level for each of the articulators for (1) words versus non-words and (2) child word versus the adult target?

Chapter II Methods

2.1 Participants

The participants in this research were two boys, Rick and Jase, and three girls, Alice, Aurie and Nenni. Data were collected for a previous study (McCune, 1995). The children were observed monthly from 9 to 24 months of age, and the 9 to 16-month data form the basis for the present study. Participants had parents that were middle class based on education, employment, and location of residence. In all cases, the mothers were primary caregivers to participants being with the children more than 50 percent of their waking hours. English was the only language spoken in the homes of all participants. All children were developing typically based on The Bayley Mental Development Index and Infant Behavior Record (Bayley, 1969). Children had no reported medical issues.

2.2 Data Collection and Preparation

2.2.1 Data Collection

Data were collected one time per month at a time of day when children were awake and normally engaged in child directed play activities. The data collection sessions consisted of a play observation using a set of toys provided by the investigator. The set of toys included dolls, small dishes, toy bottle, toy cars, boxes and books (Nicolich, 1977; McCune 1995). The toy set was designed to offer problem-solving, pretend play opportunities, and manipulation. The toys were contained in a round plastic bin that measured 14 inches in diameter by nine inches deep. Each session the same toys were protruding from the bin.

Play sessions were videotaped using an external microphone placed in close proximity to the mother and child. After 20 minutes of observation, the bin was emptied and inverted, and a subset of toys was arranged around it. These were toys that have been found to elicit pretend play. Before recording continued, the child's attention was directed so to the toys. The recording continued for another 10 minutes without interruption. The video was only stopped if the mother or the child left the room and resumed when participants were ready.

Phonetic transcriptions of the children's vocalizations were made with accompanying contextual information that included the mother's language and the actions of both the mother and child transcribers (Vihman, 1985).

For the present investigation, fifty utterances from each of the monthly transcripts for each of the six children were randomly selected using a computerized randomizer. The 50 utterances were chosen by inputting the total number of utterances and selecting 50 as the output. At times fewer than 50 utterances were available due to the number of vocalizations produced. When an utterance from the random selection was anything other than a fully transcribed spontaneous production of speech sounds, e.g. laugh, squeal, or utterance with unintelligible sounds within in it, the next transcribed utterance was selected. The following variables (words, VMS, referential words) included in the present study were identified in the sample during earlier research.

Words had been identified for Vihman and McCune's (1994). A production was considered a word based on its similarity to the adult form, the availability of the referent within the context of production, and the consistency of the production used for the same referent.

Vocal motor schemes (VMS) were defined as stable productions of supra-glottal consonants (McCune & Vihman, 1987, 2001). A sound met the criteria for VMS when there was a minimum of 10 tokens produced in three of four consecutive half-hour sessions. VMS productions were dated from the first home session that child met criteria. Communicative grunts have been identified as one of three levels of grunting that occurs early in communication development (McCune, Vihman, Roug-Hillichius, Delery, & Gogage,1996). Communicative grunts are distinguished from earlier forms of grunts as they are directed toward a communicative partner. The children in this study were credited with communicative grunts in that previous research.

Referential words are defined by McCune and Vihman (2001) based on the principal of contrast. Referential word production “requires implicit recognition that a given vocalization (word) stands as a symbol to symbolize in relation to one of a range of related entities or events while failing to apply to others” (2001, p. 671). Words were considered referential when they were observed to occur in at least two different contexts and/or in relation to two different objects. In the observed uses of the referential words, consistent aspects of the context or object need to be identified to unify the use of the words.

2.2.2 Data Preparation

A total of 1754 phonetically transcribed utterances were prepared for the data analysis. Each utterance was written on the front of an index card with the participants name and month of transcription placed on the back. There was a total of 46 sets of data. There were two steps in the description of data: labeling place of articulation and motor evaluation based on both individually transcribed sounds and the sequence of sounds in the utterance as a whole.

2.2.2.1 Placement of Articulation

First, the placement of the jaw, lips, and tongue was described for each phonetically transcribed utterance. Speech sounds are typically described by place of articulation with examples in Table 1. Placement of articulation describes the position of the articulators (jaw, lip, tongue) in the oral cavity necessary to change the flow of air for specific sounds to be produced. Consonant sounds are produced by the movable articulators (lips, tongue, jaw, velum) making gestures toward the non-movable articulators (teeth, alveolar ridge, palate). The movement of the articulators for speech sounds are expressed in transcription using the universal symbols from the International Phonetic Alphabet (IPA, 2015). The symbols from the IPA provide a shorthand description for the placement of the articulator represented. Placement of the moveable articulators for the production of vowel sounds are best described using the IPA vowel chart (Figure 2). Placement of articulation for consonants can be described as using Hayden's (2007) surface and complex PROMPT descriptions (Table 2).

Table 1

Examples of Placement of Articulation

Type	Movement	Example
Bilabial	produced with upper and lower lip making contact with mandible high	p b m
Labio-dental	produced when lower lip makes contact with upper front teeth	f v
Inter-dental	produced when tongue tip protrudes betweeen upper and lower lip	th
Alveolar	produced when tongue tip makes contact with alveolar ridge	t d n
Velar	produced when the back of the tongue contacts the soft palate	y

To describe the placement of the jaw, numbers were used to describe the height of the jaw opening necessary for the sound to be produced. Jaw height was measured from 1, closed position (e.g. /m/), to 7, open (e.g. /a/). The following is are examples of how jaw descriptions:

Utterance: “pəti”

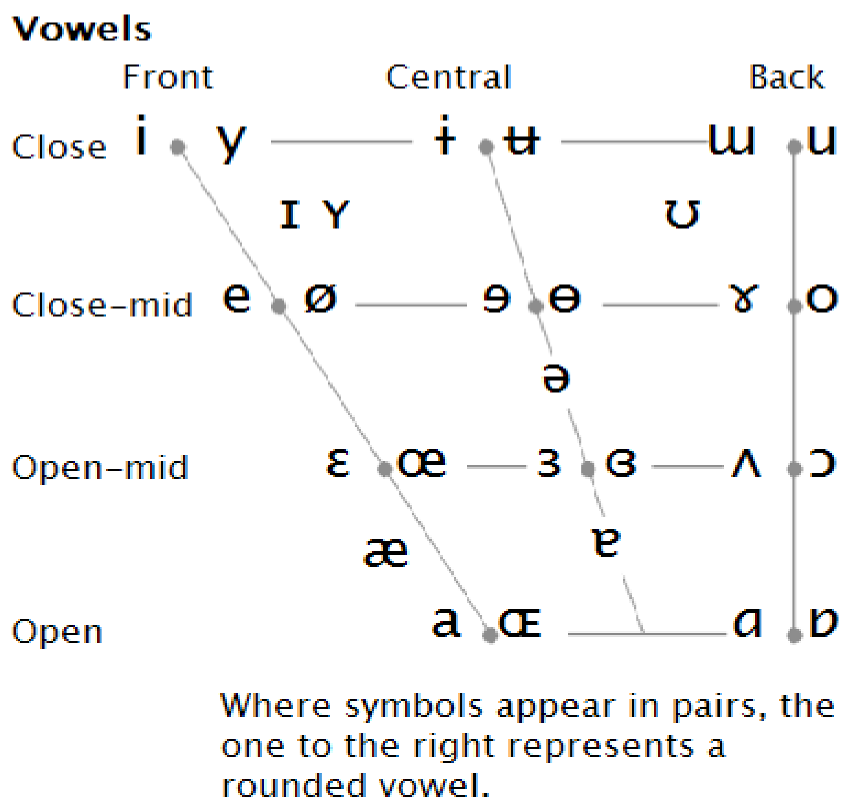
Jaw: 1411

Utterance: “dæ̃dæ̃”

Jaw: 1616

Figure 2

IPA Vowel Chart



Placement of the lips was described by their position when the sound was produced. Lips movements can be closed (e.g. /m/), open (e.g. /a/), rounded (e.g. /o/), retracted (e.g. /i/). Examples of lip movements are presented in the PROMPT (Hayden, 2007) surface and complex descriptions (Table 2) and the IPA (2015) vowel chart (Figure 2). The following are examples of lip descriptions:

Utterance: “pəti”

Lip: closed, open, open, retracted

Utterance: “dædæ”

Lip: open, open, open, open

Tongue movements were described by the placement during the production of the sound. Tongue movement was described for vowels as front, back or central (Figure 2). For consonant sounds, PROMPT descriptors (Table 2) were used to described placement. The following are descriptions of tongue descriptions:

Utterance: “pəti”

Tongue: neutral, central, tip up, front

Utterance: “dædæ”

Tongue: tip up, front, tip up, front

The description of the placement of each articulator was completed starting with the jaw, then the lips, followed by the tongue. All 46 sets of monthly data were completed one set at a time for each of the three articulators.

2.2.2.2 Motor Evaluation

Within each utterance evaluations of the sequence of placement of each articulator was necessary to determine motor control for that utterance. Assessment of motor movements was described by their control around the axis point. For gross and fine motor control of general body movements, the axis point is the anatomical position. For speech production, the axis point is the normal anatomical resting position: jaw closed, teeth together, not clenched, and the anterior portion of the tongue resting on the alveolar ridge (Merkel-Walsh & Overland, 2018). The motor evaluation was conducted blind to reduce any bias to the study. All 46 sets of data were analyzed by a computer-generated random order for blind analysis of participant and month. Three levels of motor control were evaluated: oscillation, fixed, and graded.

