Spring 2015

Mouth asymmetries during infant babbling: A brain lateralization study

Cecilia Breazile
James Madison University

Mouth asymmetries during infant babbling: A brain lateralization study

---

A Project Presented to
The Faculty of the Undergraduate
College of Integrated Science and Technology
James Madison University

In Partial Fulfillment of the Requirements
for the Degree of Bachelor of Science

---

by Cecilia Renee Breazile
May 2015

Accepted by the faculty of the Department of Communication Sciences and Disorders, James Madison University, in partial fulfillment of the requirements for the Degree of Bachelor of Science.

FACULTY COMMITTEE:

Project Advisor: Rory DePaolis, Ph.D.
Professor, Communication Sciences and Disorders

Reader: Carol Dudding, Ph. D.
Director of Speech-Language Pathology Graduate Program

Reader: Marsha Longerbeam, Ph.D.,
Assistant Professor, Communication Sciences and Disorders

HONORS PROGRAM APPROVAL:

Philip Frana, Ph.D.,
Director, Honors Program

Table of Contents

Abstract

Although babbling is both prevalent and important in the process of language development, it could be argued that we still do not understand the basic nature of babbling. To further our understanding of the nature of babbling we attempted to find evidence for brain lateralization typical of adult speech acts during early babbling. This study examined infant mouth asymmetries during babbling sequences in search of evidence that babbling is an inherently linguistic act as indicated by the lateralization of the brain. Previously recorded videos of 12 infants, all 9 months of age, were examined, 29 images were captured, and a reliable and objective method of measuring the mouth for asymmetry was created and implemented in this study. The results were not statistically significant and did not provide sufficient evidence to support the theory that the brain had lateralized for speech.

Acknowledgements

The researcher would like to thank Dr. Rory DePaolis, for without him this thesis would not have been possible. He dedicated his time and efforts to the researcher and to this project and was vital in its creation, design, and methods. He provided the researcher with support, foundational knowledge, and the subjects, who were used in a previous study he had done with Dr. Vihman and Dr. Keren-Portnoy. The researcher would also like to thank Ms. Julian White who also dedicated countless hours in helping to create and implement the methods of this project and performed its reliability measures. This project would not have been possible without either of their help and I am extremely grateful. Additionally, the researcher would also like to thank Dr. Carol Dudding and Dr. Marsha Longerbeam for their time, commitment, and guidance as readers for this project.

Introduction

Speech is the primary mode of communication for the vast majority of the human population. This universal method of communication has a pattern of development that typically developing infants follow. Babbling is a stage of language development that is viewed as a precursor to the production of an infant's first word. Despite the prevalence and importance of babbling in the process of language development, it could be argued that we still do not understand the basic nature of babbling.

Research into babbling has resulted in two prevailing views on the nature of babbling: babbling is an inherently linguistic act, and babbling is an oral motor reflex that is adapted to language through reinforcement. Studies have been conducted that support both viewpoints but none thus far have provided conclusive evidence, causing the need for further examination. Two studies that support the view that babbling is linguist act are Kooijman et al. and Mills, Coffey, and Neville (2013, 1994). They used event-related potentials to examine infants' brains while listening to spoken words and found that the brain lateralizes, meaning the left brain becomes dominant, for language comprehension and can predict language performance later in life based on how early the brain had lateralized for speech. In contrast, Thelen and Iverson et al, (1997, 2005) examined infant motor stereotypies and their relation to infant babble. Thelen (1979) defines infant stereotypy movements as movements of the body, or a part of the body, that have typical repetitive forms and temporal patterns seen in infants during the first year of life; they are thought to be a transition between uncoordinated and coordinated movements of the body. Thelen and Iverson et al, (1997, 2005) found that there was an increase in coordinated motor movements of various body parts at the onset of babble, which supports the thought that vocal productions and babble are motor movements that become refined for speech. While these two views are not conclusively supported by all of the available research, finding evidence for brain lateralization typical of adult speech acts during early babbling is a possible method to understand the nature of babble and determine if babbling is more of a speech act and less of a motor act. Assuming that asymmetric mouth openings during the production of babbling suggests brain lateralization (or the lack of lateralization), measuring asymmetry could provide evidence for or against babbling as a speech act. Thus, this method may aid the search for more concrete and conclusive evidence to the nature of babbling as a linguistic act.

Examining asymmetry of infant babbling originates from the assumption that language is primarily a left hemisphere function and therefore will result in right asymmetry of the mouth. A study done by Graves & Landis (1990) identified the presence of right asymmetry of the mouth in adults when producing speech. Holowka & Petitto (2002) used this study to examine the linguistic nature of infant babbling. If infant babbling is primarily a linguistic advance, then the same rightward asymmetry in babbling infants should exist (Holowka & Petitto, 2002). Holowka & Petitto's (2002) study found lateralization and asymmetries of the mouth during the production of babbling. However, this study was not conclusive in answering the question of when laterality occurs because it examined infants ages 5 to 12 months (Holowka & Petitto, 2002). There were also limitations due to a lack of description of Holowka & Petitto's (2002) subjective methods. This experiment is a partial replication of Holowka & Petitto (2002), using more refined methods of measurement based on two studies on lateralization of the mouth in animals: the Hook-Costigan & Rogers (1998) study on "Lateralized use of the mouth in production of vocalizations by marmosets" and the "Left Hemisphere Specialization for Oro-Facial Movements of Learned Vocal Signals by Captive Chimpanzees" study by Losin et al. (2008). The method of measuring asymmetry in animals was adapted to measure asymmetry in infants. Our study combined the concepts of the Holowka & Petitto's study with the methods of the animal literature studies (Losin et al., 2008; Hook-Costigan & Rogers, 1998). Our study viewed video recordings of 9 month old babbling infants using the video processor ELAN and the infant mouth openings were measured using ImageJ and Adobe Photoshop to examine possible asymmetries.

Literature Review

Laterality of the Adult Brain

Adult studies have shown that left hemispheric specialization occurs during speech, indicating that the left side of the brain is used more than the right during speech production, while the right side of the brain is used more for expression of emotions (Graves & Landis, 1990). Nicholls, Searle, & Bradshaw (2004) observed participants' abilities to lip-read videos of people speaking with the McGurk effect in order to see how the McGurk effect influences comprehension. The McGurk effect is an illusion in which a speaker in a video produces a sound or word but a different audio is played in synchrony with the video causing viewers to misinterpret the words the speaker is saying. In the study the speakers had either half of the mouth covered or the mouth completely shown and the viewers had to determine what was being said. The findings concluded that participants were more likely to properly read the lips when the right side of the mouth was covered due to the McGurk effect. The McGurk effect is stronger on the right side of the mouth because it is more expressive and is more likely to cause participants to incorrectly judge a word as opposed to the less expressive left which is less likely to confuse participants (Nicholls, Searle, & Bradshaw, 2004). These researchers also found that there was no significant difference in error when the left mouth was covered than when the whole mouth was shown, suggesting that the right side of the mouth is as informative as the whole mouth in speech production (Nicholls, Searle, & Bradshaw, 2004). This study further supports the findings that the right mouth is more expressive and asymmetric during adult speech.

