THE RELATIONSHIP BETWEEN TIMING OF SINGLE-SYLLABLE UTTERANCES AND BREATH SUPPORT IN INFANTS DURING THE SECOND YEAR OF LIFE

A Thesis by

Heidi M. Drechsler

Bachelor of Arts, Wichita State University, 2013

Submitted to the Department of Communication Sciences and Disorders
and the faculty of the Graduate School of
Wichita State University
in partial fulfillment of
the requirements for the degree of
Master of Arts

May 2015

THE RELATIONSHIP BETWEEN TIMING OF SINGLE-SYLLABLE UTTERANCES AND BREATH SUPPORT IN INFANTS DURING THE SECOND YEAR OF LIFE

The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Arts with a major in Communication Sciences and Disorders.

____
Douglas F. Parham, Committee Chair

____
Kathy Strattman, Committee Member

____
Trisha L. Self, Committee Member

____
Elaine Bernstorf, Committee Member

DEDICATION

To my parents—for it is you whom I strive so hard for

ACKNOWLEDGMENTS

First and foremost I would like to thank the members of my committee, Dr. Douglas F. Parham, Dr. Elaine Bernstorf, Dr. Kathy Strattman, and Dr. Trisha Self for their time, expertise, and endless support throughout the duration of this project. Their knowledge and encouragement were so important for the successful completion of this project.

I wish to express the utmost gratitude specifically to my committee chair, Dr. Parham, for his endless hours of guidance, teaching, and research expertise. Without his encouragement, I would have not thought this project to be possible. Dr. Parham has ignited my growing interest and knowledge in speech breathing across the lifespan and respiratory research. I am thankful for his dedication to infant research, which helped facilitate the completion of this project.

In addition, I would like to thank my peers, for their help with coding data to make it more accessible for the means of this project.

I would also like to thank Wichita State University for allowing the use of their equipment and space for data collection.

I am grateful for the participants and their parents who agreed to be a part of this project. Without them and the sacrifice of their time, this project would not have been possible.

Finally, I would like to thank my family and friends for their constant encouragement and kindness throughout the duration of this project.

ABSTRACT

The critical window for language development is in the first three years of life. Throughout the second year, speech development is more rapid than at any other stage. The second year of life is marked by the emergence of increasingly complex utterances and vocabulary growth. Infants at this stage have growing demands on their respiratory system. This study explored the relationship between the timing of expiration and the timing of utterance production in infants in the second year of life. Single-syllable utterances of six healthy infants (17 to 25 months) were identified along with the expiratory phases underlying them. The coders then measured and tabulated (a) the lag between the start of expiration and the start of each single-syllable utterance, and (b) the lag between the end of the utterance and the end of expiration. The collected data was plotted on scatterplots with the lag between the expiratory phase start and the utterance start on a *y*-axis, and the lag between the utterance end and the expiratory phase end on the *x*-axis and examined for patterns. Visualization of these infants' data suggested some patterns in respiratory timing for single-syllable utterances. There was some individual variation among the infants, but in general the older infants demonstrated more flexibility in the timing of respiration to support speech production. More research is needed to help explain how typically developing infants learn to produce speech, as well as identify possible physiological markers for increased language complexity in later infancy.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

REVIEW OF THE LITERATURE

Respiratory Development in Infancy

The anatomic development of the human organ system is an ongoing process that begins with fertilization and continues into adult life (Charnock & Doershuk, 1973). Development is systematic, but also individually unique, such as each infant having a unique breathing pattern. Infant development is characterized by rapid growth and maturation of the breathing apparatus, leading to emerging respiratory control for budding speech production (Boliek et al., 1996). The respiratory system is most observable in infants through observations of rib cage and abdominal motion. Infants have a horizontal orientation of the ribs and a flatter diaphragm than an adult, thus causing a smaller zone of apposition and reducing the inspiratory action of both the diaphragm and rib cage muscle groups, leading to smaller breaths and intake of air (Reilly & Moore, 2009).

As infants grow, the biomechanics of the chest wall undergo dramatic changes. Reilly and Moore (2009) stated that the defining characteristic of the developing chest wall is the minimum inspiratory forces generated by the infant rib cage. This gives the common observation that infants are “belly breathers”; producing changes in lung volume by displacement of the diaphragm rather than the rib cage. Thus, the first two years of life are associated with large decreases in the compliance of the chest wall and large increases in the inspiratory force generated by the rib cage, beginning to take shape similar to that of a typical developing child.

In their review of prenatal and postnatal lung development, Charnock and Doershuk (1973) highlighted the rapid growth of the chest after birth. This included an increase in the anteroposterior and transthoracic diameter of the chest, and proliferation and growth of the respiratory structures during the first two months of life (Charnock & Doershuk, 1973). Infants have high degrees of freedom and flexibility available when attempting to achieve the aeromechanical drive required for inspiration and expiration, demonstrating highly variable breathing patterns around the first year of life.

Infant Vocalization and Breathing

The current base of research that involves infant vocalization and breathing is provided by studies that measure chest wall movements. The available literature suggests that there are different patterns of movement for tidal breathing and speech breathing (Connaghan, Moore, & Higashakawa, 2004; Langlois, 1975; Langlois, Baken, & Wilder, 1980; Moore, Caulfield, & Green, 2001; Parham et al., 2011; Reilly & Moore, 2009; Wilder, 1972). It is known that infants use opposed chest wall kinematics when engaged in rest breathing versus breathing involving vocalizations. Connaghan and colleagues (2004) concluded that rest breathing was characterized by consistently rigid coupling among the rib cage and abdominal movements. On the other hand, breathing during vocalization was characterized by the opposite, a decrease in ribcage-abdominal coupling.

Moore, Caulfield, and Green (2001) also emphasized the significant differences in respiratory kinematics between rest breathing and speech breathing indicated by their research with 15-month-old toddlers. Coupling of the rib cage and abdomen again was most consistent during rest breathing and decoupling and increased abdominal muscle activity during speech breathing (Moore et al., 2001). Differences between rest breathing and vocalization have also shown to be affected by age, height, and body position, but not gender (Boliek et al., 1996, 1997).

Across research studies, concrete data has shown differences between respiratory kinematics of rest breathing and speech breathing. To take the research further is to ask the question of how do vocalization and breathing interact specifically. It is known through child development studies that vocalizations begin as vegetative utterances, crying, laughing, then transition to vocalic utterances, reduplicated babbling, variegated babbling, and reach the emergence of the “first words” around the first birthday. Studies focused on breathing behaviors during the first years of life have consistently reported no differences among broad categories of vocalization types, including cries, whimpers, grunts, and syllable utterances (Boliek et al., 1996, 1997; Connaghan et al., 2004; Moore et al., 2001). As the child ages, syllable utterances increase, vocalization types vary, and the variability in motor skill acquisition progressively diminishes, becoming more stable.

Development During the Second Year of Life

The critical window for language development is in the first three years of life; throughout the second year, speech development is more rapid than at any other stage. Only one study has targeted differences in breathing support during varied non-cry vocalizations categorized by syllable types in infants in the second year of life (Parham, Buder, Oller, & Boliek, 2011). The second year of life is marked by the emergence of increasingly complex utterances and vocabulary growth. Infants at this stage have growing demands on their respiratory system. According to Parham and colleagues (2011), older infants may produce detectable articulation-related adaptations of breathing kinematics, switching from the phonatory variations used as younger infants.

The relationship between vocalization and breathing is not well understood. Most studies on infant speech-related breathing collapse non-cry vocalizations together. These studies consider non-speech vocalizations, single- and multi- syllabic utterances, and true words to be similar (Boliek et al. 1996, 1997; Connaghan et al., 2004; Moore et al., 2001). To date only one study has looked at differences between different syllable types (Parham, Buder, Oller, & Boliek, 2011). This current study explored the relationship between the timing of expiration and the timing of utterance production in infants in the second year of life. Whether different utterance types are initiated and/or terminated at similar expiratory times and volumes remains an empirical question. This study might provide normative data that can be used to identify infants at risk for delays (Solomon & Charron, 1998).