Oscillations are activations of the articulator on the vertical, horizontal, inferior-posterior, and inferior-superior planes of movement. Movement was considered an oscillation when movement of the articulator rhythmically fluctuates back and forth from the resting anatomical position. A complete description of oscillations can be found in Appendix A. The following is an example of an utterance identified as an oscillation:

Utterance: “mama”

Jaw: 1717

Lip: closed, open, closed, open

Tongue: neutral, back, neutral, back

Fixed movements are irregular or abnormal movement patterns to gain stability of articulator. Movement was considered fixed when the movement of the articulator is limited in its range of movement or remains in the same or similar position from where it starts. A complete description of the assessment of motor control for fixed movements can be found in Appendix B. The following is an example of an utterance with fixed movements

Utterance: “tɪ”

Jaw: 2>1, 1

Lip: open, open

Tongue: tip up, front

Table 2

PROMPT Surface and Complex Descriptions

Sound	Jaw	Lips	Tongue
/b//p//m/	1	Closed	neutral
/t//d/n/	2>1	Open	Tongue tip up
/s//z/	1	Open	Tongue tip up
/k//g/	5	Open	Tongue back up
/ŋ/	5	Open	Tongue back up
/ʤ//ʧ/	3	Broad round	Tongue front up
/ʃ/	1-2	Broad round	Tongue tip up
/l/	2	Open	Tongue tip up
/f//v/	2	Lower lip	neutral
/i/	1	Retracted	Front
/e/	3	Retracted	Near front
/æ/	6	Open	Near front
/ɑ/	7	Open	Back
/ɔ/	7	Rounded	Back
/u/	1	Rounded	Back
/ʊ/	2	Open	Near back
/o/	3	Rounded	Back

Graded movement demonstrates control that allows the structures to perform the necessary movements to attain mature movement patterns, such as those necessary for words. The complete description of assessment of graded movements can be found in Appendix C. The following in an example of a graded utterance:

Utterance: “ʃɑrk”

Jaw: 1725

Lips: rounded, open, neutral, neutral

Tongue: tip up, back, flexion, back

Sequenced movements are those produced when the three articulators have dissociated from the each other and the movements of the articulators integrate for movements necessary to produce words. Movements of an utterance will be considered sequenced when the motor control of all three articulators are identified as graded. The above example of graded movements also demonstrates sequenced movements because all three of the articulators have been identified as having graded control.

As level of motor control of the articulators had not previously been studied, a criterion for level of control needed to be devised. It was initially proposed that five occurrences at a given level as potential criterion for given level. However, nearly all the children at every session produced five exemplars at each level, indicating that this criterion would not differentiate levels of control. To allow evaluation of potential developmental changes over time, proportion of each level of motor control (oscillation, fixed, graded) for each of the three articulators was calculated for each month for all 5 participants. Proportions of motor control could then be analyzed across all levels of the three articulators. Proportions of .5 or greater was taken to indicate control for the purposes of this initial evaluation.

2.3 Reliability

2.3.1 Transcriptions

Reliability for participants phonetic transcription collected for play sessions had been evaluated for the McCune and Vihman (2001) study following Thal, Oroz, and McCaw (1995) and Vihman and Miller (1988). Reliability of phonetic transcripts was evaluated point by point agreement for the two primary transcribers, based on approximately 2 minutes of seven participants selected to include session across the age range. Reliability for number of vocalizations included in the sample transcript was .97. Of the 117 utterances identified by both transcribers, agreement on the presence or absence of the production of supraglottal consonants was .98. Across the 75 utterances included supraglottal consonants, one or both transcribers noted the occurrence of 168 consonants with both agreeing on 155 productions (.92). The transcribers agreed on specific identification of consonants heard in 124 of the productions (.80).

2.3.2 Placement and Motor Evaluation

Two experienced master's level speech and language pathologists familiar with language development, PROMPT, and phonetic transcription. Each rater was given a copy of the measures to read prior to training.

Training began with placement of articulators. A set of 10 phonetic transcripts not related to the participants data were used to teach measures. Then each of the two raters was given a random selection of 10 of the 50 transcribed utterances from 3 of the 6 study participants. Reliability for all transcribed utterances for articulatory placement for the sample was 1.0.

After the agreement for placement of articulators was reached, the raters were trained for assessment of motor movements. The 6 sets of transcriptions used for articulator placement were used as a training tool. Half of the cards were used for group training and the other half were divided among the raters. Reliability for all transcribed utterances for the assessment of motor movements sample was .9.

2.4 Statistical Analysis

To answer the questions, both quantitative and qualitative analysis were used. The specific hypothesis proposed to answer the first question were evaluated using one and two-way analysis of variance (ANOVA) to find the statistical significance observed for the proportion of means of speech motor control. To evaluate the exploratory questions proposed, qualitative analysis was performed.

One-way ANOVA was used to discover is the mean proportion of levels of articulatory control differed significantly for each articulator each month. For each one-way ANOVA, months was identified as the independent variable and level of motor control (graded, fixed, oscillation) was the dependent variable. A one-way ANOVA was for done for each of the three articulators for each of the three levels of motor control for a total of 9 analysis. To find the specific groups within the one-way ANOVA that show statistical differences, post hoc testing using the Tukey multiple comparison was conducted when there was significance in the ANOVA.

The two-way ANOVA is used to determine whether there was an effect of two variables and their interaction. Independent variables for the two-ANOVA analysis were month and articulator. The dependent variable was level of motor control. Three two-way analysis were completed. When statistically significant interactions were found, a Tukey multiple comparison was conducted to determine any simple main effects.

Qualitative analysis was necessary to address the exploratory questions proposed in this study. The proportion of .5 or greater was necessary to show majority in this analysis of motor control within and across children. Citation The qualitative analyses were considered using the dynamic variables found in previous research that investigated early language precursors (McCune, 2008; McCune & Vihman, 1994, 2001; McCune & Zlatev, 2015).

Chapter III Results

There are two primary questions addressed in the research: (1) What is the developmental sequence of control of the speech motor system from babble to the production of words? and (2) What impact does the sequence of motor control have on linguistic development from babble to words. The following sections will present a bried overview and then the results regarding the specific hypothesis and exploratory questions.

One and two-way analysis of variances were conducted to compare the mean differences in the proportion of the level of control within and across articulators for all participants. Overall, there was an increase in graded jaw movement from 9 to 16-months. Fixed jaw movements remained the same. Jaw oscillation decreased but showed no significance. Graded lip movements increased across the study while fixed lip movements decreased. Lip oscillations did not differ across months. There was no variation in tongue oscillations, fixed, or graded movements across the study.

Independent control of the jaw was credited first. The proportion of graded jaw movements was very close to independent control from the onset of the study. Independent control of the lips was the next to be credited. Tongue movements did not reach the level of independent control during the study.

A description of the relationship between graded control of the jaw and lip to the dynamic variables found to be predictive of the transition to referential word production suggests their importance in the transition to reference.

3.1 Question 1: What is the Developmental Sequence of Control of the Speech Motor System from Babble to the Production of Words?

This question was addressed by three specific hypotheses: (1*) Independent control within each of the three articulators will begin with oscillation, then to fixed movements,* *and finally to graded control. (2) Independent Articulator Control will begin with jaw control, then lip control, and finally tongue control. (3) Sequenced movements of the articulators will emerge when graded control is achieved across articulators.* Data analysis to address these questions will be presented below.

3.1.1 Hypothesis 1: Independent Control of the Articulators will Begin with Oscillation, then to Fixed Movements, and Finally to Graded Control.

For each of the three articulators, the mean proportion of the three levels of articulatory control was analyzed across children. For a detailed description of the proportion of movements of all 3 articulators across the study for all 5 children see Appendix D. The mean proportion of the level of motor control for each individual articulator is discussed separately.

Table 3

Mean Proportion of Jaw Movements

Month	9	10	11	12	13	14	15	16
Oscillation	0.1526	0.1738	0.1094	0.1686	0.163	0.044	0.1364	0.1752
Fixed	0.3640	0.3326	0.2062	0.3446	0.191	0.2014	0.2670	0.2066
Graded	0.4834	0.5216	0.6844	0.4864	0.646	0.7546	0.6366	0.6182

3.1.1.1 Proportion of Jaw Movements

The proportion of jaw movements (Figure 3) for each of the three levels of movement were tested for homogeneity of variances. The Levene Statistic was not

Table 4

One-Way ANOVA Proportion of Jaw Oscillations

	Sum of Squares	df	Mean Square	F	p
Between Months	0.07	7	0.01	2.36	0.046
Within Months	0.136	32	0.004		
Total	0.206	39			

significant for oscillation (.178), fixed (p = .087), or graded (p= .253) movements allowing the assumption of homogeneity of variances.

The proportion of jaw oscillations varied across months as determined by a one-way ANOVA (F (7,32) = 2.360, p = .046). A Tukey post hoc test (p = .057) revealed a decrease in jaw oscillations at 14 months when compared to months 10, 12, and 16. There is a decrease in jaw oscillation as depicted graphically in a means plot in Figure 3. The decrease in jaw oscillation across months appears large on the graph but it did reach significance (.05).