FMRI and brain lesion studies have shown that the left anterior insula, the left inferior frontal gyrus, dorsolateral temporal lobes, and bilaterally in the subcortical motor, cortical motor and cerebellar motor output systems are used in speech production (Warren et al., 2005; Geranmayeh et al., 2014; Blank et al. 2002; Simmonds et al., 2014). When Bear, Connors, & Paradiso (2007) compiled a list of types of aphasias and their locations of damage within the brain, they found that when the left, or dominant, hemisphere was affected in the perisylvian region being: the premotor cortex, frontal lobe anterior to Broca's area, posterior and superior temporal lobe or Wernicke's area, inferior temporal lobe, arcuate fasciculus, left angular gyrus, and frontal lobe. Damage to these areas can cause problems with speech production, repetition, comprehension, grammar, and fluency (Bear, Connors, & Paradiso, 2007). Further, a study on lateralization of the brain in people ages 5-67 found that the brain is already lateralized for language by 5 years of age and the lateralization continues to strengthen until around 20 to 25 years (Szaflarski, Holland, Schmithorst & Byars, 2006). Similarly, by taking objective measurements, Graves & Landis (1990), highlighted that the existence of right asymmetry for speech and left asymmetry for expression of emotions are independent of gender and handedness.

The Stages of Babbling

While it may not be clear if babbling is a linguistic or motor reflex, a general consensus regarding the nature of babbling does exist. Stark (1980) found that before babbling occurs, an infant goes through 3 stages of producing prelinguistic sounds. The first stage is reflexive crying and vegetative sounds, and all of the sounds are involuntary and are created during feeding or other physical activity (Stark, 1980). The second stage contains cooing and laughter which are voluntary productions that occur when an infant is relaxed. In this stage infants may produce sounds that are similar to vowels or velar fricatives and may engage in sustained laughter (Stark, 1980). During the third stage, the vocal play stage, infants 4 to 7 months of age strengthen control and manipulation of the laryngeal and oral mechanisms (Stark 1980).

In addition, infants create periodic and aperiodic productions of glottal stops, fricatives, nasals, bilabials vocoids and contoids (Roug, Landberg & Lundberg, 1989; Vihman, 2014). Their productions are more prosodic than their vocalizations were in the cooing and laughter stage (Wängler, 2012). Further, in order for babbling to occur anatomical changes must occur. The vocal tract must lengthen and change position, the skull must grow which causes oral cavity of the face to enlarge and create more room for tongue movement, and infants need to gain more control of the tongue and other structures of the mouth (Stark, 1980; Kent, 1981). Vihman (2014) noted that when infants enter the babbling stage their approximations of consonants and vowels become more adult-like and they begin to create syllables. These syllables, consisting of consonants and vowels, mark the beginning of the canonical or reduplicated babbling stage.

In examining infants' first productions of adult like syllables, many researchers have found that the babbling stage is composed of two parts: the first is reduplicated or canonical babbling, which begins around seven months of age and is when the infant produces a repeated consonant-vowel syllable (Roug, Landberg & Lundberg, 1989; Stark, 1980; Oller, 2000), and the second is non-reduplicated. According to Oller (2000) the reduplicated syllable has four criteria that make it adult-like speech: normal phonation, articulation, full resonance, and rapid transitions. These criteria distinguish the earlier sound productions from these babble productions and create an approximation to speech. The second stage, which begins or is strengthened in the last few months of the first year, is variegated or non-reduplicated babble, which is a production of a string of syllables with differing consonants and vowels (Roug, Landberg & Lundberg, 1989; Stark, 1980; Oller, 2000). Stark (1980) found that as infants get older and continue to babble, they will use longer strings of babbles with prosodic features found in the ambient language, and will soon thereafter begin produce their first word in conjunction with the variegated babbles.

While it is clear that the first word has a linguistic rather than motor nature, the nature of babbling being a linguistic or motor aspect is still being debated. It is unknown when the brain starts to use babble for linguistic purposes as opposed to a motor reflex. If lateralization of the brain could be found in babbling infants then the nature of babbling may be clarified.

The Development of Lateralization and Linguistic Aspect of Babbling

While there is still a question of when the brain is lateralized in infants, a study by Dehaene-Lambertz, Dehaene, & Hertz-Pannier (2002) used an fMRI to study brain activity in sleeping and awake 3 month old infants while hearing normal and reversed speech. They found that the left temporal lobe and angular gyri were active in the infants and the right prefrontal cortex was active only in awake infants hearing normal speech. This study shows that the dominance of the left hemisphere for language is present at a young age and is in place before the infant has begun to approximate adult-like vocalizations.

Research studying infants' brain activity while listening to familiar, unfamiliar and backwards words using event-related potentials (ERPs) demonstrated that infants ages 13-17 months old exhibited brain activity in both hemispheres, with slightly more activity in the right than the left hemisphere with recognizing familiar words (Mills, Coffey, & Neville, 1994). In contrast 20 month old infants showed increased activity in the temporal and parietal regions of the left hemisphere when presented with the same types of words. This study suggests that the brain is lateralized for speech increasingly between 17 and 20 months of age (Mills, Coffey, & Neville, 1994).

A recent study by Kooijman et al. (2013) used event related potentials (ERPs) to examine the brain activity of 7 month old infants listening to familiar and unfamiliar words repeated in isolation and in sentences. The researchers attempted to determine if the child could successfully segment the newly heard unfamiliar words. Kooijman et al. (2013) chose to focus on speech segmentation because it is important for an infant to master so that they can understand spoken language more efficiently and build a vocabulary. Speech segmentation is an effective means to test a child's language abilities before they have begun to speak because it signifies a certain mastery of a language by being able to understand when one word ends and the next begins (Kooijman et al., 2013). The data from the study categorized the infants into two groups based on their brain activity, the first group had a left-lateralized negative-going brain response and the second group had a distributed positive-going brain response when exposed to sentences containing the unfamiliar words (Kooijman et al., 2013). These same children were tested at 3 years of age for speech comprehension and speech production (Kooijman et al., 2013). The children who had a left-lateralized brain response at 7 months scored significantly higher on the Reynell Test voor Taalbegrip, a Dutch developmental language scale assessment, than the children who had a distributed response at 7 months (Kooijman et al., 2013). This study suggests that early lateralization of the brain is positively correlated with language abilities later in life.

Instead of examining brain lateralization, Boysson-Bardies, Sagart, & Durand (1984) focused on babbling productions and its ties to linguistic communities. They examined the abilities of 40 French adults to distinguish whether babbling infants at 6, 8, and 10 months were from the same or different linguistic community (Boysson-Bardies, Sagart, & Durand, 1984). The adults individually listened to 16 pairs of 15 second audio clips consisting of one French infant and one Arabic or Chinese infant, resulting in 32 total clips, the listeners had to try to determine which clip in each pair was from a French infant or a foreign infant (Boysson-Bardies, Sagart, & Durand, 1984). They found that the listeners as a whole could not reliably identify the French infant at 6 months but were much more likely to identify the French infant at 8 and 10 months suggesting audible characteristics of linguistic communities in babbling infants as young as 8 months old (Boysson-Bardies, Sagart, & Durand, 1984).