CHAPTER 2

MOTIVATION FOR THE STUDY

Motivation

A potential informative area of infant speech development is the timing between vocalization and expiration. It is an empirical question whether different utterance types are initiated and/or terminated at similar expiratory times and volumes. This study explored age-related patterns in respiratory timing for single syllable utterances in infants in the second year of life. It was hypothesized that visualization of this data could suggest some patterns in respiratory timing for single syllable utterances in infants in the second year of life. If patterns exist, it was speculated that they could be explained by additional factors that might predict atypical development in infancy (e.g., breathiness or expressive language delays).

Variables of Interest

In order to compare timing patterns, the study measured two variables that describe the timing relationship between the expiratory phase and single-syllable utterances: (1) the lag between the start of expiration and the start of the utterance, and (2) the lag between the end of utterance and the end of expiration. It is possible to plot the lag between the expiratory phase start and the utterance start on the *y*-axis, and the lag between the utterance end and the expiratory phase end on the *x*-axis. In this way, possible respiratory-utterance patterns could be compared across and within infants. Figure 1 (Parham, 2012a, 2012b; Parham, Francois, & Blincoe, 2012) shows the possible patterns. Black curves represent respiratory cycles (inspiration and expiration); red segments represent utterances and their duration (from left to right) within the expiratory phase.

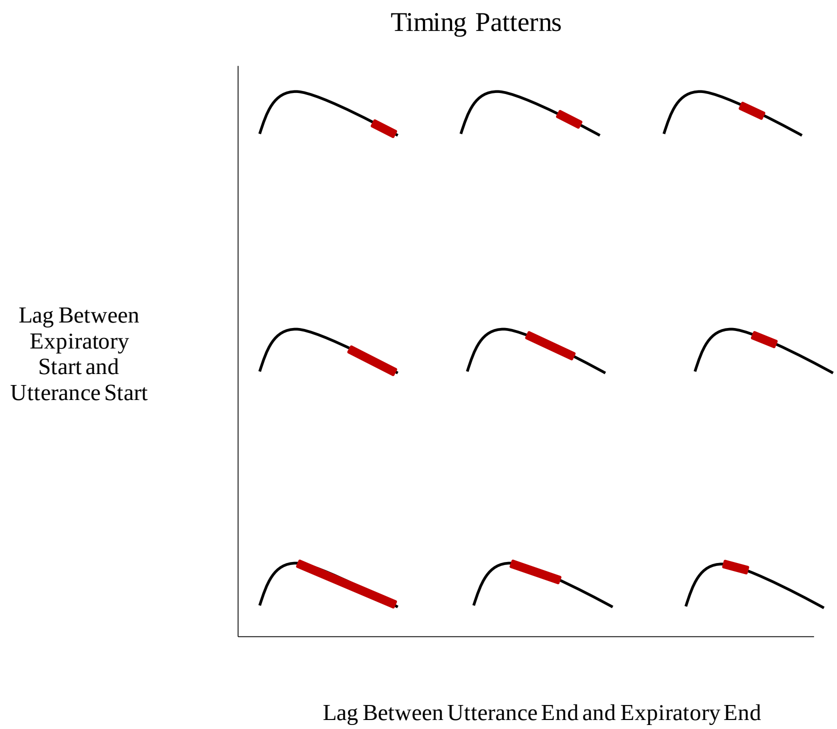

Figure 1. Graph of possible respiratory-utterance timing patterns (Parham, 2012a, 2012b; Parham, Francois, & Blincoe, 2012).

This graph was used to plot the relationships between the utterances and their respective breathing cycles. Utterances that take up the length of the expiratory phase are located in the bottom left area of the scatterplot. This relationship mimics that of crying, in which the entire expiratory phase underlies the cry. Shorter utterances that occur in the middle of the expiratory phase—and represent flexibility of timing before and after the utterance—are found in the top right of the scatterplot.

Research Questions

(1) *Are there age-related patterns in expiratory timing for single-syllable utterances in infants in the second year of life?*

An earlier study looked at breath support for single-syllable utterances in infants around the first year of life (Brady, 2013). Figures 2 and 3 show data from infants ages 9 to 15 months.

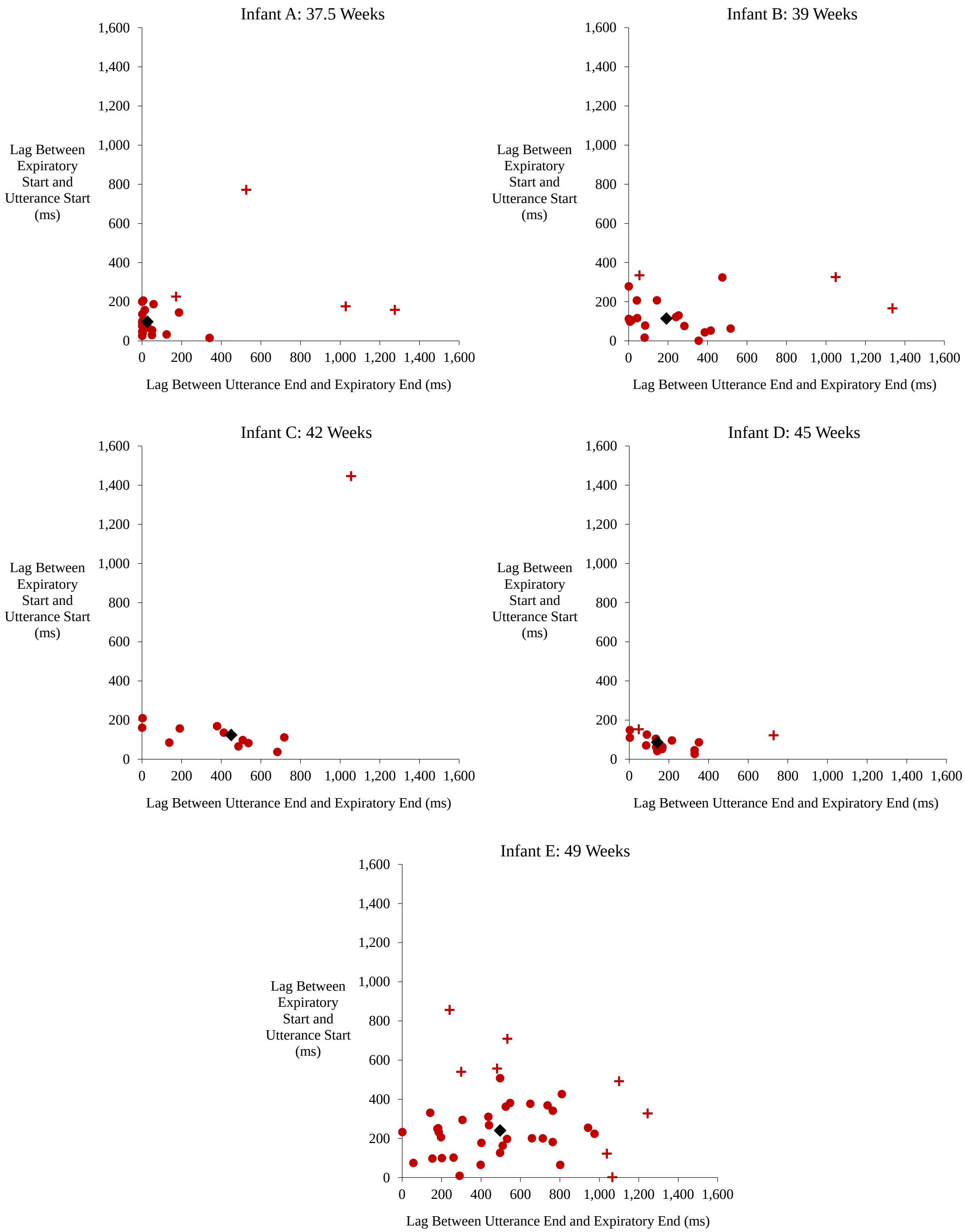

Figure 2. Lag scatterplots of five infants ages, 9 to 11 months (Brady, 2013; black diamond = median; red cross = data at the 90th percentile).