Table 5

One-Way ANOVA Proportions of Fixed Jaw Movements

	Sum of Squares	df	Mean Square	F	p
Between Months	0.185	7	0.026	1.59	0.174
Within Months	0.533	32	0.017		
Total	0.719	39			

The proportion of fixed jaw movements did not differ statistically across months (Table 6) as determined by a one-way ANOVA (F (7,32) = 1.590, p = .087). A means plot displayed in Figure 3 presents the means for graded jaw movements.

Table 6

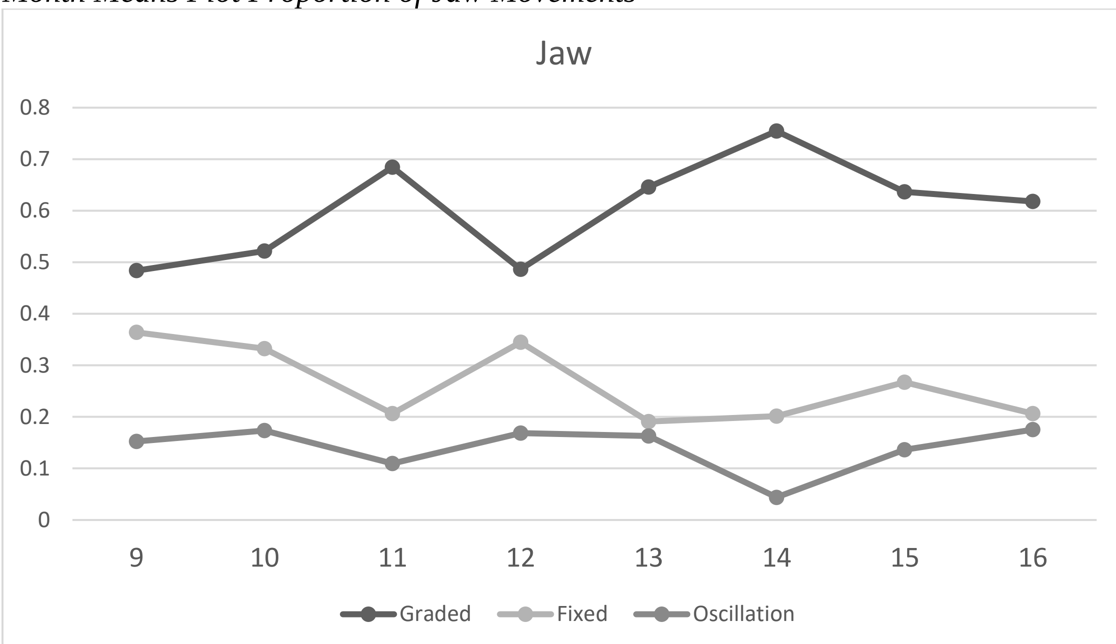
One Way ANOVA Proportion of Graded Jaw Movements

	Sum of Squares	df	Mean Square	F	p
Between Months	0.336	7	0.048	3.527	0.006
Within Months	0.436	32	0.014		
Total	0.772	39			

The proportion of graded jaw movements differed significantly (.05) across months as determined by one-way ANOVA (F (7,32) = 3.527, p = .006) (Table 6). A Tukey post hoc test revealed that month 14 was significantly different than month 9 and month 12. Between 9 to 16 months, jaw grading increases from 9 to 14 months. The means plot of jaw movement shows that the proportion of graded movement starts low and steadily increases until 14 months. There is a small drop/leveling off 15 to 16 months.

Figure 3

Month Means Plot Proportion of Jaw Movements



3.1.1.2 Proportion of Lip Movement

The proportion of lip movements were analyzed at all three levels of motor control (Table 7). A test for homogeneity of variances found the Levene Statistic was not significant for oscillation (p = .079), fixed (p = .496), or graded (p = .178) movements.

Table 7

Mean Proportion of Lip Movements

Month	9	10	11	12	13	14	15	16
Oscillation	0.0280	0.0216	0.0128	0.0134	0.0298	0.0636	0.0258	0.0348
Fixed	0.7488	0.7186	0.5738	0.6266	0.5256	0.4460	0.4806	0.4932
Graded	0.2232	0.2598	0.4136	0.36	0.4446	0.4904	0.4936	0.4720

The proportion of lip oscillations did not differ significantly across months (Table 8) as determined by a one-way ANOVA (F (7,32) = 0.478, p = .843). Figure 4 presents a means plot for lip oscillations across months.

Table 8

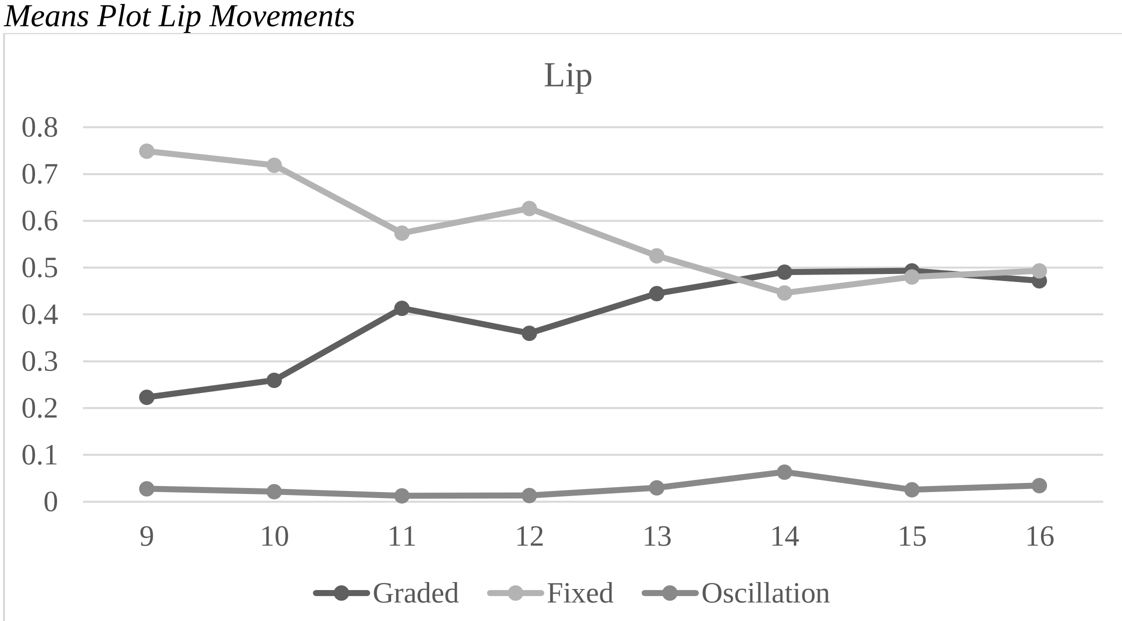
One-Way ANOVA Proportion of Lip Oscillations

	Sum of Squares	df	Mean Square	F	P
Between Months	0.009	7	0.001	0.478	0.843
Within Months	0.086	32	0.003		
Total	0.095	39			

The proportion of fixed lip movements across months was highly significant (Table 9) as determined by a one-way ANOVA (F (7,32) = 4.675, p = .001). Figure 4 presents the mean proportion of fixed lip movement across months. At 9 months there is

Figure 4

Means Plot Lip Movements



a significant difference than months 14, 15, and 16. There is a significant decrease in fixed movement at 12 months. A Tukey post hoc revealed that 9 and 10 months are significantly different than months 14 and 15. The mean proportion of fixed movement is also significantly different between 9 and 16 months. Fixed movement of the lips decrease from 9 to 16 months.

Table 9

One-Way ANOVA Proportions of Fixed Lip Movements

	Sum of Squares	df	Mean Square	F	p
Between Months	0.441	7	0.063	4.675	0.001
Within Months	0.431	32	0.013		
Total	0.872	39			

The mean proportion of graded lip movement varied between the months (Table 10) as determined by a one-way ANOVA ($F(7,32) = 4.31$, $p = .002$). There is increase in the proportion of graded lip movement across months with a dip in month 12. A Tukey post hoc test comparison revealed that months 9 and 10 are statistically different than months 14 and 15. Month 9 is statistically different than month 16. An increase in the proportion of graded lip movement can be seen in the means plot in Figure 4.

Table 10

One-Way ANOVA Proportion of Graded Lip Movement

	Sum of Squares	df	Mean Square	F	p
Between Months	0.383	7	0.055	4.341	0.002
Within Months	0.403	32	0.013		
Total	0.786	39			

3.1.1.3 Proportion of Tongue Movements

The mean proportion of tongue movement (Table 11) at all three levels of motor control were tested for homogeneity of variance. The Levene Statistic was not significant for oscillation ($p = .411$) and fixed ($p = .323$) movements allowing the assumption of homogeneity of variances for ANOVA analysis. The Levene Statistic was significant (p =

.047) for graded tongue movements. Homogeneity of variance cannot be assumed for graded tongue movements.

Table 11

Mean Proportion of Control for the Tongue Across Months

Month	9	10	11	12	13	14	15	16
Oscillation	0.4616	0.4956	0.3638	0.4858	0.4748	0.3968	0.5458	0.5422
Fixed	0.5136	0.4922	0.6162	0.4702	0.4762	0.5642	0.4128	0.422
Graded	0.0246	0.012	0.0204	0.0516	0.049	0.039	0.0414	0.0358

There is no difference in the proportion of tongue oscillations across months (Table 12) as determined by a one-way ANOVA (F (3,2) = 1.310, p = .278). Figure 5 presents the means plot of the proportion of tongue oscillations across months. This shows that the proportion of tongue oscillations month to month is statistically the same from 9 to 16 months.