Iverson et al. (2007) tried to determine the nature of babbling through examining rhythmic arm movements in infants. In their study they discussed three aspects of babbling that provide evidence of babbling being a linguistic behavior. First, babbling is composed of syllables, and syllables create words that belong to languages. Therefore, producing syllables is linguistic because it is the first step in producing language (2007). Second, there is a strong link between an infants' babbling patterns and their first words. An infant's first word often uses the same speech sounds that are already in the infants' babbling repertoire. These first words are often used concurrently with babble production (Iverson et al., 2007; Lamb, Bornstien, & Teti, 2002). Third, delayed babble onset is an indicator of delayed or disordered language development. This pertains specifically to children with Down syndrome who have delayed language that is disordered (Iverson et al., 2007; Lamb, Bornstien, & Teti, 2002)

Motor Aspects of Babbling

There are two popular views on the nature of babbling: babbling is an inherently linguistic act, and babbling is an oral motor reflex that is adapted to language through reinforcement. Many infant studies have identified movements that are regulated or rhythmically driven in infants towards the middle to the end of their first year, which coincides with babbling and first word emergence (Vihman, 2014). Vihman reviewed many studies on infant's 'rhythmic stereotypes' in movements and motor skills of the infants' body. These studies revealed that fingers, torso, limb and jaw movements are used in a rhythmic pattern as infants are learning to organize their movements into more precise actions (2014). A study done by Thelen (1979) found that infant rhythmical stereotyped movements preceded complex and coordinated movements using the same muscles. Originally, movements are unorganized and have no intent, but towards the end of the first year the movements have intent and are more refined, which is a similar trajectory for babble resulting in speech (Thelen, 1979).

Iverson et al. (2007) attempted to find a relation between infant rhythmic arm movement and babbling. Their study examined the possibility of a relationship between reduplicated babble onset and laterality biases in infant rhythmic arm movements. They proposed that both babbling and arm movements in infants are rhythmic motor movements and that babbling starts around the same time that rhythmic arm movement starts (Iverson et al., 2007). They based their study on one by Locke et al. (1995) that concluded infants have a "temporary right hand preference in manual activity at reduplicated babble onset." These findings supported the laterality of the left side of the brain for language, speech and babble, and linked babbling to the increased the right hand preference which would also be influenced by the left brain (Locke et al., 1995). The Locke et al. (1995) study's methods were problematic because they used a cross-sectional method of observing infants so it is unclear exactly when the onset of babbling occurred in the infants studied. The cross sectional methods would make it hard to determine if the onset of babble was related to right hand preference or not (Iverson et al. 2007). Iverson et al. based their study from the Locke et al. study but created a longitudinal design that examined infants in the prebabbling, recent babbling, and experienced babbling stages. The infants, ages two to nineteen months, were filmed for forty-five minutes every two weeks performing regular activities and a trial activity. For the trial activity, the infant was presented with a rattle and the researchers examined which hand grasped the rattle, if the infant shook the rattle, and where the infant was in the babbling stage (Iverson et al., 2007). In contrast with the previous findings by Locke et al. (1995), they found no significant difference in a shift of hand preference during reduplicated babble but did find a significant increase in rattle shaking at the onset of babbling that remained in babbling infants (Iverson et al., 2007). The lack of significant data caused Iverson et al. (2007) to conclude that babbling and increased arm movement is part of the development of motor process that is adapted to become a function of language and reflect the infant's linguistic environment, as opposed to being a product of the language-specific mechanism.

Nelson, Campbell, & Michel (2014) examined hand use preference in infants and its relation to later language ability. They examined 38 infants each month from ages 6-14 months and again monthly at 18-28 months (Nelson, Campbell & Michel, 2014). To assess hand preference at the younger ages they offered infants toys 10 times at the infants' midline of their body at shoulder height and noted which hand they grasped the toy with (Nelson, Campbell & Michel, 2014). The 18-28 month old toddlers' hand preference was determined by offering a toy that the infants would have to manipulate with both hands; one hand to stabilize the toy and the other to twist, take off a lid, or unzip the toy (Nelson, Campbell & Michel, 2014). When the infants reached 28 months old they were administered the Bayley Scales of Infant and Toddler Development by a clinically trained observer in order to assess language, motor and cognitive skills (Nelson, Campbell & Michel, 2014). Results showed that infants who had a consistent right hand preference at 6-14 months scored higher on the Bayley assessment for language at 28 months than the infants who did not have a hand preference at 6-14 months (Nelson, Campbell & Michel, 2014). This finding was similar to the results from the Kooijman et al. study suggesting a correlation between hemispheric specialization and language abilities in infants and toddlers (Nelson, Campbell & Michel, 2014; Kooijman et al., 2013)

Feeding, like babbling, is a task that requires an oral temporal coordination pattern. Wilson, Green, & Weismer (2012) looked at the temporal characteristics in jaw motions of infants ages 4-35 months old during chewing and found linear sequence of development in chewing patterns that begins at 7 months infants, is learned by 12 months of age, and is "refined" by 35 months. Wilson, Green & Weismer (2012) compared this pattern to speech patterns which also require a temporal muscle coordination of the mouth. The canonical babbling stage, which begins around 6-10 months in normal developing infants, is consistent with the time frame for the emerging chewing patterns, thereby supporting the view that babbling is an oral motor stereotype (Lamb, Bornstien, & Teti, 2002). The fact that these two coordinated oral motor activities are occurring at the same time support the view that babbling is primarily a motor aspect as opposed to a linguistic aspect.

Hypothesis

The purpose of this study is to look for evidence in the canonical babbling stage for lateralization in the infant's brain by creating a reliable and objective method of measuring the mouth for asymmetry. Our goal is to use an objective method of measuring the mouth for asymmetries in order to examine whether babbling is fundamentally linguistic as opposed to an oral motor reflex that is later adapted to produce speech. We predict that our reliable and objective measurements of the mouth during babbling will result in a significant amount of right asymmetric mouth openings, supporting the idea that left hemispheric lateralization of the brain has occurred in these infants. Since there is limited research on when lateralization occurs in infants, this area of study should be further studied to understand the process of language development in infants and to gain a better grasp on the nature of babbling.

Methods

Participants

The participants were nineteen 9 month old infants with no known neurological, motor, behavioral, sensory, or cognitive concerns. The nineteen participants were taken from a larger, longitudinal study that had recorded multiple video sessions of fifty-nine infants in the United Kingdom (Vehman and Keren-Portnoy 2009). Only the first two prerecorded video sessions for each of the nineteen infants were viewed so that the infants were all approximately the same age and their babbling abilities did not progress between the two videos. Of the 19 infants analyzed, only 12 infants, 7 boys and 5 girls, had useable video for this study.