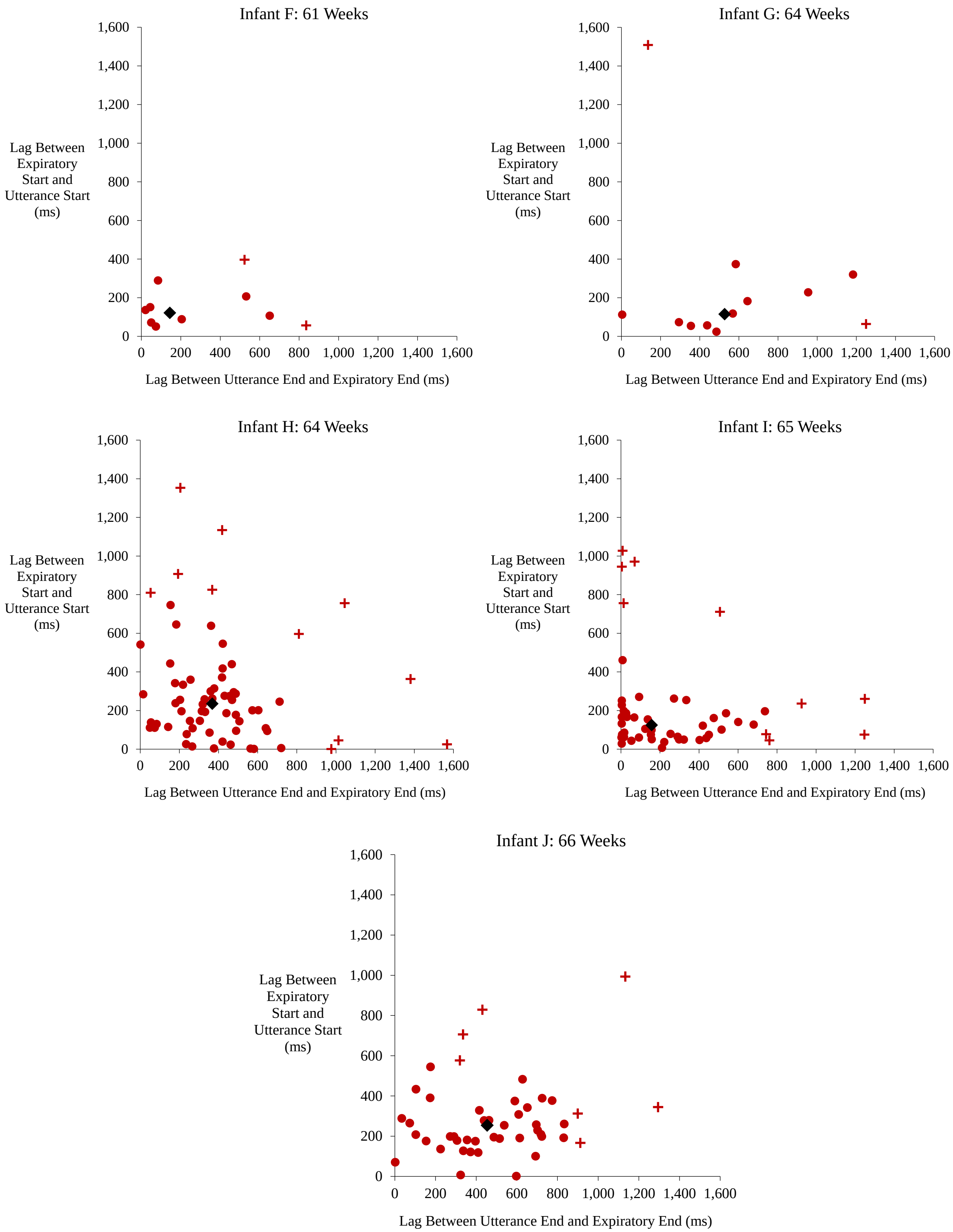

Figure 3. Lag scatterplots of five infants, ages 14 to 15 months (Brady, 2013; black diamond = median; red cross = data at the 90th percentile).

Visualization of that data suggested that older infants have more variety in their patterns of breath support, as indicated by more spread in the data in the scatterplots. The variety was explained by accounting for increased maturity of the respiratory system. With the results from that study as a starting point (Brady, 2013), the current study continued the same line of research looking at respiratory support for single-syllable utterances in children in the second year of life. It was speculated that older infants (i.e., infants approaching 24 months of age) would show more variety in their respiratory patterns than younger infants.

(2) *Are there individual patterns that emerge?*

It was hypothesized that the infants would show differences within the age groups, namely that some of the younger infants might perform like the older infants, and vice versa. This was seen in the Brady (2013) study. In Figure 2, Infant E demonstrated more variety in breathing patterns than the other younger infants, and the patterns of Infants F and G resemble those of younger infants more than they do those of their age cohort (Infants H-J). These differences reportedly reflected language development in the infants: younger infants with more varied patterns showed more language development than others in their age cohort; older infants with less varied patterns showed less language development than others in theirs. It was speculated that this phenomenon would be observable in the infants in this current study.

CHAPTER 3

METHODS

IRB Approval/Patient Confidentiality

The protocols for this study were approved by the Institutional Review Board at Wichita State University (IRB No. 1425; Project Title: "Vocalization and Speech Breathing in Infants and Adults"; Appendix A). After a member of the research team explained the purpose of the study and the study's procedures, the parents of the participants signed an informed consent form allowing their infants to be subjects (Appendix B). Families received $20.00 compensation for their participation in each recording.

Study Population

The subjects for this study were six infants ranging in age from 17 to 25 months. Every infant was born at full term (i.e., within typical gestational limits). The infants were healthy and typically developing. For the purpose of this study, typical development has been defined as that of reaching age-appropriate development milestones in accordance with parent reports. No infant was ill within 3 months of the recording (e.g., respiratory illnesses or ear infections). Formal measures of height and weight were not taken during the recordings; all infants were within normal growth limits based on parent report. For an age group comparison, the infants were categorized into a younger group (17 to 19 months) and an older group (21 to 25 months). Because of previous reports in the literature that indicated no difference in the respiratory variables of male and female infants (Boliek et al., 2006), gender was a non-factor in recruitment. All families were monolingual speakers of American English.

Setting

The recordings took place in the Speech Development and Communication Lab at Wichita State University's Metropolitan Complex. The lab contains an observational playroom where the recordings took place; this room was separated from an instrumentation room by a large one-way mirror.

Instrumentation

Respiratory movements were measured using a respiratory inductive plethysmography (RIP), specifically Inductotrace®, Model 10.9000 (Ambulatory Monitoring, Inc., Ardsley, NY). The Inductotrace® is a standard system used in infant/child respiratory research because no electrical connection exists between the subject and the RIP device (Boliek et al., 1996, 1997; Parham et al., 2001).

Speech output from the participants was captured using a Sennheiser Evolution G2 100 Series wireless microphone system (Sennheiser Electronic Corporation, Old Lyme, CT). A lapel microphone was attached to the infant's shirt. A high-quality digital audio recorder was used to capture an additional audio signal.

Except for the digital audio recorder, all signals were captured using USB-based data acquisition modules (Data Translation, Inc., Marlboro, MA) at 10,000 samples per second, then digitally recorded and stored on a computer using a software program called TF32 (Lab Automation Level; Milenkovic, 2001).

Study Protocol

Each infant was placed in a high chair in the playroom; the parent was seated in a comfortable chair facing the infant. If an infant was wearing multiple layers of clothing, the layers were removed until there was only one layer (typically a t-shirt or "onesie"); this allowed for proper placement of the RIP elastic bands. Next, the microphones and respiratory instruments were placed on the infant. Following standard procedure, one RIP elastic band was placed around the rib cage and another around the abdomen—to track all chest wall movements. The respiratory signals were calibrated using standard protocols (Boliek et al., 1996).