Table 12

One-Way ANOVA Proportion Tongue Oscillations

	Sum of Squares	df	Mean Square	F	p
Between Months	0.143	7	0.02	1.31	0.278
Within Months	0.499	32	0.016		
Total	0.642	39			

The proportion of fixed tongue movements does not vary across months (Table 13) as determined by a one-way ANOVA (F (7,32) = 1.602, p = .171). The proportion of fixed tongue movement month to month is statistically the same. The mean proportion of fixed tongue movements across is presented in a means plot in Figure 5.

Table 13

One-Way ANOVA Proportion Fixed Tongue Movements

	Sum of Squares	*df*	*Mean Square*	*F*	*p*
Between Months	0.164	7	0.023	1.602	0.171
Within Months	0.469	32	0.015		
Total	0.634	39			

The proportion of graded tongue movement does not vary across months (Table 14) as determined by a one-way ANOVA ($F(7,32) = 1.190$, $p = .337$). Statistically, the proportion of graded tongue movement is the same month to month. Figure 5 presents a means plot for graded tongue movement across months.

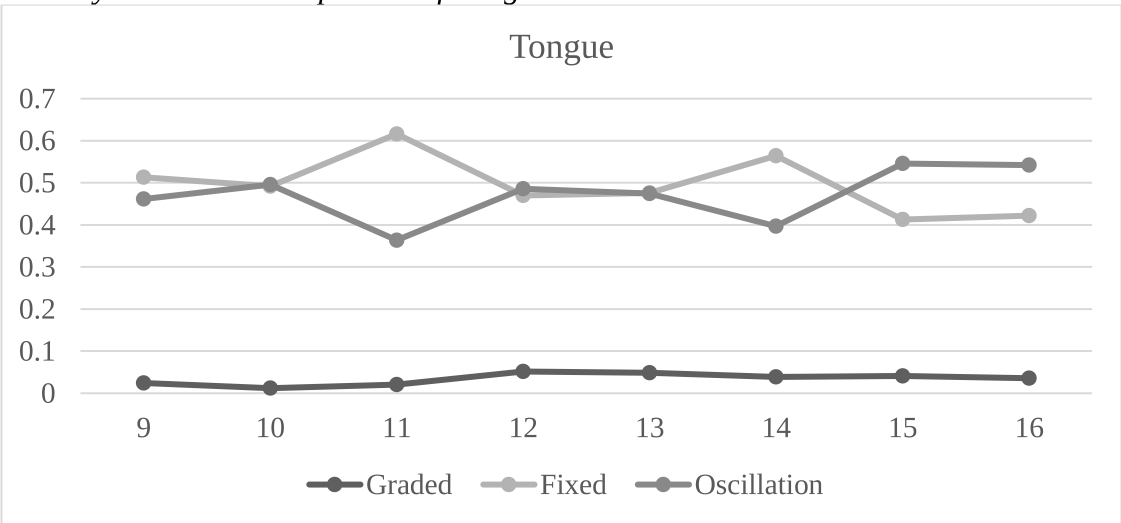
Table 14

One-Way ANOVA Proportion Graded Tongue Movements

	Sum of Squares	df	Mean Square	F	p
Between Months	0.007	7	0.001	1.19	0.337
Within Months	0.026	32	0.001		
Total	0.033	39			

Figure 5

Monthly Means Plot Proportion of Tongue Movements



3.1.2 Hypothesis 2: Independent Articulator Control Will Begin with Jaw Control, then Lip Control, and Finally Tongue Control

As reported above, the one-way ANOVA analysis indicated that graded movements of the jaw and lips increased between 9 to 16 months. To compare proportions of controlled movements a two-way analysis of variance (ANOVA) was conducted. The interaction of articulator and month on level of articulatory control was tested. For each test, the independent variables are month and articulator and the dependent variable is level of articulatory control.

Table 15

Test of Between-Subject Effects

Source	Type III Sum of Squares	d.f.	Mean Square	F	p
Correcteed Model	7.370[a]	23	0.32	35.546	0.00
Intercept	14.223	1	14.223	1577.78	0.00
Months	0.46	7	0.066	7.29	0.00
Articulator	6.644	2	3.322	368.513	0.00
Month *Articulator	0.266	14	0.019	2.107	0.018

Note: R squared = .895 (Adjusted R squared = .870). p = *.05*

The analysis indicated a strong interaction for graded movement, moderate interaction for fixed movements, and no interaction for oscillation. To address the question of independent control of the articulators, the simple main effects are reported for graded movements.

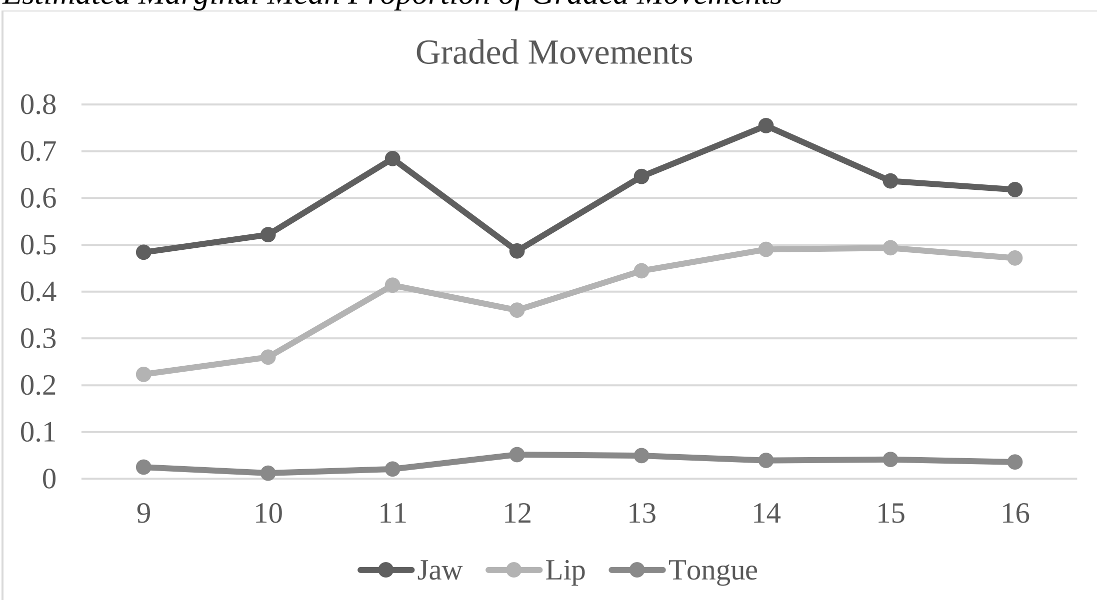
Results of the two-way ANOVA for graded movements can be seen in Table 15. For graded movements the simple main effects analysis showed that there is a statistical significance between articulator (p =.00) and month (p = .00) on the level of graded control. The interaction of months and articulator also has a significant (p = .018) effect on graded movements.

Taking account of the interaction of months and articulator on level of graded control, results can be described as follows. Graded movement of the lip and jaw increase from 9 to 11 months. Both the jaw and lip have a decrease in graded control at 12 months. Graded movements of the jaw and lip have a steady increase after 12 months and level off after 14 months. There is no change in the level of graded control of the tongue across months.

Figure 6 presents the estimated marginal means of graded movement for jaw, lip, and the tongue. The estimated marginal means of the proportion of graded control for the jaw is greater than that of graded control for the lips across the months of the study. The estimated marginal means of the proportions of graded control of the lips is greater than that of the tongue across the months of the study. The estimated marginal means of graded movement for the tongue show no change.

Figure 6

Estimated Marginal Mean Proportion of Graded Movements



Descriptive statistics for the range of the month of acquisition of graded control of the jaw and the lip presented in Table 16 demonstrates that graded movement of jaw is achieved before graded movement of the lips. Only 4 of the 5 participants were credited with graded movements of the lip during the course of the study. Since graded movement of the tongue did not occur, it is clear that graded movements of the lip occur before graded movements of the tongue for 4 of the 5 participants.

Table 16

Achievement of Graded Control of Jaw and Lip

Motor Achievement	M	SD	Range	N
Graded Jaw	10.00	1.00	9 - 11	5
Graded Lip	14.25	1.71	12 - 16	4

3.1.3 Hypothesis 3: Sequenced Movements of the Articulators will Emerge when Graded Control of Each Articulator is Achieved

This hypothesis could not be tested because graded control of the tongue did not reach a level of significance to demonstrate achievement.

3.2 Question 2: What Impact does the Sequence of Motor Control have on Linguistic Development from Babble to Words?

This question was addressed by 4 exploratory questions: (1) What are the changes in speech motor control in relation to dynamic system variables (e.g. mental representation, play, VMS, communicative grunts, context limited words, referential words)? (2) Do children demonstrate variegated babble at level of sequenced movements? (3) What is the motor level for each of the articulators at month of 2 VMS? (4) What is level of speech motor control for words versus non-words, child word versus adult target, and lexical development?