Procedures

The videos of the infants used in this study were viewed using the video processor ELAN (Max Planck Institute for Psycholinguistics). The videos had been analyzed and babble sequences transcribed from the previous Vehman and Keren-Portnoy (2009) study. Using ELAN, the researcher examined the transcribed segments that contained babble or speech; every babbled sequence in the video. If the infants' faces were oriented towards the camera, no visible emotions were present, and the facial features were distinguishable, then the sequence was considered potentially useable the sequence was given a score based on three criteria. The segments were given a G if they were considered "good," or ideal images, or P, meaning it was a possibility for measurement but was not ideal based on lighting or the proximity of the infant to the camera. Then the images were given a 1 or 2 depending on face orientation. A score of 1 meant the infant's face was oriented towards the camera and a 2 meant the face was slightly oriented away from the camera. Finally, the images were given either an A, which meant the image had a clear resolution, or B, which meant the image was pixelated. The ideal image had a score G1A, indicating that the image had good lighting, no visible emotions, the infant was close to the camera, the infant's face was oriented towards the camera, and the image had a good resolution. Images that were deemed unusable due to face orientation and visible emotions were not scored. After all useable segments were scored, the researcher reexamined each segment and captured an image during the middle of a babble sequence when the mouth was maximally open; only one image for each babble sequence was captured.

Analysis

The objective form of measurement for mouth asymmetry was based primarily on two previous studies (Hook-Costigan & Rogers,1998 & Fernandez-Carriba et al., 2002). Images selected using ELAN were analyzed using ImageJ and Adobe Photoshop. A line between the inner canthi was drawn (line A) using ImageJ, the midline was calculated, and a perpendicular line (line B) was drawn starting at the midline and splitting the face into two symmetrical halves. All of the mouth openings were divided into two hemimouths based off of this line (B). Once line A was drawn, the angle of the line was calculated and the image was rotated so that line A was parallel with the computer screen. Two more lines were drawn (lines C and D) between the outer canthi of each eye and were divided into two halves by the perpendicular line B, the two halves were measured in order to see if one half was longer than the other, indicating rotation of the face.

To further assess rotation of the face, a second set of lines was drawn focusing on the nose. A line between the darkest pixels in the middle of each nostril was drawn (line D). Line D's midline was found and line E was drawn from the midline perpendicular to line D and was compared to line B, if the two lines (E and B) were further than 1 pixel apart, the image was discarded since this indicated that the head was rotated making it difficult to make an accurate measure of mouth asymmetry. Lines F and G were created as another method used to assess over rotation. Line F and G were drawn between the ala each nostril and were compared to the midline of line E in order to examine if the nose indicated rotation as well. Once the image was determined straight enough for an accurate measurement of asymmetry, if lines E and B were less than one pixel apart and the nose and eye facial asymmetry indexes (FAIs) were close to 0 than the images were transferred to Adobe Photoshop where the mouth lines were created.

The mouth lines were drawn in Adobe Photoshop to allow for accurate and objective lines to be created. To measure hemimouth area, a wand tool was used that selects pixels of similar or the same color and an area was objectively obtained for the mouth on each side of line B. Each hemimouth had a line drawn around the perimeter creating line H and line I. The images were then examined in ImageJ where all of the lines were measured and facial asymmetry indexes (FAI) were calculated.

Each image had 3 separate FAIs calculated. FAIs were calculated for the outer canthi lines (C and D), the ala line (F and G) and the mouth hemispheres (lines H and I). An FAI was calculated by subtracting the left side or area from the right side or area then the difference is divided by the sum of the two sides or areas. Negative FAIs indicate a left facial asymmetry and positive FAIs indicate a right facial asymmetry. During this procedure, the researcher discarded 52 images because lines E and B were too far apart, the image was too pixelated to find the canthi or nostrils, the mouth opening was too small to measure, the lighting was too dark or bright, the mouth and lips were indistinguishable, or the child’s face was asymetric.

$$\frac{(\text{Right} - \text{Left})}{(\text{Right} + \text{Left})} = \text{FAI}$$

Figure 1: Sample of lines drawn on a sample infant

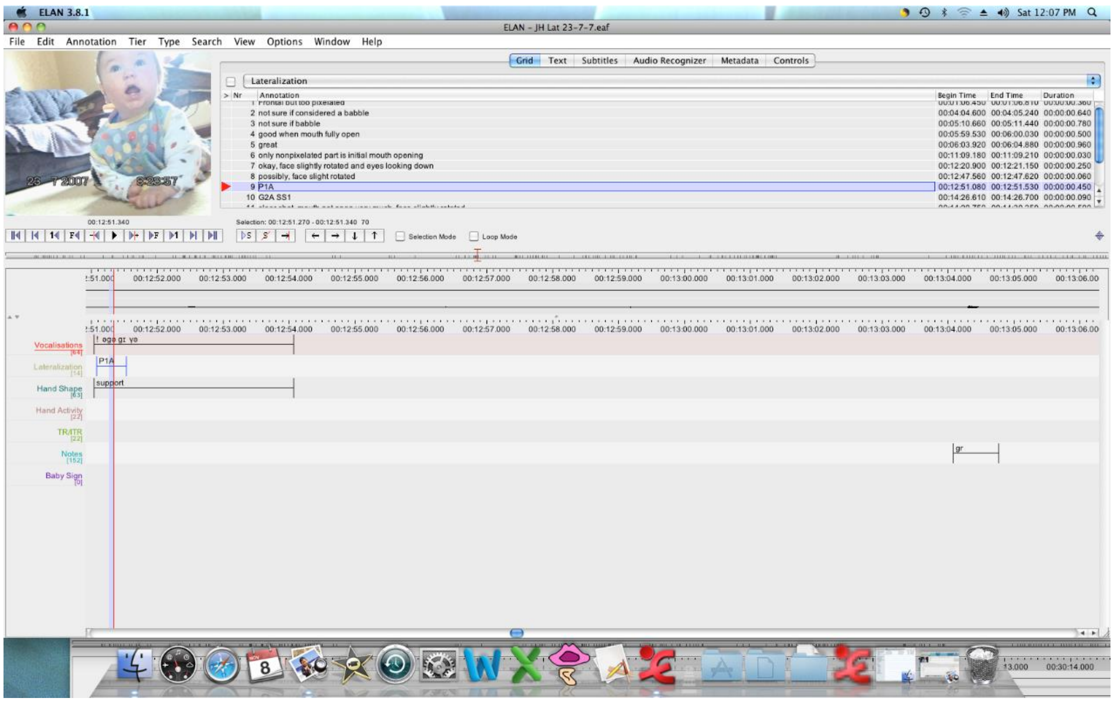

Figure 2: Sample of image in ELAN being examined and coded

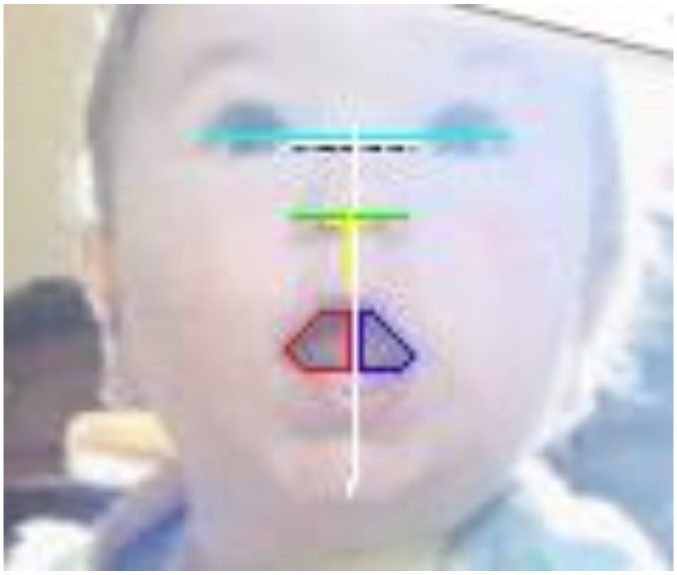

Figure 3: (Jim) Image from Figure 2 enlarged with lines drawn in ImageJ and Adobe Photoshop. Infant had right asymmetry present.