The parents were given the following instructions: “Please play naturally with your child as you would at home.” Speech output and respiratory movements were collected from the infant during face-to-face interaction. In order to standardize the recordings as much as possible, the same stimuli (e.g., board books and small plush toys) were provide to each mother-infant pair. Recordings continued as long as the child was alert and active up to 45 minutes; recordings were stopped if the infant became distressed or attempted to climb out of the high chair. Recording times lasted between 30 minutes and one hour.

Data Analysis

Each infant’s speech output and respiratory signals were examined to determine whether both the rib cage and abdominal signals were analyzable. Both signals were calibrated, added together, and downsampled to 100 samples per second to create a signal represent the movement of the chest wall. This combined signal was used to measure the durations of the expiratory phases and single-syllable utterances.

Two independent coders identified the vocalizations in each recording, including all of single-syllable utterances that were associated with analyzable expiratory phase signals (i.e., expiratory phase and utterance signal pairs). The coders used the TF32 program to label expiratory phases and utterances. Figure 4 shows an example of a label file containing respiratory coding.

16083.600	16685.800	i1
16685.800	18184.300	e1
147006.000	147292.800	i2
147292.800	148569.100	e2
152892.500	153473.300	i3
153473.300	154011.000	e3
157273.300	157976.000	i4
157976.000	159295.200	e4
186031.800	186497.800	i5
186497.800	188734.800	e5
242451.800	243656.300	i6
243656.300	244868.000	e6
261746.000	262140.300	i7
262140.300	266865.300	e7
266879.700	267395.900	i8
267395.900	269138.200	e8
288124.100	289027.500	i9
289027.500	290325.200	e9
290325.200	290898.800	i10
290898.800	292490.600	e10
297007.600	297394.800	i11
297394.800	299631.800	e11
299631.800	300377.500	i12
300377.500	302585.800	e12
304084.300	304564.700	i12
304564.700	306887.700	e12
306887.700	307360.900	i13
307360.900	311053.400	e13
311053.400	311411.900	i14
311411.900	312673.800	e14
333968.500	334319.800	i15
334319.800	334814.500	e15

Figure 4. Example of a label file containing respiratory coding (first column: start times; second column: end times; third column: sequential respiratory phases [i = inspiration; e = expiration]).

The label files were then used to calculate the means, standard deviations, and medians of the expiratory phase durations and utterance durations, as well as identified the minimum and maximum scores of each duration type.

Table 1 shows the number of vocalizations that each infant produced across his or her respective recordings, as well as the number of analyzable expiratory cycle and single-syllable utterance signal pairs.

TABLE 1

NUMBER OF ANALYZABLE EXPIRATORY PHASE AND SINGLE-SYLLABLE UTTERANCE SIGNAL PAIRS PRODUCED BY EACH INFANT

Infant	Total vocalizations	Number of expiratory phase and utterance signal pairs
	Younger group	
A (17 mos)	344	8
A (18 mos)	252	10
B (18 mos)	267	21
B (19 mos)	268	8
C (18 mos)	236	24
	Older group	
D (21 mos)	244	27
E (24 mos)	241	30
F (25 mos)	460	72

As Table 1 shows, despite the large number of total utterances produced by the infants, the number of analyzable single-syllable utterances and their respective expiratory phase signals were small; however, this has been reported in the literature (Boliek et al., 1996, 1997; Parham et al., 2011). The number of analyzable pairs across infants showed variety, with older infants have more available data.

The coders then measured and tabulated (a) the lag between the start of expiration and the start of each single-syllable utterance, and (b) the lag between the end of the utterance and the end of expiration. Figure 5 shows an example of the variables that were measured using a typical signal pair. Both variables were measured in milliseconds. Figure 6 shows an example of a completed set of data ready for analysis. As with the expiratory phase and utterance durations, the coders calculated the means, standard deviations, medians, minima, and maxima of both of the lag variables for each infant.

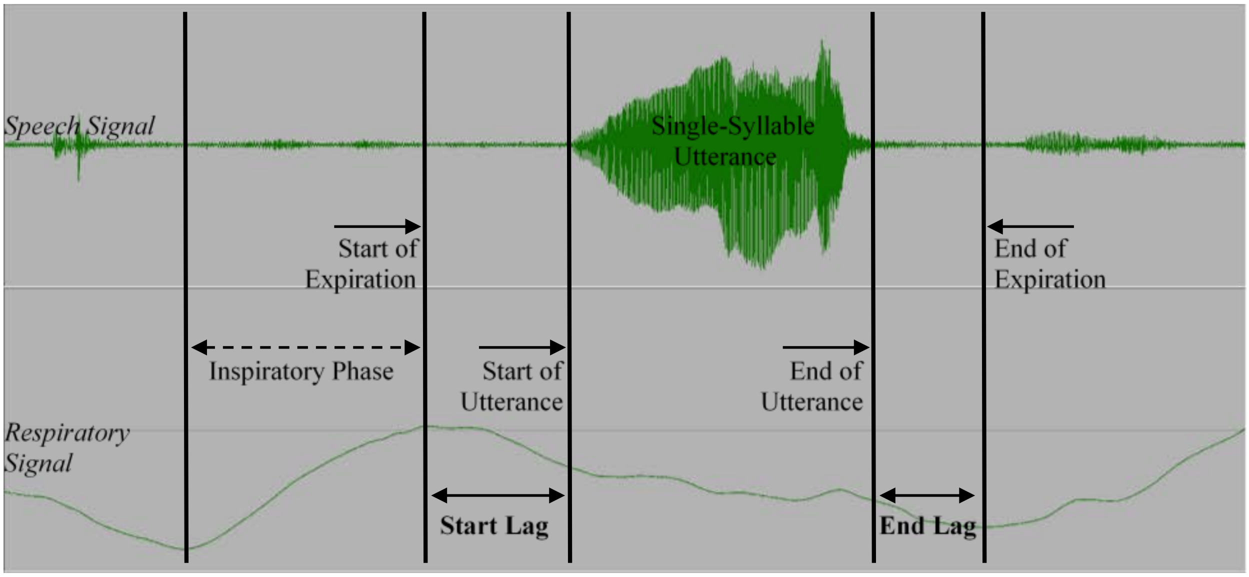

Figure 5. Example of single-syllable utterance signal (top half), expiratory phase signal (bottom half), and variables measured (black lines).

Expiratory Code	Expiratory Start	Expiratory End	Utterance Code	Utterance Start	Utterance End	Expiratory Duration	Utterance Duration	Lag from Expiratory Start to Utterance Start	Lag from Utterance End to Expiratory End
e1	66933.9	69082.6	u1	67480.4	67874.7	2148.7	394.3	546.5	1207.9
e2	212943.9	214266.7	u2	213077.4	213589.8	1322.8	512.4	133.5	676.9
e3	335334.1	336868.0	u3	335672.6	335998.6	1533.9	326.0	338.5	869.4
e4	344289.0	346152.0	u4	344503.2	345018.7	1863.0	515.5	214.2	1133.3
e5	355339.7	356774.2	u5	355560.2	356619.0	1434.5	1058.8	220.5	155.2
e6	416772.3	418076.4	u6	416834.4	417551.7	1304.1	717.3	62.1	524.7
e7	461006.3	462981.1	u7	461105.7	461599.4	1974.8	493.7	99.4	1381.7
e8	472137.8	473482.2	u8	472435.9	473078.6	1344.4	642.7	298.1	403.6
e9	509540.7	510969.0	u9	509826.4	510459.8	1428.3	633.4	285.7	509.2
e10	513577.2	514400.1	u10	513757.3	514400.1	822.9	642.8	180.1	1.0
e11	523578.5	525031.6	u11	523677.8	524323.7	1453.1	645.9	99.3	707.9
e13	568818.5	570544.9	u13	569327.7	569914.6	1726.4	586.9	509.2	630.3
e14	580875.2	583114.0	u14	581427.9	582421.5	2238.8	993.6	552.7	692.5
e15	596033.9	597260.4	u15	596499.7	596937.5	1226.5	437.8	465.8	322.9
e16	632263.2	633741.2	u16	632452.6	633641.8	1478.0	1189.2	189.4	99.4
e17	634144.8	635461.3	u17	634380.8	635386.8	1316.5	1006.0	236.0	74.5
e17	655234.0	656494.7	u17	655420.3	656230.7	1260.7	810.4	186.3	264.0
e18	699638.8	700874.6	u18	699859.2	700241.2	1235.8	382.0	220.4	633.4
e19	746151.8	747393.8	u19	746437.5	747083.3	1242.0	645.8	285.7	310.5
e20	782517.7	783520.6	u20	782728.9	782964.8	1002.9	235.9	211.2	555.8
e21	791488.1	792823.3	u21	791773.8	792180.5	1335.2	406.7	285.7	642.8
e22	902784.1	903914.3	u22	903203.3	903569.7	1130.2	366.4	419.2	344.6
e23	961338.4	962006.0	u23	961561.9	961947.0	667.6	385.1	223.5	59.0
e24	962350.6	963157.9	u24	962499.7	962953.0	807.3	453.3	149.1	204.9

Figure 6. Example of a data file containing coding (all durations are in milliseconds; first column: start times; second column: end times; third column: sequential respiratory phases [i = inspiration; e = expiration]).