3.2.1 Specific Question 1: What are the Changes in Speech Motor Control in Relation to Dynamic Systems Variables?

The month of achievement of graded control of the jaw and lip for each of the participants presented in Table 17 which is an extension of the comparison of dynamic variables made by McCune and Zlatev (2015) used to identify control parameters for the transition to referential words. The timing of achievement of graded articulatory control, context limited word production, VMS and reference are presented.

Table 17

Month of Acquisition Dynamic Variables

Dynamic Variables	Alice	Aurie	Rick	Jase	Nenni
Object Permanence	10	12	10	13	9
Play Onset	9	12	13	12	12
Context Limited Words	10	13	10	13	14
Play Combinations	9	13	15	15	13
Communicative Grunts	13	13	14	13	14
Vocal Motor Schemes	14	14	13	13	-
Reference Production	14	14	15	15	-
Graded Jaw Movement	9	11	9	11	10
Graded Lip Movement	12	14	16	15	-

The four children who achieved VMS did so following achievement of graded jaw control. One child achieved jaw control but not VMS. The five children achieved context limited words (months 10 to 14) only following jaw control (9 to 11 months). The four children who achieved referential production (14 to 15 months) did so following jaw control. Lip control was also achieved by three of those children (12 to 15 months) prior to referential word productions, while the fourth child was credited with lip control the month following (16 months) the referential transition. While we do not present a test for significance, the results suggest the likely importance of graded jaw and lip movements for linguistic skill acquisition.

3.2.2 Specific Question 2: Do Children Demonstrate Variegated Babble at Level of Sequenced Movements?

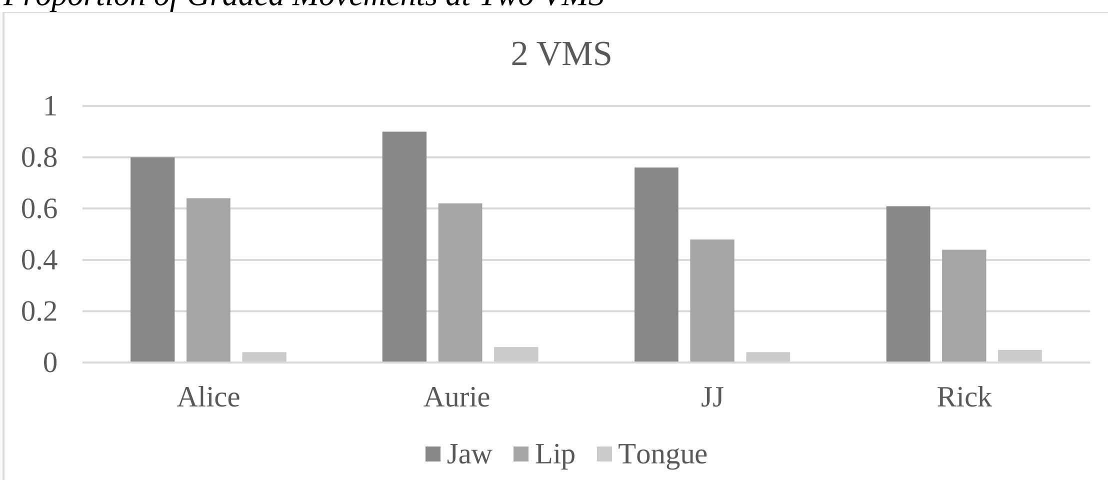
This question could not be answered because none of the participants were credited with sequenced movements.

3.2.3 Specific Question 3: What is the Motor Level for each of the Articulator at Month of Two VMS?

Four of the five participants were credited with 2 VMS. Both Alice and Aurie were credited with 2 VMS at 14 months. Jase was credited with 2 VMS at 13 months. Rick achieved two VMS at 13 months. These four children exhibited proportion of graded control for the jaw above .5. Two of the 4 participants, Alice and Aurie, exhibit proportion of graded lip control above .4. The proportion of graded tongue control was less than .05 for all participants at the point of two VMS. The levels of graded control of each articulator for the month of achievement of two VMS are presented in Figure 7.

Figure 7

Proportion of Graded Movements at Two VMS



3.2.4 Specific Question 4: What is the Level of Speech Motor Control for Words Versus Non-words, Child Words matching the Adult Target Word Production?

3.2.4.1 Words versus Non-words

The level of speech motor control of words versus non-words was compared for each of the participants at 16 months and are presented in Tables 18. The proportion of graded control for each articulator for words is similar to the graded control for each articulator for non-words with the exception of one participant. Alice, who produced the most words of all 5 of the participants, has nearly double the graded control of the jaw and lips for words when compared to non-words.

Table18

Proportion of Graded Movement Words versus Non-Words

	Jase		Alice		Nenni		Aurie		Rick	
	Words	NW	Words	NW	Words	NW	Words	NW	Words	NW
Jaw	0.59	0.58	0.80	0.40	0.63	0.61	0.63	0.59	0.85	0.76
Lip	0.66	0.53	0.53	0.40	0.31	0.35	0.57	0.51	0.33	0.51
Tongue	0.00	0.03	0.01	0.00	0.06	0.11	0.00	0.03	0.00	0.00
n	29	36	79	25	16	46	35	41	40	41

Note: NW = non-word

3.2.4.2 Child Production matching the Adult Target

As discussed in Chapter 1, word production in the emergence of spoken language is variable when compared to the adult target. To answer this question, each participant's words (Vihman & McCune, 1994) were examined and compared to the adult target. In the present case, proportion of child word tokens that matched adult targets ranged from 6 to 24 percent across children (Table 19). Even the most precocious child, Alice, only produced matching tokens 24 percent of the time.

Alice produced 79 tokens of 27 types of words. Of the 79-word tokens she produced, 19 matched the motor control level of the adult target. Aurie produced 35 tokens of 13 types of words. She produced 12 types of words that matched the motor control of the adult target. Rick produced 40 tokens of 10-word types. There were 4-word types of the same word that matched the adult target. Jase produced 27 tokens of 8 different word types. Rick produced 5 tokens that matched the motor control of the adult target. Nenni produced 16 tokens of 4 different word types. One of the token productions matched the motor control of the adult target.

Table 19

Words versus Non-Words

	Jase	Alice	Nenni	Aurie	Rick
Types	8	27	4	13	10
Tokens	29	79	16	35	40
Matches	5	19	1	12	4

3.3 Summary of the Results

The main goals of this work were to study the sequence of speech motor control from babble to word productions in children from 9 to 16 months of age and to determine what impact the sequence of speech motor control has on linguistic development from babble to word productions. Changes in speech motor control were found for the jaw and lip. The increase in motor control of the jaw and lip are likely to be important in the production of words.

Chapter IV Conclusion

The objective of this study was to describe changes in speech motor control of the jaw, lips, and tongue in the transition from babble to words. Movements of the jaw, lip, and tongue were described longitudinally for five children from nine to 16 months of age as they produced spontaneous vocalizations during play. The results revealed an increase in speech motor control from the production of babble to the production of words.

The findings support the importance of the developing speech motor system as a factor in developing spoken language. During the transition from babble to word productions, jaw control was found to be associated with the production of context limited words. In the transition from context limited words to referential word productions, both lip and jaw control increase.

The following sections will focus on the developmental sequence of speech motor control of the jaw, lips, and tongue and the impact speech motor control plays in the dynamic emergence of spoken language. Sections are organized by hypothesis and exploratory questions.

4.1 Question 1: What is the Developmental Sequence of Control of the Speech Motor System from the Production of Babble to the Production of Words?

The answer to this question was addressed by three specific hypotheses: (1) Independent control within each of the three articulators will begin with oscillation, then to fixed movements, and finally to graded control. (2) Independent Articulator Control will begin with jaw control, then lip control, and finally tongue control. (3) Sequenced movements of the articulators will emerge when graded control is achieved across articulators. The results of each hypothesis will be presented individually.

4.1.1 Hypothesis 1: Independent Control of the Articulators will Begin with Oscillation, then to Fixed Movements, and Finally to Graded Control.

The analysis of levels of articulatory control were found to be more complicated than initially hypothesized, and the results of the study did not support the predicted levels of articulatory control. This is not surprising as there had been no previous study of these variables. The hypotheses were derived from a hierarchy of speech motor control aimed at treatment of speech production disorders.

The sequence of motor control was hypothesized to begin with oscillation because it has been hypothesized that babble is triggered by rhythmical stereotypies of the jaw similar to those found in the arms and legs (MacNeilage & Davis, 1993; Thelen, 1979). Neither the jaw nor lips progressed through a production stage where oscillations were the dominant motor level. It is possible that the theoretical notions that suggest jaw oscillations as the catalyst for the onset of babble did not consider a distinction between oscillation and control of the jaw for speech sound productions. For the lips, it is likely that because there is no axis point (joint) from which to begin movement. The fact that the lips are intervened by more than a single muscle it is likely that tradition levels of control may not apply. Tongue movements had some months with oscillation being the dominant level of motor control, but there was no consistent pattern of improvement of level of control. This study began at nine months of age, three months past the typical onset of reduplicated babble, it could be that this study began after the oscillations of the jaw and lip would have been produced. It is unclear as to how the level of control of the tongue progressed from this study. It could be that the level of articulatory control of the tongue related to the level of control of the jaw (MacNeilage & Davis, 1993). All three of the articulators produced oscillations throughout the study, but none at a level to consider a developmental sequence.