Figure 4: (Rosie) Image that was discarded due to lines being too far apart and due to camera angle.

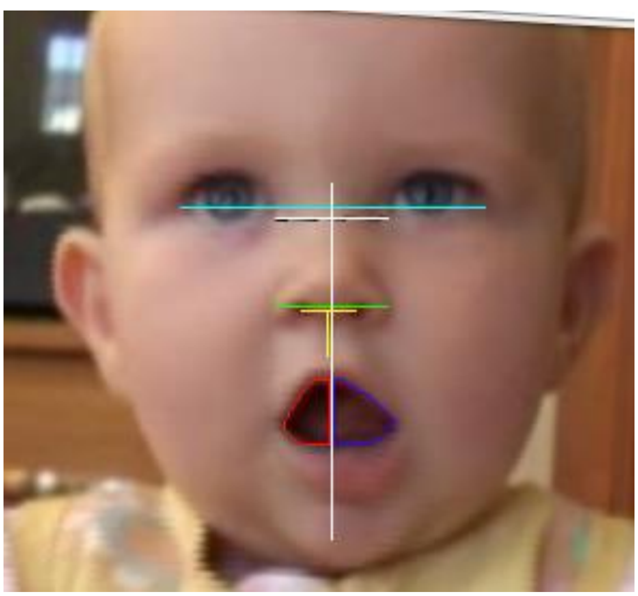

Figure 5: (Leila) Image of infant displaying left asymmetry of the mouth during babble sequence.

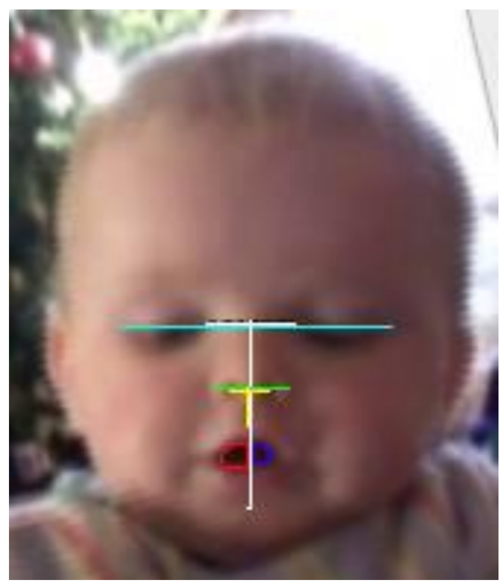

Figure 6: (Carlos) Example of poor quality or pixilation of data.

Results

A second researcher was taught the same methods and independently measured the 25 of the images that were used in the experiement to test for reliability, all of the measurements were done on the same computer to eliminate differences due to computer screen resolution. The correlation between the two researchers' measurements was high (r=0.88) which indicates that the objective methods are a reliable measure of asymmetry.

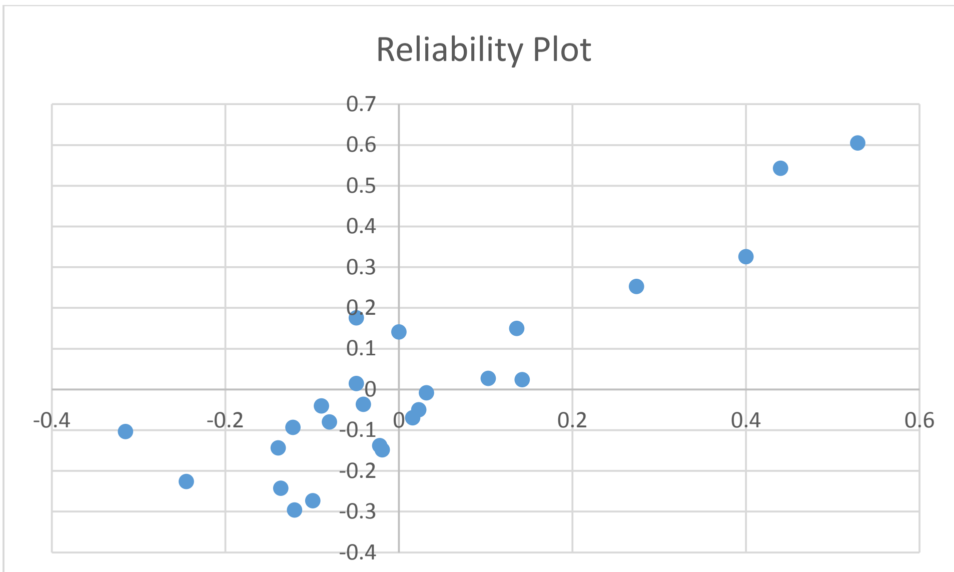

Figure 7: Reliability Plot: The two researchers' FAIs are plotted and compared, a 0.88 correlation was found.

The 29 images' FAIs were calculated and each child had differing results. Of the 12 children examined, 6 had a negative average FAI indicating left asymmetry and 6 had a positive average FAI indicating present right asymmetry. A one sample t-test was performed on the FAIs. Our results were not statistically significant ($t(11)=0.984$, $p=0.346$) and did not provide sufficient evidence to reject the null hypothesis that no asymmetry would be present during infant babble.