Data Visualization and Comparisons

The collected data was plotted on scatterplots with the lag between the expiratory phase start and the utterance start on a *y*-axis, and the lag between the utterance end and the expiratory phase end on the *x*-axis and examined for patterns (see Figure 1).

(1) *Are there age-related patterns in expiratory timing for single-syllable utterances in infants during the second year of life?*

The data for the younger infants and the older infants, respectively, was combined into two scatterplots (to look for age group patterns), and separate scatterplots were created for each infant.

(2) *Are there individual patterns that emerge?*

Each infant's scatterplot was analyzed for patterns (e.g., clustering or data density in one area of the scatterplot vs. data spread). Scatterplots were arranged together to determine if a specific infant's data appeared differently from those of his or her age cohort.

CHAPTER 4

RESULTS

Results of Descriptive Statistics

The means, standard deviations, medians, minima, and maxima for the expiratory phase durations and the single-syllable utterance durations are presented in Table 2.

TABLE 2
DESCRIPTIVE STATISTICS FOR EXPIRATORY PHASE DURATIONS AND SINGLE-SYLLABLE UTTERANCE DURATIONS

	Descriptive statistic					
Infant	*N*	Mean	*SD*	Median	Minimum	Maximum
Duration of expiratory phases associated with an utterance (milliseconds)						
A (17 mos)	8	1250.0	253.3	1320	830	1600
A (18 mos)	10	1202.0	238.0	1235	780	1490
B (18 mos)	21	1313.3	488.6	1160	820	2340
B (19 mos)	8	1017.5	414.6	865	620	1870
C (18 mos)	24	1387.4	391.4	1329	668	2239
Younger Group	71	1282.2	403.2	1250	620	2340
D (21 mos)	27	1458.1	452.1	1470	660	2350
E (24 mos)	30	1511.7	760.7	1270	390	3950
F (25 mos)	72	1666.0	441.1	1570	990	3110
Older Group	129	1586.6	537.5	1510	390	3950
All Infants	200	1478.5	514.1	1415	390	3950
Duration of single-syllable utterances (milliseconds)						
A (17 mos)	8	305.3	162.2	268.2	121.8	600.0
A (18 mos)	10	473.1	205.4	455.9	141.8	846.5
B (18 mos)	21	551.4	365.6	461.2	210.1	1543.3
B (19 mos)	8	505.2	259.4	544.8	181.0	810.9
C (18 mos)	24	603.4	251.4	551.2	235.9	1189.2
Younger Group	71	525.0	286.4	461.7	121.8	1543.3

(Table 2 continues)

TABLE 2 (continued)

Infant	Descriptive statistic					
	N	Mean	*SD*	Median	Minimum	Maximum
Duration of single-syllable utterances (milliseconds)						
D (21 mos)	27	674.3	211.8	659.5	238.8	1206.7
E (24 mos)	30	618.9	659.7	341.3	153.0	2903.2
F (25 mos)	72	575.9	343.8	503.6	174.8	1630.1
Older Group	129	606.5	418.1	536.8	153.0	2903.2
All Infants	200	577.6	377.9	509.4	121.8	2903.2

Although the standard deviations for both of the duration measures were high across the infants, this variability is consistent with the literature (Parham et al., 2011).

The means, standard deviations, medians, minima, and maxima for the two lag variables are presented in Table 3.

TABLE 3
DESCRIPTIVE STATISTICS FOR LAG VARIABLES

Infant	Descriptive statistic					
	N	Mean	*SD*	Median	Minimum	Maximum
Lag between start of expiration and start of utterance (milliseconds)						
A (17 mos)	8	469.1	287.0	550.7	23.8	747.9
A (18 mos)	10	158.2	158.7	101.7	64.7	595.9
B (18 mos)	21	248.6	303.8	135.0	29.4	1275.6
B (19 mos)	8	230.2	218.9	177.4	3.0	698.6
C (18 mos)	24	267.2	140.1	222.0	62.0	553.0
Younger Group	71	264.9	236.0	186.3	3.0	1275.6
D (21 mos)	27	398.2	317.5	357.9	5.3	1258.6
E (24 mos)	30	380.6	352.8	230.4	19.2	1562.7
F (25 mos)	72	421.3	320.9	321.6	8.0	1471.4

(Table 3 continues)

TABLE 3 (continued)

Infant	Descriptive statistic					
	N	Mean	*SD*	Median	Minimum	Maximum
Lag between start of expiration and start of utterance (milliseconds)						
Older Group	129	407.0	325.7	318.2	5.3	1562.7
All Infants	200	356.6	304.1	243.6	3.0	1562.7
Lag between end of utterance and end of expiration (milliseconds)						
A (17 mos)	8	475.6	216.6	439.8	230.4	968.2
A (18 mos)	10	570.7	203.5	571.0	208.1	855.7
B (18 mos)	21	558.1	250.5	578.7	116.5	1049.9
B (19 mos)	8	312.5	250.0	343.8	10.7	591.2
C (18 mos)	24	516.9	368.7	517.0	1.0	1382.0
Younger Group	71	509.0	291.0	517.4	1.0	1382.0
D (21 mos)	27	422.2	297.0	419.2	5.8	932.5
E (24 mos)	30	413.1	496.3	214.3	1.4	1553.1
F (25 mos)	72	652.3	297.1	663.2	115.8	1528.8
Older Group	129	548.5	369.3	522.1	1.4	1553.1
All Infants	200	534.5	343.3	519.8	1.0	1553.1

In the case of these data for the two lag variables, the variability across infants is apparent given not only the large standard deviations, but also in the minimum and maximum scores. For this reason, the median scores are a more accurate measure of central tendency for the lags.

Results of Scatterplot Visualization

The visual representation of the two timing relationship variables for all of the infants is found in Figure 5 (younger infants) and Figure 6 (older infants). In all of the scatterplots, the lag between the start of the expiratory phase and the start of the utterance is plotted on the *y*-axis, and the lag between the end of the utterance and the end of the expiratory phase is plotted on the *x*-axis.