Fixed movements were predicted to occur between oscillation and graded levels of control because during development children tend to lack strength and produced patterns of movement that require compensatory movements to produce a desired outcome (Rosenfeld-Johnson, 2005). The initial hypothesis assumed that when a child attempted to produce a voluntary sound there may be fixing of the articulators due to limitation of speech motor control. The only articulator to have any significant fixed movements was the lips. Initially, there was a greater proportion of fixed lip movements than either graded or oscillations. This is consistent with finding that the at the lip movements at the onset of speech sound productions are related to the opening and closing of the jaw (Green et al, 2000) with independent lip control from mandibular movement increasing with age (Green et al, 2002). Tongue movements did not varied between fixed and oscillation across the months of the study. Again, it could be that tongue control at this stage of speech sound production may be related to jaw movements. Fixed movements are often noted in abnormal development due to the child producing compensatory movements patterns due to motor dysfunction. It could be that during normal development, fixing is limited because typical patterns of movement prevail as the system organizes.

The jaw and the lip both produced graded jaw control above the criterion of a proportion greater than .5. This study supports previous findings that the jaw is the primary articulator for babble and first words (Green et al, 2000; Green et al, 2002). This study found jaw movements to be primarily graded from the beginning of the study before to the onset of word productions. Graded lip movements increased across the months of the study. Previous cross-sectional research on lip control found increases in control from one to two years of age as the movement of lips dissociate from the jaw (Green et al, 2000). The tongue did not demonstrate articulatory control during the study.

Movements of the tongue in the emergence of language have theoretically been attributed to the movement of the jaw (MacNeilage & Davis, 1993). Tongue movements begin from its placement at the onset speech. The degree of movement of the tongue is most likely related to the amount of jaw movements that occurs within a given sound production. The tongue is a muscular hydrostat that consists of eight muscles that provide intrinsic and extrinsic support and control. The tongue creates its own structure through the extension and flexion movement patterns of its muscles. Currently, the anatomical specialization that underlie the complex movements of the tongue for speech production are largely unknown (Sanders & Liancai, 2013). The tongue's functions are complex and the lack of identification of its control in this study may a be result of the tongue's limited capacities in the production of babble and first words. It is also possible that the coding system used to describe the tongue's movements was unable to capture the complexity of the movements. Either way, understanding the developmental sequence of tongue control is necessary to advance a full theory of the emergence of spoken language.

This study presents initial findings that show changes in levels of motor control of the jaw, lip, and tongue from babble to the production of words. These preliminary finding supports motor control of the speech motor system as a variable to consider in the emergence of spoken language. This study demonstrates that changes in speech motor control influence production as children begin to use words to communicate.

4.1.2 Hypothesis 2: Graded Movements Across Articulators Will be Achieved according to the Hierarch Stages: Mandibular, Labial, Lingual, and Finally Sequenced Movements.

The initial hypothesis that graded movements of the articulators would be achieved according to the PROMPT treatment hierarchy (Hayden, 1986) assumed that each level of articulatory control would be necessary prior to the onset of reverential words because it was assumed sequenced movements were necessary to produce words.

This study supports previous research that concluded mature jaw productions preceding organized lip movements (Green et al, 2000; Green et al, 2002). Jaw movements in this study supports previous findings that the jaw is the primary articulator in the production of babble and first words. Jaw movements were primarily graded from the beginning of the study prior to the onset of word productions (Green et al, 2000; Green et al, 2002; Kent, 1999; MacNeilage, Davis, Kinney, & Matyear, 2000). Graded control of the lips occurred after jaw control was established. The results confirmed that graded lip movements increased over time, similar to previous research that found improvements in lip control from one to two years of age (Green et al, 2000; Green et al, 2002). Tongue movements did not achieve graded control so sequenced movements could not be evaluated.

The motor speech hierarchy was developed for treatment and not as a developmental sequence. It is likely that during the development of speech, control of the articulators and the coordination of their movements have a more complex interaction than the hierarchy offers. The production of context limited words was supported by phonation and graded jaw movements. Referential word productions were supported by phonation and graded movements of the jaw and lips. It was initially hypothesized that referential word productions would require sequenced movements of the three articulators according to the hierarchy stages, however, the study found the process to be more complex.

The highly refined movements of the speech motor system needed for adult production accuracy take years to master (Sanders, 1972; Walsh & Smith, 2002) and it is likely the sequence of control of the speech motor system begins during babble and first word productions. This study demonstrates that control of jaw, lips, and tongue follow a developmental sequence of control. This provides evidence to support motor control as a necessary skill during babble and early speech.

4.1.3 When the Child is Credited with Referential Word Productions, all Articulators Will be at the Level of Graded Control.

As mentioned above, sequenced movements of the three articulators could not be investigated because graded control was not achieved for the tongue. Sequenced movements are described as those that include coordinated movements on multiple planes of movement and include voicing, jaw control, lip control, tongue control, and timing. Although early word productions lack the complexity of the adult target, the initial hypothesis assumed that sequenced movements would be necessary to produce referential words. Given that speech sound productions are not mastered until later in development, it is possible that sequenced movements may not occur until that time.

4.1.4 Summary

To produce speech, there must be activation and coordination of at least 70 muscles and body parts (Thelen,1991). Theories of the emergence of spoken language have yet to propose the sequence of control of the speech motor system.. The limited repertoire of speech sounds and sound combinations produced in the early stages of production have been hypothesized to be guided by universal constraints that have not been specifically identified (Kent, 1992, 1999; Oller, 1980). Although recent studies have provided evidence that the control of the jaw occurs prior to lip control in the production of specific sounds (Green et al, 2002; Green et al, 2000) no sequence of development was proposed or determined. This study provides evidence that in the transition from babble to word productions, there is an increase in motor control that justifies that the sequence of control is not just a maturational process. This study provides a starting to point for a more complex understanding of the sequence of speech motor control in the emergence of spoken language.

4.2 Question 2: What Impact Does Speech Motor Control Have on Phonetic and Phonological Development from Babble to Words?

This question was addressed by 4 exploratory questions: (1) What are the changes in speech motor control in relation to dynamic system variables (e.g. mental representation: addressed by representational play, VMS, communicative grunts, context limited words, referential words)? (2) Do children demonstrate variegated babble at the level of sequenced movements? (3) What is the motor level for each of the articulators at month of 2 VMS? (4) What is level of speech motor control for words versus non-words, child word versus adult target, and lexical development? Each question will be addressed individually.

4.2.1 Specific Question 1: What are the Changes in Speech Motor Control in Relation to Dynamic Systems Variables?

In the emergence of spoken language, the transition to referential word use signals the onset of a sharp increase in the number of lexical items produced by a child (McCune & Vihman, 2001). Findings of the timing of achievement of the variables acting as potential control parameters for the onset of referential word use identified mental representation (identified by levels of play), vocal development (identified as Vocal Motor Schemes or VMS), and communicative grunts (McCune, 1992, 2008). The least understood of the variables is vocal development because the necessary motor skill for speech sound productions was neither considered nor evaluated. This study evaluated the speech motor skill development considering context limited words, VMS, and the transition to referential word productions.

The study found that the four children who achieved VMS did so following the onset of graded jaw control. The five children who produced context limited words all had been previously credited with graded jaw control. The four children who transitioned to the production of referential words did so following jaw control. Lip control was also achieved by three of those children prior to the transition to referential words, while one of the children was credited one month following. The one child who did not achieve VMS or referential word productions was not credited with graded lip control. Along with the dynamic variable described by McCune and Zlatev (2015) speech motor control may contribute to the transition to reference because without graded control of both the jaw and lips, reference was not achieved.

This study provides another subsystem that supports understanding the emergence of spoken language from a dynamic system perspective. Skill acquisition from a dynamic systems approach is said to occur through the cooperative interaction of the subsystems necessary for specific developmental outcomes (Thelen, 1991). The emergence of language requires the child’s desire to communicate combined with cognitive skills, social skills, linguistic development, biological maturation, and the development of the motor skills necessary to produce speech (McCune, 2008). Previous studies have acknowledged speech motor development but did not investigate specific control parameters. This study provides evidence to support that the development of speech motor control is a valuable subsystem that contributes to the onset of language production.

4.2.2 Specific Question 2: Do Children Demonstrate Variegated Babble at the Level of Sequenced Movements?

Sequenced movements could not be addressed, as the operational definition of "sequenced movements" was graded control of the jaw, lips, and tongue and the tongue did not achieve graded control. Sequenced movements do not occur during babble given brevity of vocalizations typically produced. First words typically contain single syllables, simplifications of the adult target with a reduced rate of articulation (Nip, Green, & Marx, 2011). Sequenced movements of the articulators occurring in smooth intelligible speech require rapid modification of the speech motor system to change the shape of the oral cavity. Given that sequenced movements of the articulators require the differentiation of the three articulators, along with their integration, it is likely sequenced movements develop later, as the child gradually masters all the sounds of their language.