Infant Measurements and Facial Asymmetry Indexes											
Child	**Age**	**Image**	**Mouth**			**Eyes**			**Nose**		
			Right	**Left**	**FAI**	**Right**	**Left**	**FAI**	**Right**	**Left**	**FAI**
Carlos	0;9.22	1	77	49	0.222	44	48	-0.043	12	14	-0.077
		2	50	92	-0.296	45	45	0	15	13	0.071
		3	139	160	-0.08	41	40	0.012	10	10	0
		4	118	159	-0.148	45	44	0.011	14	12	0.077
Leila	0;9.7	1	527	635	-0.093	70	71	-0.007	25	28	-0.056
		2	47	21	0.382	37	31	0.088	12	10	0.09
		3	113	130	-0.069	31	33	-0.031	11	13	-0.083
		4	66	88	-0.143	31	32	-0.016	12	11	0.043
Ivy	0;9.3	1	160	177	-0.05	50	53	-0.029	18	20	-0.053
		2	230	117	0.326	52	49	0.029	18	18	0
John	0;9.8	1	30	21	0.176	20	18	0.052	3	5	-0.25
		2	347	207	0.253	58	53	0.045			
Jim	0;9.6	1	74	70	0.027	23	25	-0.042	9	7	0.125
		2	227	177	0.124	41	44	-0.035	14	15	-0.034
		3	105	79	0.141	27	27	0	10	10	0
		4	56	98	-0.273	21	23	-0.045	8	8	0
Rosie	0;9.15	1	114	28	0.605	30	29	0.017	12	9	0.143
Lily	0;9.23	1	58	95	-0.242	31	34	-0.046	10	11	-0.048
		2	62	77	-0.108	30	34	-0.063	11	12	-0.043
		3	151	144	0.024	46	49	-0.032	19	17	0.056
Tobias	0;9.6	1	34	33	0.015	20	20	0	8	7	0.067
		2	109	70	0.15	21	21	0	8	7	0.067
		3	81	107	-0.138	21	22	-0.023	7	9	-0.125
		4	60	65	-0.04	21	21	0	7	7	0
		5	103	68	0.205	23	21	0.045	7	8	-0.067
Beatrice	0;9.5	1	54	16	0.543	48	45	0.032			
Ralph	0;9.3	1	246	250	-0.008	29	29	0	9	11	-0.1
Larissa	0;9.5	1	60	95	-0.226	19	20	-0.026	6	6	0
Timmy	0;9.17	1	266	286	-0.036	60	60	0	26	26	0

Figure 8: Table of infant measurements and calculated FAIs.

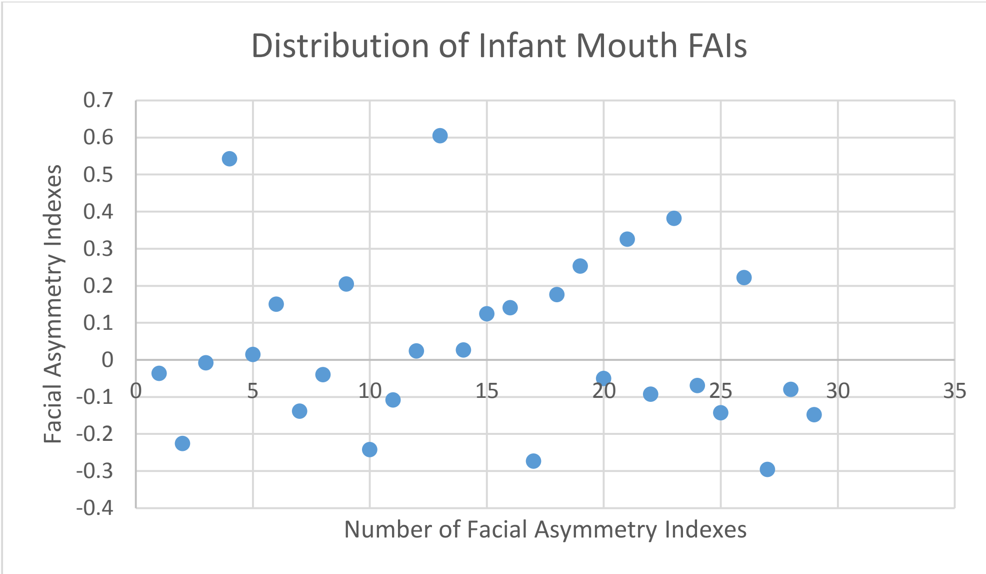

Figure 9: Distribution of Infant Mouth FAIs: Scatter plot depicting the 29 mouth FAIs across all children.

Discussion

This study hypothesized that if non-emotional infants' mouths were objectively measured during babble sequences then right asymmetry of the mouth would be present. An objective method of measuring the mouth for asymmetry was created and determined reliable. The researcher examined 9 month old infants' mouths during babble sequences in order to determine if the infant brain shows evidence of left lateralization for language specialization at approximately 9 months of age. The results were not significant, thus, we found no evidence that the brain had lateralized for language specialization at 9 months of age. Upon further examination of the individual data, we found that half of the infants' average facial asymmetry indexes (FAIs) had right asymmetry present and the other half had left asymmetry. The results were unexpected because there was no consistency of asymmetry within the individual infants, and within the infants as a whole, aside from one child, John, who had both of his images presenting right asymmetry. These results were different from the Holowka & Petitto (2002) study that found consistent right asymmetry in infants ages 5 to 12 months.

Since measuring asymmetries in the mouths of adults during speech and chimpanzees and marmosets during vocalizations has proven to be an effective method of language or communication use, we expected it to be present in infants if babbling is linguistic in its nature (Graves & Landis, 1990; Losin et al., 2008; Hook-Costigan & Rogers, 1998). It is possible that a larger sample with more babbled sequences would produce evidence right asymmetry in the FAIs but the individual differences suggest that this might not be true.

There were several limitations of this study that may have influenced our findings. First, it should be noted that only the first 2 videos of 19 infants were examined, so that the infants' babbling abilities would not have progressed considerably, but this resulted in some of the infants having only one or no useable babble sequences limiting the amount of available data. Second, because the videos of the 19 infants were taken from a previous study that examined babbling and body movements, many of the videos were focused on the infants' bodies instead of their faces, thus severely limiting the amount of useable footage available. For example, some infants had one useable image while others had multiple images. Third, because the images were captured in ELAN and were later enlarged and reexamined in ImageJ, many of the images were discarded due to lighting, pixilation, rotation of the head, etc. This severely restricted the amount of data. The study concluded with 29 images from 12 children. However, because some infants only had one measureable image while other infants had more, the average number of images per infants was 2.42. This may have affected the data in that, if an infant was not showing asymmetries at the time that the image was captured, but had asymmetries of the mouth present during other babble sequences the infant may have been incorrectly categorized as not having experienced brain lateralization. Therefore, the actual asymmetry of the infants babbling may not be represented due to the small amount of available images. For example, of the 7 infants with multiple images, only one had all images (2 images total), showing the same right asymmetry. All of the other infants had at least one image showing differing asymmetry. These results led us to conclude that the infant's brains had not lateralized for language due to the variability in the sample.

Our results differed from the similar previous study done by Holowka & Petitto (2002) that found right asymmetries of the mouth present during babble. The following differences in the two studies' methods may explain some of the differences in results. Holowka & Petitto (2002) studied 10 infants ranging from 5 to 12 months of age depending on when the infants were confirmed to have started the reduplicated babbling stage. Their study does not specify the specific ages of the infants, which could have been mostly over or under 9 months of age. Conversely, our study focused on infants who were known to be 9 month old babbling infants, but it is unknown how long they had been babbling. Further, the babble sequences used in the Holowka & Petitto (2002) study had a particular criteria for what was defined as a babble or a non-babble. The babble sequences used in their data had to have no referents and had to contain phonetic units found in spoken language with reduplicated consonant-vowel alterations; all other vocalizations were coded as non-babbles (2002). Holowka & Petitto (2002) also examined non-babbles and smiles in their study to determine if asymmetries of the mouth were present in those productions as well. Their results found that the non-babbles had no asymmetry and the smiles had left asymmetry. Due to the limited amount of data available, our study focused on all non-emotional babbles, and therefore may have included segments that Holowka & Petitto (2002) would have considered non-babbles. For example our babble sequence may not have been reduplicated or may have had a referent (Holowka & Petitto, 2002). The final difference between our study and Holokwa & Petitto's (2002) study was that they had two blind coders subjectively observe mouth asymmetries while our study required that all images were oriented towards the camera so that each side of the mouth was equally shown in the images, and established that the infant mouths were objectively measured using Adobe Photoshop and ImageJ to examine asymmetries. The differences between the methods of obtaining and measuring the data between the two studies could likely be the reason for differing results; our study had numerical data to show asymmetries while the Holowka & Petitto study did not.