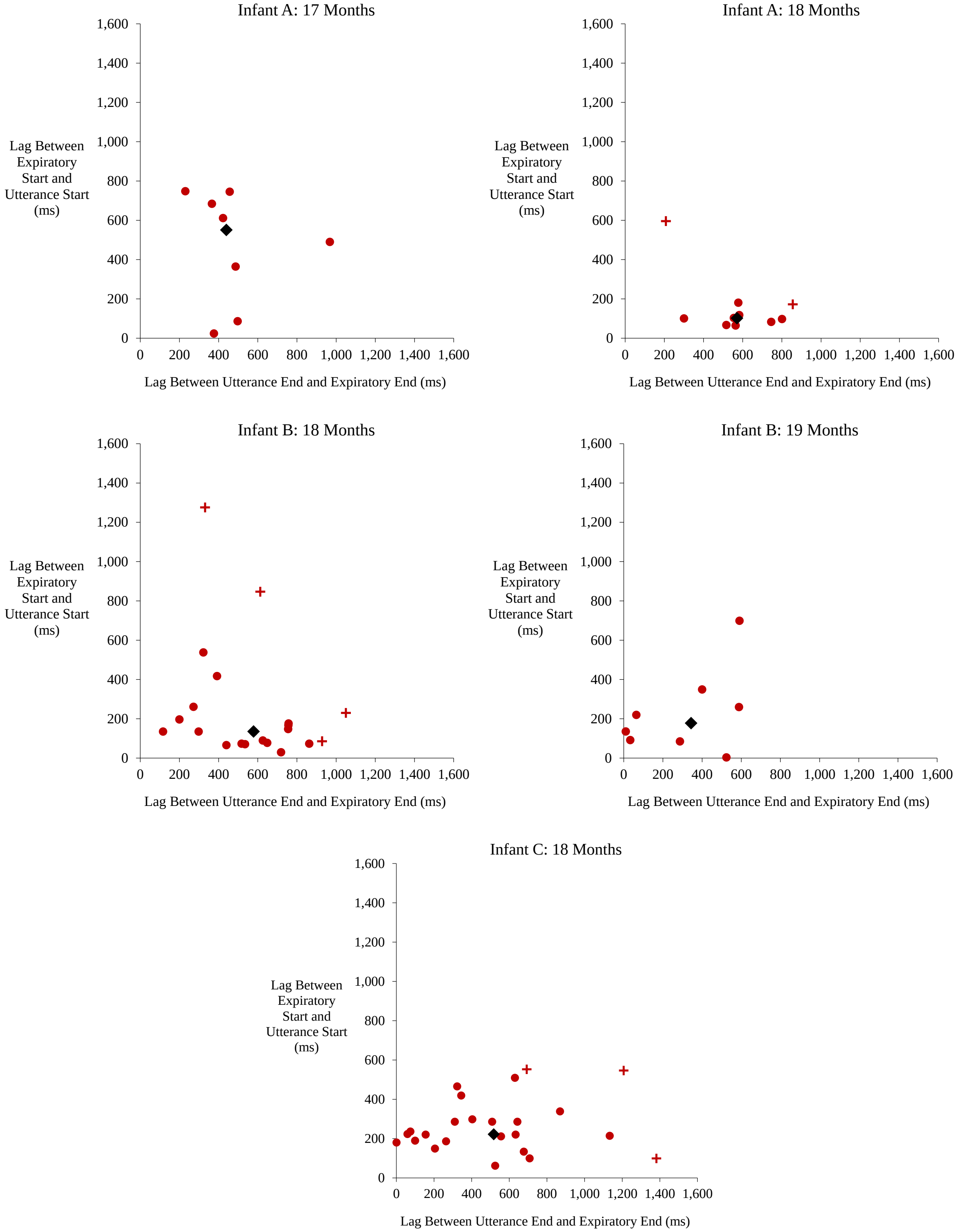

Figure 7. Lag scatterplots of the younger infants (17 to 19 months).

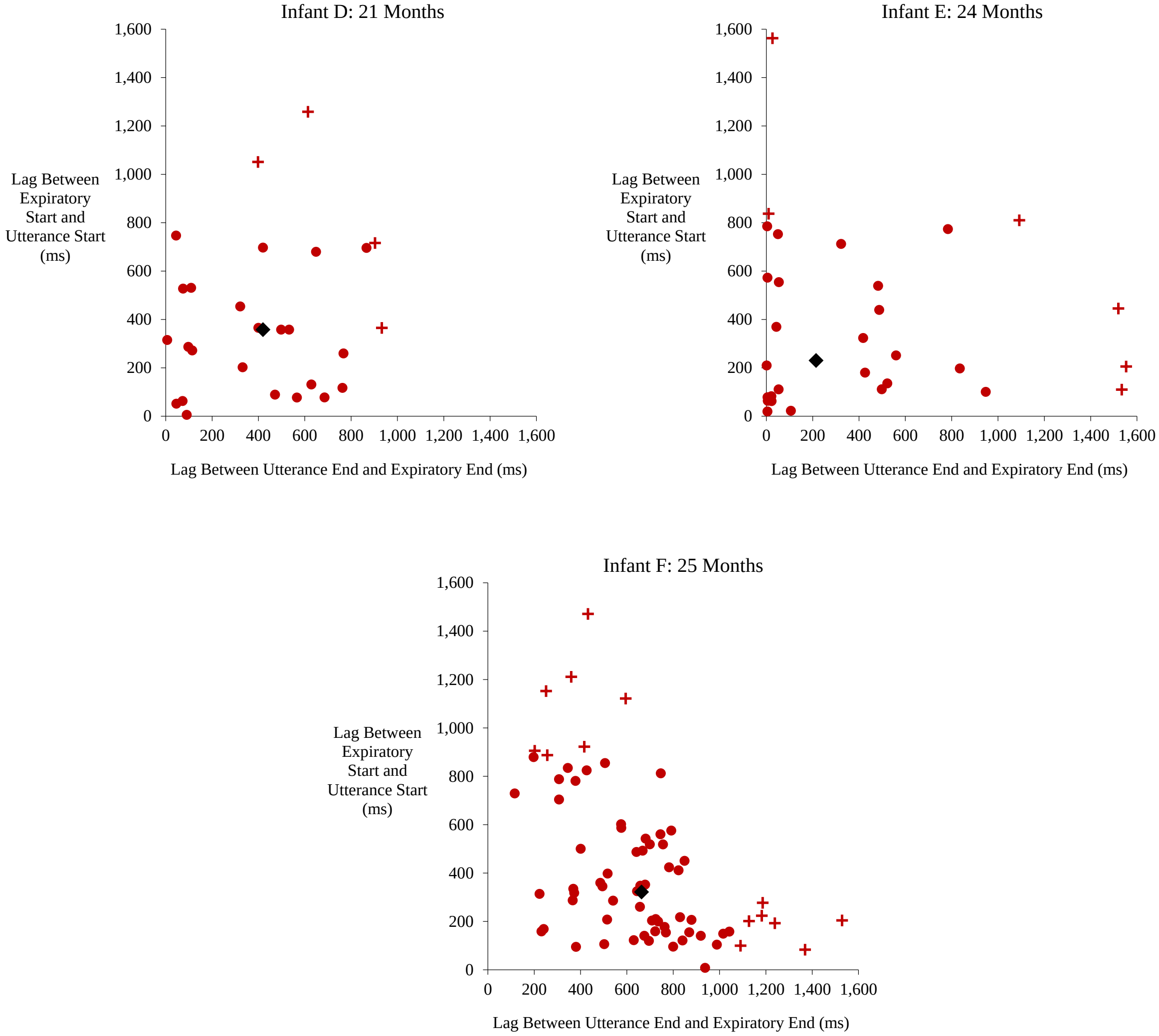

Figure 8. Lag scatterplots of the older infants (21 to 25 months).

Individual data points are identified by red markers: the red circles indicate data that lie under the 90th percentile on both of the lag variables; the red crosses signify that the data point lies outside of the 90th percentile on one or both of the lag variables. The black diamond represents the median for both lag variables.

CHAPTER 5

DISCUSSION

Restatement of Research Questions and Findings

This study explored age-related differences in two expiratory-phase timing variables: (a) the lag between the start of expiration and the start of the single-syllable utterance and (b) the lag between the end of utterance and the expiratory end. These two variables were used to explore two research questions in infants between the ages of 17 and 25 months.

(1) *Are there age-related patterns in expiratory timing for single-syllable utterances in infants during the second year of life?*

It was expected that patterns would emerge within the two age groups recruited for this study. This expectation was supported by the results of previous research (Brady, 2013). It is well established that children around the second year of life experience a language gain burst. They develop from having around five to ten words to fifty words, begin to put two or more words together, and communicate with intent and joint attention with their various communication partners.