4.2.3 Specific Question 3: What is the Motor Level for Each of the Articulators at Month of Achievement Two VMS?

During early speech production, children gain volitional control of a small subset of speech sounds that can be found in both babble and first word productions (McCune & Vihman, 2001). This study investigated the motor control necessary for the achievement of two VMS as this achievement promotes the production of words. The production of two VMS was discovered to occur following the achievement of graded jaw control. The small subset of speech sounds produced in early lexical development has been attributed to their ease of production without defining specific production limitations (Stoel-Gammon, 1998). The present findings attributes ease of access to control of the jaw. Although it has be theoretically assumed that the jaw is the primary articulator at the onset of speech production (Green et al, 2000 & 2002; MacNeilage & Davis, 1998), specific levels of motor control were neither consider nor investigated. As mentioned previously, this study demonstrates motor control as a variable to justify a more complex explanation than a maturational process.

4.2.4 Specific Question 4: What is Level of Speech Motor Control for Words versus Non-words, Child Word matching the Adult Target?

There has yet to be a study that has investigated speech motor control needed to produce words as children begin talking. The first words produced by a child lack the complexity of the adult target with rules of production being the primary explanation. The following sections will separately describe the motor differences for words versus non-words, child words versus adult target, and lexical development.

4.2.4.1 Words versus Non-words

This comparison was done to understand whether the effort to produce a word verses a babbled production challenges their speech motor skills. It was initially hypothesized that the demand of word production would challenge the child’s production skills. The results suggest that the child produces vocalizations, both words and babble, using their current level of speech motor control.

4.2.4.2 Child Word matching the Adult Target

The five children in the study varied in their lexical acquisition by the final month of the study. The most verbally precocious child (Alice), was credited with graded jaw and lip control and produced 27 different words. The least verbal child (Nenni) was only credited with jaw control and produced 4 words. Around 18 months of age, children begin to develop vocabulary at an increased rate. It is likely that as speech motor skills continue to refine vocabulary will increase.

Each child's word productions at 16 months were compared with the adult target. The study found that at best, the most verbally precocious of the children only motorically matched 24 percent of word productions to the adult target. The child with the fewest verbal productions produced only a six percent motor match to the adult target. Considered from the perspective of motor movements produced in an utterance, when child productions were compared with their mothers', very few child productions succeed in matching the target. These findings combined with those that compare the child's words versus non-words provide support that the patterns of production produced in the emergence of spoken language can be explained by the child's level of speech motor control.

4.2.4.3 Summary

It is commonly understood that a child's babble and first words include only a small subset of speech sounds (Locke, 1983; Vihman, 1992) due to the inherit ease of production of these sounds (Stoel-Gammon, 1998). This study provide evidence to support that the child's level of speech motor control is a factor to consider in the development of speech sound productions, words, and lexical development.

When children begin producing sounds, the small subset of sounds produced may be explained by production being limited to jaw control. A child's first words contain the same sounds as those consistently produced in babble because jaw control also supports the production of context limited words. Increases in vocabulary development at the transition to referential word productions may be the result of the integration of controlled lip movements with the already controlled jaw. The lack of match between adult and child productions is likely due to limitations in motor control, which adds an additional variable to consider in the explanation of production consistencies in the early stages of speech production.

Early patterns of word productions have typically been described as phonological processes due to the consistency of how children are described as solving articulatory problems. This assumes that the production is based on linguistic skills rather than considering the production capacity of the child. In the comparison of the child word productions to the adult target, it seems that a child produces words given their level of articulatory control. The simplification of the target words appears to be the child using their available motor skills to match the adult target. The child's level of speech motor control to produce words may be responsible for patterns of production. This justifies a more comprehensive evaluation of production patterns identified as phonological processes typical during lexical development.

4.3 Contributions of the Study

4.3.1 Theory

Current developmental theories that aim to understand the emergence of spoken language have for the most part considered the developing speech motor system as a general biological process during the acquisition of the production skills necessary to produce language (e.g. Gleason & Ratner, 2009; Kent, 1992; Macken & Ferguson, 1983). Theories of phonological development recognize that there are limitations in a child's ability to produce complex speech sounds, however, they do not specifically address speech motor control. Given that the production of speech is a highly refined motor skill, understanding the developmental sequence of motor skill acquisition has the potential to advance current theories of how children come to produce spoken language.

The first contribution to theory is an explanation of the limited repertoire of speech sounds in the production of babble and first words that includes motor skill development. Theoretical views have claimed that a child's limited speech output in the emergence of spoken language is the result of universal production constraints (Smith, 1973; Stampe, 1979), limited representation (Macken & Ferguson, 1985) and ease of production (Gleason & Ratner, 2009; Stoel-Gammon, 1998). This study found that the production of context limited words are associated with control of the jaw and referential words were associated with increased control of lip. This is the first study to directly investigate and provide support of speech motor control as a factor that influences the sounds produced in the emergence of spoken language. This study provides a framework to better understand production constraints in the emergence of language considering a sequence of speech motor skill development.

Development from a dynamic systems approach considers the complex interaction of the many subsystems necessary for skills to emerge. For speech production, there are many variables that have been found to predict the onset of spoken language. This study contributes to a dynamic system account because it adds motor control as a variable for consideration.

Thelen (1991) described the capacity for spoken language describing the motor components necessary, similar to other motor skills like walking. From this perspective the argument is that the motor capacity for speech production is “dynamically assembled from the subsystems that themselves change over time rather than being scripted from a maturational or cognitive device” (p. 358). This study supports that speech production emerges with the onset of new skills (graded jaw and lip control) with stable existing skills (phonatory control). The methodology designed for this study provides a platform to continue to understand how speech motor skills continue to develop as vocabulary improves and word combinations emerge.

McCune (1992, 2008; McCune and Zlatev, 2015) identified dynamic variables to predict the onset of referential production and comprehension. In the individual analysis of 10 children, individual variables alone did not predict the onset of reference but contributed collectively. This study supports the notion of improvements in speech motor control in development of vocal skills. Speech motor control is an additional dynamic variable to be considered in the transition to reference. Although speech motor control did not predict the onset of referential words, they added an additional variable to consider.

This study demonstrates the importance of speech motor skills in the emergence of spoken language and provides a foundation for continued research concerning the developmental sequence of speech motor control as the child transition from babble, to words, to adult like productions. The sequential development of jaw and lips control found across children provides support to consider speech motor development as a factor that influences production skills rather than a simply a maturation process.

A theory of speech development that considers speech motor control will provide a framework for the treatment of the speech motor system when delays in development occur. This study sets the groundwork necessary for a greater understanding of the developmental sequence of control of the speech motor system in the emergence of spoken language as a specific set of skills rather than a general maturational process.

4.3.2 Assessment and Treatment of Speech Production Disorders

When a two-year old child has no verbal communication and cannot imitate speech sounds, the recommended treatment often involves alternative communication rather than strategies that promote the development of the speech motor skills for production (DeThorne, Johnson, Walder, & Mahurin-Smith, 2009). Current theory for the emergence of spoken language is interpreted to mean that efforts to improve motor control for production are not relevant because the underlying skills necessary are considered linguistic. Treatment models for the remediation of speech production disorders generally focus on developmental norms in speech sound acquisition (Locke, 1983) and phonological acquisition (Hodson, 2010) without a focus on the child's ability to produce speech sounds.

Developmental milestones have been identified for many motor skills. These milestones are important clinically because they identify areas of dysfunction in assessment which drives treatment of a variety of developmental disorders. In the emergence of speech, the developmental milestones have focused on speech sound productions, phonological skills, words, word combinations, and grammar. Developmental milestones have yet to be identified for the speech motor system in the acquisition of language. Although more needs to be understood, this research provides a descriptive framework from which a developmental sequence of speech motor control can be developed. Understanding the developmental milestones of the speech motor system will provide clinical tools for assessment which will provide more effective treatment options for children who do not produce speech typically. At this point, motor based therapeutic interventions for speech production disorders lacks much needed empirical support (Lof, 2015; Lof & Watson, 2008).

Measures of jaw, lip, and tongue control are not standard in the assessment of speech and language skills of children who are minimally and non-verbal because speech production is based on the development of linguistic skills. The sequence of speech motor skill acquisition has yet to been considered in the emergence of spoken language. This study supports the jaw as the primary articulator for both babble and words, with lip control very likely necessary for increased lexical development. This study provides evidence that improvements in the child's ability to control the articulators advances production skills. There is an immediate need for a therapeutic tool to assess motor deficits in speech production. Specific intervention strategies could then be applied at the child's level of motor functioning.

Therapeutic activities that target control of the speech motor system are criticized because there is a lack of evidence to support that oral motor movements outside of speech production are necessary to produce speech (Lof, 2015). The results identify the jaw is the first articulator necessary for production of both babble and words. At this point, using motor activities to improve jaw and lip control have yet to be accepted due to lack of empirical support. In general, programs for improved motor control for speech have a cookie-cutter treatment plan and lack incorporation of specific speech production goals. This study provides the foundation for studies to test whether improving jaw and lip control improves speech production skills in minimally and nonverbal children.

4.4 Limitations of the Study

This study is limited by a small sample size and the use of retrospective data. A larger sample size would have provided a better representation of speech motor skill development from babble to words. The use of previously collected data required the use of pre-prescribed methods. During the course of this investigation, there was no means of collecting extra data that may have added to the data analysis. In the future, during data collection for analysis of speech motor skills, weekly sessions would benefit the researcher in identifying emerging skills as some months saw the identification of more than one variable. In designing a future study, transcriptions can be made rapidly and experimental probes can be implemented to determine skill acquisition. Although the use of pre-collected data was a limitation, it did provide a starting point for a better understanding of the developmental sequence of speech motor control in the production of babble and words productions.