Another possible reason why our study and Holokwa & Petitto's study had differing results could be the different babble productions that were measured. While Graves & Landis (1990) found asymmetries of the mouth during adult speech, Nicholls & Searle (2006) found evidence that the asymmetries may not always be present and therefore may not be the most ideal method of testing for brain lateralization. Nicholls & Searle (2006) explored asymmetries of the mouth during speech by having 20 right handed adults watch and categorize videos for asymmetry of 16 right handed adults while they said the words "bat, cat, fat," and "sat" (Nicholls & Searle, 2006). The speakers' mouths presented the greatest right asymmetry during the production of the words "bat" and "fat" which have initial sounds, bilabials and interdentals, involving the lips during production (Nicholls & Searle, 2006). There was less asymmetry present in the production of the word "sat" and almost no asymmetry present in the word "cat" which have initial sounds, alveolar and velar, that do not require lip movement and are produced further back in the mouth (Nicholls & Searle, 2006). This study found that the production of certain sounds or words affects asymmetries of the mouths during speech which may have influenced the data in our study. While the infants' speech production was transcribed and present during the viewing of the videos in ELAN, the particular sounds the infants produced during their babble sequences were not noted, this may have influenced our data if non-labial sounds were produced during the infant babble sequences that were captured. While it is not likely that non-labial sounds produced by the infants significantly influenced our data, the sounds being produced should be noted in further research in order to eliminate this as an extraneous variable.

Due to the lack of conclusive data, it is still unclear when the infant brain lateralizes for language specialization and if babbling is a linguistic act or a motor stereotypy that becomes refined for speech. Further research is needed to understand this complex process of development. If this study were to be replicated, the researcher suggests that infants should be examined longitudinally during the babbling period in order to examine changes over time and, like Holowka & Petitto (2002), the infant's vocal productions should be categorized as babble, non-babble, or smile in order to examine if asymmetries are present for any of those acts for instance, if the brain has lateralized emotions on the right brain for smiles but the left brain has not yet lateralized for language.

An interesting aspect of this study is the presence of a subgrouping of infants who showed evidence that lateralization had begun at 9 months of age. A potential method of continuing this research could be to use the same methods in this experiment to examine the sub grouped infants, who had right asymmetry present at 9 months, longitudinally to learn if their language skills were more advanced at a later age due to the earlier brain specialization for language. For example, when Kooijman et al. (2013) used ERPs to categorize 7 month old infants in two sub groups based on brain activity during speech segmentation tasks, they found that the first group of infants with left-lateralized negative-going brain responses scored significantly higher in speech comprehension and speech production at 3 years compared to the second group who had a distributed brain response at 7 months of age, it would be interesting to examine the infants in our study to see if the same correlation would be present for the infants who presented right mouth asymmetries over those who did not.

Many studies have found potential indicators of brain asymmetries in infants at various ages (Sato, Sogabe, & Mazuka, 2010; Bortfeld, Fava, & Boas, 2009). A study by Sato, Sogabe, & Mazuka (2010) used near-infrared spectroscopy (fNIRS) to measure cortical hemodynamic responses of the brain hemispheres in 4 and 10 month infants while listening to speech pitch-accent pattern changes versus listening to pure-tone pitch changes. Their study found that the 10 month old infants showed left hemisphere dominance when listening to the pitch-accent pattern changes but not the pure-tone pattern changes while the 4 month old infants had distributed brain activity (Sato, Sogabe, & Mazuka, 2010). This shows that the infant brain has begun to or has already lateralized for speech perception at 10 months of age. Another fNIRS study done by Bortfeld, Fava & Boas (2009) found that infants aged 6 to 9 months displayed activity in the left temporal region of the brain in response to an audiovisual stimulus as opposed to when just being presented with a visual stimulus. These infants were presented with a series of short stimulus that either presented a black screen, a screen with a silent movie, or a screen with a movie and audio (Bortfeld, Fava, & Boas, 2009). When the movie with the audio was presented, the infants' left temporal lobe brain activity increased while it remained relatively consistent when presented with the two other stimuli (Bortfeld, Fava, & Boas, 2009). These two fNIRS studies have provided evidence showing that the 9 month old infants in our study's brains should have been lateralized for speech processing when the videos were recorded. Whether or not their brains were lateralized for speech production is up to further debate (Sato, Sogabe, & Mazuka, 2010; Bortfeld, Fava, & Boas, 2009).

While there have been studies that provide evidence for lateralization of the brain for speech perception, another study has provided evidence that the brain has lateralized for motor movements which correlated with language abilities as well (Sato, Sogabe, & Mazuka, 2010; Bortfeld, Fava, & Boas, 2009; Nelson, Campbell & Michel, 2014). Nelson, Campell, & Michel (2014) found that infants ages 6 to 14 months who had consistent right hand preference in grasping toys medially presented to them performed better on the Bayley Scales of Infant and Toddler Development at 28 months of age than the infants who did not have consistent right hand preference. The predominant use of the right hand is related to left hemisphere lateralization, if the brain is lateralized for motor activity it is plausible that the brain is lateralized for language as well especially since babbling can be viewed as a motor activity

(Nelson, Campbell & Michel, 2014). While this study does not explain the nature of babbling it does connect early motor movements with language in infants.

Iverson et al. (2007) also examined hand movements and its relation to babbling. Iverson et al. (2007) examined rattle shaking and rhythmic arm movements in prebabbling, recent babbling, and experienced babbling infants, they found a significant increase in arm movement at the onset of babble but did not find a presence of right hand preference at the onset or during babble. Due to the lack of lateralized hand movements Iverson et al. (2007) concluded that babbling and rhythmic arm movements are part of a process of motor development and that babbling is a motor stereotypy that is refined and adapted for language through reinforcement.

While it would be easy to conclude that the infants in our study's brains had not yet lateralized and therefore babbling is not a linguistic act, there is not enough evidence to come to this conclusion. Studies have found evidence of lateralization of the brain in infants ages 6 months and older so there is a possibility that the infants in our study had brains lateralized for speech perception and possibly language (Sato, Sogabe, & Mazuka, 2010; Bortfeld, Fava, & Boas, 2009; Nelson, Campbell & Michel, 2014). Although a reliable and objective method of measuring the mouth was found, our method may not be a realistic way to measure lateralization. Further research needs to be done to examine if the methods are valid by measuring the same infants over time to see when the right asymmetries of the mouth become present.