With such a rapid growth in language comes an expected change in the anatomical systems that support language. One is the respiratory system. Patterns within the older age group (21-25 month olds) could be accounted for by their increased control of their expiration for utterance production. As their neuromuscular system develops and becomes more advanced, infants are able to manipulate more easily the inspiration start and end and the expiration start and end for more mature vocal utterances. The lag time needed between the phases for vocal production becomes more varied. This prediction is also supported by other research that suggest the development of the neuromuscular system assists in advance control of chest wall movements necessary for utterance production (Reilly et al., 2009).

With increased control of the respiratory system comes increased variability in utterances and speech breathing patterns. Variability can be seen within the scatterplots of the two age groups. The older age group (21-25 month olds) was expected to have a larger spread of data across the plot, indicating a variety of time lags during expiration for speech production. The younger age group (17-19 month olds) was expected to have a smaller spread, with the plots showing data more condensed in the lower left area. This would represent a more uniform speech-breathing pattern that correlates to the infant's lesser developed control of the chest wall. This is somewhat evident in Figure 7, particularly as relates to the median values (black diamonds) for both age groups.

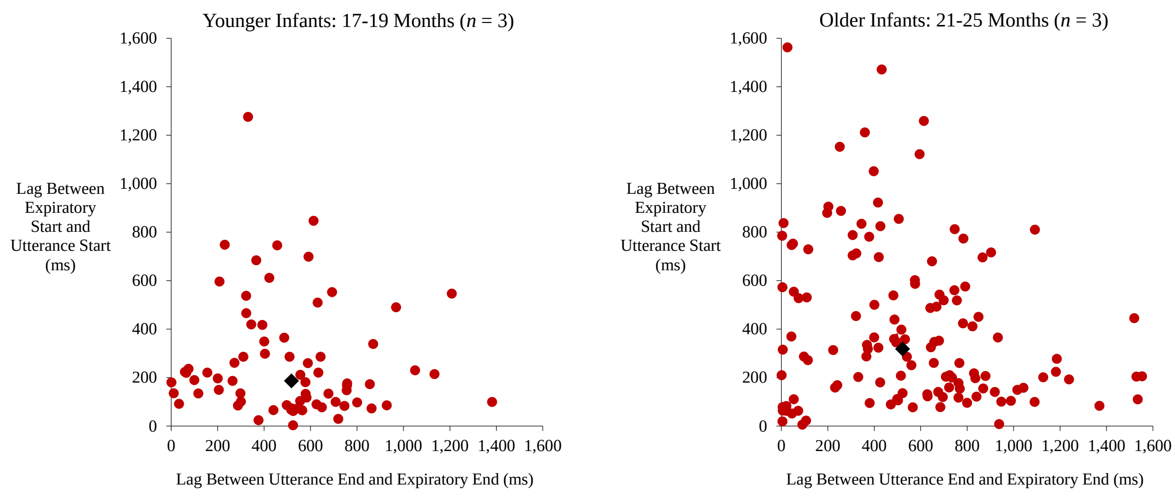

Figure 9. Combined lag scatterplots of infants in this study.

With a less mature respiratory system, the younger group would be expected to have less variety in lag times than the older group, with more variety indicating more flexibility in breath support when the infant is producing an utterance.

(2) *Are there individual patterns that emerge?*

There are always outliers in research. When analyzing possible speech patterns between the two infant groups, it was speculated that there might be an infant in the younger group who looked like an infant in the older group or vice versa. In other words, the infant might not fit into one specific mold. This is to be expected because development can occur at a different pace within a group of individuals. Some infants do not begin talking at the expected one year of age. Others do not begin walking until past their first birthday as well. Infant development follows a general order of events, but the processes in which the events are accomplished are unique to the individual.

Individual patterns and variations could be accounted by many factors besides chest wall control and age. Not all recorded vocalizations could be used due to motion artifact or recording abnormalities; thus, leaving the amount of usable data at a much smaller number than the true number collected. Also, some infants might not have performed the same in the recording lab as they would in a familiar environment. An infant with few vocalizations during the study could look quite different in the home setting. Also, depending on the time of the recording, the infant could have been less alert or engaged with the parent and/or researcher. How the mother was communicating with the infant also could have been a factor in determining patterns.

Related to speech breathing, if no patterns—individual or age-related—had emerged it would not necessarily mean that the data was inconclusive. One reason for the variability could be that the number of participants was not large enough to gather the appropriate number of speech breathing cycles with vocalizations to see patterns emerge. Because some infants might not produce enough analyzable data, the analyzable expiratory phrase and utterance pairs produced might be drastically less than needed.

Another conclusion that could be made is that as infants enter their second year of life, they begin to experiment with chest wall movement and vocalization control. There is no one specific pattern infants follow, but a variety of movements and expiratory phase lag times can be present as their respiratory systems become more mature. A longitudinal study could be done, following the infants through early childhood development, measuring chest wall movements and inspiration and expiration phrases during vocalization. Such a study could address the question of how the respiratory system changes and compensates for the continuing increase of speech demands, especially as speech and language become more adult-like.

Study Limitations

There are several limitations associated with any study of infant speech-related breathing. First, all of the infants produced a large number of utterances, but only a fraction of those were able to be used in this analysis. It could be that respiratory support for the other utterances is different than what is reported here. Second, it is always possible that the infants performed vocally in a different way than they would have at home or in a more familiar environment. Third, the Inductotrace® bands are negatively affected by movement, which helps explain why so many utterances were excluded, namely there was no analyzable expiratory phase signal to pair with them. Fourth, more subjects will be needed to determine if these patterns are generalizable to other infants in this age range.

Conclusion

Visualization of these infants' data suggested some patterns in respiratory timing for single-syllable utterances. There was some individual variation among the infants, but in general the older infants demonstrated more flexibility in the timing of respiration to support speech production. More research is needed to help explain how typically developing infants learn to produce speech, as well as identify possible physiological markers for increased language complexity in later infancy.

REFERENCES

REFERENCES

Boliek, C. A., Hixon, T. J., Watson, P. J., & Morgan, W. J. (1996). Vocalization and breathing during the first year of life. *Journal of Voice*, *10*, 1–22.

Boliek, C. A., Hixon, T. J., Watson, P. J., & Morgan, W. J. (1997). Vocalization and breathing during the second and third years of life. *Journal of Voice*, *11*, 373–390.

Brady, A. M. (2013). *The relationship between timing of single-syllable utterances and breath support in infants around the first year of life*. Unpublished master's thesis, Wichita State University, Wichita, KS.

Charnock, E. L., & Doershuk, C. F. (1973). Developmental aspects of the human lung. *Pediatric Clinics of North America*, *20*(2), 275–291.

Connaghan, K. P., Moore, C. A., & Higashakawa, M. (2004). Respiratory kinematics during vocalization and nonspeech respiration in children from 9 to 48 months. *Journal of Speech, Language, and Hearing Research*, *47*, 70–84.

Langlois, A. (1975). Respiratory patterns in infants aged six to thirteen months (Doctoral dissertation, Columbia University, 1975). *Dissertation Abstracts International, 36*(08B), 3889B.

Langlois, A., Baken, R. J., & Wilder, C. N. (1980). Pre-speech respiratory behavior during the first year of life. In T. Murry & J. Murry (Eds.), *Infant communication: Cry and early speech* (pp. 56–84). Houston, TX: College-Hill Press.

Milenkovic, P. (2001). Time-frequency analysis for 32-bit Windows (TF32) (Lab Automation Level) [Computer software]. Madison, WI: Author.

Moore, C. A., Caulfield, T. J., & Green, J. R. (2001). Relative kinematics of the rib cage and abdomen during speech and nonspeech behaviors of 15-month-old children. *Journal of Speech, Language, and Hearing Research*, *44*, 80–94.

Parham, D. F. (2012, March). *Expiratory timing relationships between breath support and vocalization in infants*. Paper presented at the annual meeting of the Kansas Academy of Science, Wichita, KS.

Parham, D. F. (2012, March). *Timing relationships between vocalization and breath support in infants*. Paper presented at the biennial meeting of the Conference on Motor Speech, Santa Rosa, CA.