4.5 Future Research

To better understand the developmental sequence of control of the speech motor system in the emergence of spoken language, the study should be replicated beginning at the onset of babble (6 months) with a larger sample size. The findings would confirm and extend the current results to include if in fact oscillations occur as part of developmental sequence of motor control.

To better understand sequenced movement necessary for coarticulation, the methodology from this study can be used to identify changes in speech motor skills from the onset of word productions multiword utterances. Research during the period of rapid lexical development and the beginning of word combinations would provide an understanding of the refinement process of the articulators, including when sequenced movements begin to occur.

The results from this study can be used to create an assessment tool to describe limitations in speech motor control for minimally and non-verbal children. An assessment tool that can identify limitations in speech motor control for production will provide a clinician important information when creating a treatment plan for intervention.

The results of this study also provide the support to begin empirical studies to determine the effectiveness of oral motor exercises in children who do not begin to produce speech sounds typically. The study found that graded jaw control is necessary to produce context limited words. These finding provide a foundation for using therapeutic activities to improve jaw control to develop stable speech sounds, in the form of VMS, to encourage word productions.

Finally, the results of this study summarized with McCune and Zlatev (2015) can be used to create an assessment tool to identify missing components in skill acquisition in children who are language delayed. Both this study and McCune and Zlatev (2015) identify measurable components that support the transition to referential word production. The ability to more efficiently identify missing skills in the emergence of language will allow for more precise intervention that focuses on the underlying skills necessary for word production rather than simply identifying the child cannot produce words. A more targeted assessment tool for the early identification of missing skills might increase the response to early intervention for children delayed in language acquisition.

Appendix A

Description of Oscillations

Articulator	Criteria	Example
Jaw	Single syllable: jaw height must move from an open to closed or closed to open jaw position considering the consonant and vowel combination. Multisyllabic production: the initial CV sound using criteria above must repeat	1 or 2 to 5,6, or 7 5, 6, or 7 to 1 or 2
Lip	Single syllable: retraction to protrusion, protrusion to retraction. Multisyllabic production: the initial sound combination must repeat	/iu/ /wi/
Tongue	Single syllable: Tongue movements fluctuate from central or neutral position to back position or opposite direction for consonant productions. Tongue movements fluctuate from central or neutral position to front position or opposite position for consonant productions Tongue movement must fluctuate from front to back, back to front, central to front or back for all consonants within the production. Mulitsyllabic Productions: Tongue up to tongue back first to second syllable Tongue front or back to central first to second syllable First syllable repeats	 /muk/ /hug/ /pat/ /tam/ /tak/ /taki/ /tami/ /patpat/

Appendix B

Description of Fixed Movements

Articulator	Description	Example
Jaw	Single syllable: position of jaw remains in the same position for the production of the vocalization. Multisyllabic production: jaw position is exactly the same or deviates by one either in the open or closed position.	/ti/ /timi/
Lip	Single syllable: Lip rounding or retraction remains in the same position for the production of the vocalization. Lip open and closing moves with jaw	/oh/
Tongue	Single syllable: tongue position remains in either the front or back position for the production of the consonants in the vocalization. Multisyllabic productions: The tongue position remains from central to front or central to back for all consonant productions.	/tæ/ /taɪ tɪ/

Appendix C

Description of Graded Movements

Articulator	Description	Example
Jaw	Single syllable: Final consonant whether same or different from the initial consonant Multisyllabic production: Change of consonant within production Change of vowel within production	/bim/ /pati/ /tæi/
Lip	Single Syllable Lip placement moves from a retracted position to a neutral or closed position Lip moves from rounded position to closed or open position Lip placement moves from a neutral or closed position to a retracted or rounded position. /f/or /v/ produces Multisyllabic production Lips move from rounded to closed to retracted Lips move from open to rounded to neutral /f/ or /v/ produced	 /tim/ /wab/ /mi/ /wami/ /ʃɛmi/
Tongue	Single syllable: not enough tongue movement necessary in a single syllable to demonstrate graded movement given production of consonants in a single syllable production. Multisyllabic productions: Tongue movements occur in various placement points for the production of consonants in a production.	Back, central, front /ʃərk/

Appendix D

Proportion of Movements All Participants

Alice	9	10	11	12	13	14	15	16
Jaw	n=50	n=50	n=51	n=50	n=50	n=50	n=51	n=50
graded	0.6	0.64	0.68626	0.42	0.62	0.8	0.84	0.56
fixed	0.18	0.2	0.1175	0.42	0.18	0.14	0.04	0.22
oscillation	0.22	0.3	0.1961	0.16	0.2	0.06	0.12	0.22
Lip								
graded	0.2	0.18	0.4706	0.6	0.42	0.64	0.56	0.42
fixed	0.68	0.82	0.5098	0.38	0.58	0.32	0.44	0.58
oscillation	0.12	0	0.0196	0.02	0	0.04	0	0
Tongue								
graded	0.04	0.02	0.0196	0.02	0.04	0.04	0	0
fixed	0.42	0.3	0.5686	0.5	0.68	0.5	0.44	0.52
oscillation	0.54	0.68	0.4116	0.48	0.28	0.46	0.56	0.48

Aurie	9	10	11	12	13	14	15	16
Jaw	n=50	n=21	n=50	n=52	n=50	n=50	n=50	n=50
graded	0.5	0.2857	0.62	0.6154	0.74	0.9	0.6	0.64
fixed	0.46	0.6191	0.3	0.2115	0.14	0.04	0.24	0.18
oscillation	0.04	0.0952	0.08	0.1731	0.12	0.06	0.16	0.18
Lip								
graded	0.3	0.381	0.46	0.3462	0.44	0.62	0.46	0.5
fixed	0.7	0.6191	0.54	0.6539	0.54	0.36	0.54	0.48
oscillation	0	0	0	0	0.02	0.02	0	0.02
Tongue								
graded	0.06	0	0.04	0.0385	0.06	0.06	0.08	0.04
fixed	0.68	0.7619	0.66	0.4	0.52	0.48	0.4	0.54
oscillation	0.26	0.2381	0.3	0.6	0.42	0.46	0.52	0.42

Nenni	9	10	11	12	13	14	15	16
Jaw	n=15	n=49	n=43	n=35	n=18	n=51	n=50	n=50
graded	0.467	0.6531	0.7907	0.5714	0.5	0.5882	0.5	0.62
fixed	0.467	0.18367	0.11628	0.3143	0.3889	0.4118	0.34	0.24
oscillation	0.067	0.16327	0.0930	0.1143	0.1111	0	0.16	0.14
Lip								
graded	0.333	0.26531	0.4884	0.3714	0.4444	0.4509	0.38	0.36
fixed	0.667	0.69388	0.4884	0.6286	0.5	0.5294	0.6	0.64
oscillation	0	0.04082	0.0233	0	0.0556	0.0196	0.02	0
Tongue								
graded	0	0.02041	0	0.0857	0.0556	0	0.02	0.1
fixed	0.4	0.51020	0.6047	0.4571	0.2222	0.4314	0.46	0.36
oscillation	0.6	0.46939	0.3954	0.4571	0.7222	0.5686	0.52	0.54

Jase	9	10	11	12	13	14	15	16
Jaw	n=50	n=45	n=48	n=50	n=50	n=50	n=50	n=50
graded	0.34	0.488889	0.666667	0.34	0.76	0.58	0.7	0.54
fixed	0.48	0.4	0.208333	0.48	0.1	0.32	0.28	0.22
oscillation	0.18	0.111111	0.125	0.18	0.14	0.1	0.22	0.24
Lip						.		
graded	0.12	0.333333	0.4375	0.24	0.48	0.36	0.72	0.58
fixed	0.86	0.6	0.541667	0.74	0.52	0.64	0.28	0.42
oscillation	0.02	0.066667	0.020833	0.02	0	0	0	0
Tongue								
graded	0	0	0.041667	0.06	0.04	0	0.02	0.02
fixed	0.58	0.488889	0.5625	0.48	0.52	0.6	0.46	0.44
oscillation	0.42	0.511111	0.395833	0.46	0.44	0.4	0.52	0.54

Rick	9	10	11	12	13	14	15	16
Jaw	n=43	n=50	n=38	n=37	n=41	n=21	n=46	n=52
graded	0.5116	0.54	0.6579	0.4865	0.6098	0.9048	0.5435	0.7308
fixed	0.2326	0.26	0.2895	0.2973	0.1463	0.0952	0.4348	0.1731
oscillation	0.2558	0.2	0.0526	0.2162	0.2439	0	0.0217	0.0962
Lip								
graded	0.1630	0.14	0.2105	0.2432	0.4390	0.38	0.3478	0.5
fixed	0.8372	0.86	0.7895	0.7297	0.4878	0.38	0.5435	0.3462
oscillation	0	0	0	0.027	0.0732	0.2381	0.1087	0.1538
Tongue								
graded	0.0233	0.02	0	0.0541	0.0488	0.0952	0.087	0.0192
fixed	0.4884	0.4	0.6842	0.5135	0.4390	0.8095	0.3043	0.25
oscillation	0.4884	0.58	0.3158	0.4324	0.5122	0.0952	0.6087	0.7308

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