Parham, D. F. (2013). Speech-related breathing in infants: How much do we really know? *Perspectives on Speech Science and Orofacial Disorders (ASHA Special Interest Group 5)*, *23*(1), 27–33.

Parham, D. F., Buder, E. H., Oller, D. K., & Boliek, C. A. (2011). Syllable-related breathing in infants in the second year of life. *Journal of Speech, Language, and Hearing Research*, *54*(4), 1039–1050.

Parham, D. F., Francois, J. R., & Blincoe, C. C. (2012, November). *Respiratory-utterance timing relationships in infants: Developmental patterns and clinical implications*. Poster session presented at the annual meeting of the American Speech-Language-Hearing Association, Atlanta, GA.

Reilly, K. J. & Moore, C. A. (2009). Respiratory movement patterns during vocalizations at 7 and 11 months of age. *Journal of Speech, Language, and Hearing Research*, *52*, 223–239.

Solomon, N. P., & Charron, S. (1998). Speech breathing in able-bodied children and children with cerebral palsy: A review of the literature and implications for clinical intervention. *American Journal of Speech-Language Pathology*, *7*, 61–78.

APPENDICES

APPENDIX A

INSTITUTIONAL REVIEW BOARD (IRB) APPROVAL LETTER

WICHITA STATE UNIVERSITY
RESEARCH AND TECHNOLOGY TRANSFER

Date: September 11, 2013

Principal Investigator: Douglas Parham

Co-Investigator(s): N/A

Department: CSD

IRB Number: 1425

The Wichita State University Institutional Review Board (IRB) has reviewed your application for continuation of the research project entitled, **"Vocalization and Speech Breathing in Infants and Adults".** The IRB has approved the project to continue according to the Federal Policy for the Protection of Human Subjects. As described, the project also complies with all the requirements and policies established by the University for protection of human subjects in research.

This approval is for a period of one year from the date of this letter and will require continuation approval if the research project extends beyond **September 10, 2014**.

Please keep in mind the following:

1. Any significant change in the experimental procedure as described should be reviewed by the IRB prior to altering the project.
2. When signed consent documents are required, the principal investigator must retain the signed consent documents for at least three years past completion of the research activity.
3. At the completion of the project, the principal investigator is expected to submit a ***final report***.

Thank you for your cooperation. If you have any questions, please contact me at ext. 6945.

Sincerely,

Michael Rogers, Ph.D.
Chairperson, IRB

Wichita State University, Wichita, Kansas 67260-0007 Telephone: (316) 978-3285 Fax: (316) 978-3750

APPENDIX B

IRB APPROVED CONSENT FORM

Wichita State University
Institutional Review Board Approval
9/11/13 – 9/10/14

WICHITA STATE UNIVERSITY
COLLEGE OF HEALTH PROFESSIONS
Department of Communication Sciences and Disorders

Consent Form for Adult Participants and Their Infants

Purpose: You and your infant are invited to participate in a study of speaking and breathing. The purpose of this research is to explore how speaking and breathing develop across different stages of the human life span.

Participant Selection: You and your infant are eligible to participate in this study because it focuses on how infants learn to speak. Your infant's speech can be compared with those of other infants and persons across the human life span. It is anticipated that between 40 and 50 infants and their families will participate in this study.

Explanation of Procedures:

- This study will take place in the Speech Development and Communication Lab at the Eugene M. Hughes Metropolitan Complex, located at Oliver and 29th Street.
- If you decide to participate, you will be asked to provide basic information related to your infant's health, such as the history of ear infections and/or complications during or after birth.
- Your role will be to encourage your infant to produce speech sounds.
- Your infant will be seated in a high chair or an alternative (for example, a Bumbo baby seat). You will be seated in a chair facing your infant. If your infant is too young or too small to fit in the seating devices, you will hold your infant.
- You and your infant will each wear a microphone, respiratory bands (around the rib cage and abdomen), and body movement sensors. You yourself can opt not to wear the equipment.
- To measure breath volume, you will be asked to blow air into a tube for several minutes and your infant will breathe into a small face mask for several seconds.
- You and your infant's speech, respiration, and body movements will be recorded. A video recording will also be made of the interaction.
- During the recording session, your infant will also interact with a graduate student from the Department of Communication Sciences and Disorders who is associated with the study. The role of the graduate student is to encourage your infant to produce speech sounds.
- Each recording session will last between one and two hours, but will be stopped if your infant becomes upset or distressed.
- You and your infant may be eligible to participate in future recording sessions while this research project is in progress.
- You will also be given the options of having your infant's hearing and/or overall development screened. If you are interested in one or both of these screenings, they will be scheduled either as part of the initial recording session or for a separate visit at another time.
- It is possible that the video recording will be used in the future in educational and/or academic settings. Your permission for the educational use of the video recording is an entirely separate issue than your participating in the study. You and your infant may agree to be in the study without agreeing to the educational use of the video recording.

Wichita State University
Institutional Review Board Approval
9/11/13 – 9/10/14

Consent Form for Adult Participants and Their Infants 2

Discomfort/Risks: There are no known physical risks to the infants or adults participating in this study. The instrumentation systems and the data collection methods are non-invasive and do not pose any direct physical risk to you or your infant. Regarding potential emotional risks, your infant might express some discomfort being in an unfamiliar setting, interacting with an unfamiliar adult, or wearing a face mask during the first part of the recording session. Your infant will not be out of your physical or visual contact, and you may stop the recording session at any time. Although no other risks are anticipated with this study, there is always a small chance of unforeseen risk.

Benefits: By participating in this research, you can be expected to benefit from knowledge gained about human development. The findings of this research will fill in the gaps of the current scientific knowledge of speech development.

Compensation:

- For you and your infant's combined participation in each recording session, you will receive a one-time monetary compensation of $20.00.
- Wichita State University does not provide medical treatment or other forms of reimbursement to persons injured as a result of or in connection with participation in research activities conducted by Wichita State University or its faculty, staff, or students. If you believe that you have been injured as a result of participating in the research covered by this consent form, you can contact the Office of Research Administration, Wichita State University, Wichita, KS 67260-0007, telephone (316) 978-3285.

Confidentiality:

- Any information obtained in this study in which you can be identified will remain confidential to the extent permitted by law and will be disclosed only with your permission.
- The data from you and your infant will be associated with unique codes known only to the study's research team and will be referenced only by those codes.
- Study-related files will be kept locked away when not in use by the research team.
- Federal agencies such as the Food and Drug Administration (FDA) and the Office for Human Research Protections (OHRP) may review study data as allowed by law.
- You will have the right to decide about the special use of the video recording for educational purposes (see separate form).
- You also reserve the right to have part or all of the recordings of you and your infant permanently erased at any time during or after the study.

Refusal/Withdrawal/Termination: Participation in this study is entirely voluntary for you and your infant. Your decision to participate or not will not affect your future relations with Wichita State University. If you agree to participate in this study, you are free to withdraw from the study at any time without penalty. If the Principal Investigator determines that your participation or your infant's participation in the study is causing undue discomfort or distress to you or your infant, the recording session will be terminated.

Contact: If you have any questions about this research, you can contact Douglas Parham, PhD, Principal Investigator, at the Department of Communication Sciences and Disorders at Wichita

Wichita State University
Institutional Review Board Approval
9/11/13 – 9/10/14

Consent Form for Adult Participants and Their Infants 3

State University, Wichita, KS 67260-0075 (Telephone: 316-978-5634; E-mail: douglas.parham@wichita.edu). If you have questions pertaining to your rights as a research subject, or about research-related injury, you can contact the Office of Research Administration at Wichita State University, Wichita, KS 67260-0007 (Telephone: 316-978-3285).

You are under no obligation to participate in this study. You may stop your participation and the participation of your infant at any time. Your signature indicates that you have read the information provided above and have voluntarily decided to participate. You will be given a copy of this consent form to keep.

____ ____________________
Signature of Parent/Legal Guardian as Participant — Date

____ ____________________
Signature of Parent/Legal Guardian to Give Permission For the Infant to Be a Participant — Date

____ ____________________
Signature of Person Conducting Informed Consent Discussion — Date