Bibliography

Bear, M., Connors, B., & Paradiso, M. (2007). Language. In *Neuroscience: Exploring the brain* (3rd ed., pp. 617-641). Baltimore: Lippincott Williams & Wilkins.

Blank, S.C., et al. (2002). Speech production: Wernicke, Broca and beyond. *Brain: A Journal of Neurology*. *125*(Pt 8), 1829-1838.

Bortfield, H., Fava, E., & Boas, D.A. (2009). Identifying Cortical Lateralization of Speech Processing in Infants Using Near-Infrared Spectroscopy. *Developmental Neuropsychology, 34*(1), 52-65.

Boysson-Bardies, B., Sagart, L., & Durand, C. (n.d.). Discernible differences in the babbling of infants according to target language. *Journal Of Child Language, 11*, 1-15. doi: 10.1017/S0305000900005559

Dehaene-Lambertz, G., Dehaene, S., & Hertz-Pannier, L. (2002). Functional Neuroimaging of Speech Perception in Infants. *Science, 298*(5600), 2013-2015.

Dehaene-Lambertz, G., Hertz-pannier, L., & Dubois, J. (2006). Nature And Nurture In Language Acquisition: Anatomical And Functional Brain-imaging Studies In Infants. *Trends in Neurosciences, 29*(7), 367-373.

Ejiri, K. (1998). Relationship between rhythmic behavior and canonical babbling in infant vocal development. *Phonetica, 55*(4), 226-237.

Fernández-Carriba, S., Loeches, Á, Morcillo, A., & Hopkins, W. (2002). Asymmetry in facial expression of emotions by chimpanzees. *Neuropsychologia, 40*, 1523-1533.

Geranmayeh, F., et al. (2014). Overlapping networks engaged during spoken language production and its cognitive control. *The Journal of Neuroscience: The Official Journal Of The Society For Neuroscience, 34*(26), 8728-8740. Doi:10.1523/JNEUROSCI.0428-14.2014

Graves, R., & Landis, T. (1990). Asymmetry in mouth opening during different speech tasks. *International Journal of Psychology*, *25*(2), 179-189. doi: 10.1080/00207599008247856

Holowka, S., & Petitto, L. A. (2002). Left hemisphere cerebral specialization for babies while babbling. *Science*, 297, 1515.

Hook-Costigan, M., & Rogers, L. (1998). Lateralized use of the mouth in production of vocalizations by marmosets. *Neuropsychologia*, *36*, 1265-73.

Iverson, J. M., Hall A. J., Nickel L., Wozniak R. H. (2007). The relationship between reduplicated babble onset and laterality biases in infant rhythmic arm movements. *Brain Language*, *101*, 198–207.

Iverson, J. M., & Fagan, M.K. (2014). Infant Vocal-Motor Coordination: Precursor to the Gesture-Speech System?. *Child Development,* (4). 1053.

Kent, R. (1981). Articulatory–acoustic perspectives on speech development. In R. Stark (Ed.), *Language Behavior in Infancy and Early Childhood* (pp. 105-126). New York.

Keren-Portnoy,T., Vihman M. M. and DePaolis, R.A. (2010a). Exploring cultural impact on segmentation and first word recognition: End of award report to the ESRC.

Kooijman, V., Junge, C., Johnson, E., Hagoort, P., & Cutler, A. (2013). Predictive Brain Signals of Linguistic Development. *Frontiers in Psychology*, *4*.

Lamb, M. E., Bornstien, M. H., & Teti, D. M. (2002). Origins of Language in Infancy. In B. Webber (4th ed.), *Development in Infancy: An Introduction* (279-327). Mahwah, NJ: Lawrence Erlbaum Associates.

Locke, J.L., Bekken, K.E., McMinn-Larson, L., Wein, D. (1995). Emergent control of manual and vocal-motor activity in relation to the development of speech. *Brain and Language, 51*, 498–508.

Losin, E. et al. (2008). Left hemisphere specialization for oro-facial movements of learned vocal signals by captive chimpanzees. PLoS ONE 3(6): e2529. doi:10.1371/journal.pone.0002529

Mills, D., Coffey-Corina, S., & Neville, H. (1994). Variability in Cerebral Organization durin Primary Language Acquisition. *Human Behavior and the Developing Brain* (pp. 427-455). New York: The Guilford Press.

Nelson, E. L., Campbell, J.M., & Michel, G. F. (2014). Early handedness in infancy predicts language ability in toddlers. *Developmental Psychology, 50*(3), 809-814. Doi:1037/a0033803

Nicholls, M.R., & Searle, D.A. (2006). Asymmetries for the visual expression and perception of speech. *Brain And Language, 97*(3), 322-331.

Nina. (Photographer). (2012). *Mama* [digital image]. Retrieved from http://blackbirdinkphotography.com/blog/wp-content/uploads/2012/05/mama1.jpg

Oller, D. (2000). *The emergence of the speech capacity*. Mahwah, N.J.: Lawrence Erlbaum Associates.

Reynolds Losin EA, Russell JL, Freeman H, Meguerditchian A, Hopkins WD (2008) Left Hemisphere Specialization for Oro-Facial Movements of Learned Vocal Signals by Captive Chimpanzees. *PLoS ONE 3*(6), 2529. doi:10.1371/journal.pone.0002529

Roug, L., Landberg, I., & Lundberg, L. (2009). Phonetic development in early infancy: A study of four Swedish children during the first eighteen months of life. *Journal Of Child Language,16*(01), 19-40. doi:10.1017/S0305000900013416

Sato, Y., Sogabe, Y., & Mazuka, R. (2010). Development of Hemispheric Specialization for Lexical Pitch-Accent in Japanese Infants. *Journal of Cognitive Neuroscience,* 22(11), 2503-2513.

Simmonds, A. J., et al. (2014). Parallel systems in the control of speech. *Human Brain Mapping, 35*(5), 1930-1943. Doi:10.1002/hbm.22303

Stark, R. E. (1980). Stages of speech development in the first year of life. In G. H. Yeni-Komshian & J. F. Kavanagh & C. A. Ferguson (Eds.), *Child phonology*. New York, NY: Academic Press.

Szaflarski, J. P., Holland, S. K., Schmithorst, V. J., & Byars, A. W. (2006). An fmri study of language lateralization in children and adults. *Human Brain Mapping*, *27*(3), 202-212. doi: 10.1002/hbm.20177

Thelen, E. (1979). Rhythmical stereotypies in normal human infants. *Animal Behavior, 27*, 699-715. doi: 10.1016/0003-3472(79)90006-X

Thelen, E. (1981). Kicking, rocking, and waving: contextual analysis of rhythmical stereotypies in normal human infants. *Animal Behavior., 29*, 3-11.

Vihman, M. M. (2014). Infant vocal production. (2nd ed.), *Phonological development: the first two years (2-29).* West Sussex: John Wiley and Sons.

Vihman, M. M., DePaolis, R. A. & Keren-Portnoy (2009). Babbling and words: A Dynamic Systems perspective on phonological development. In E. Bavin (ed.), *Handbook of Child Language* (pp. 163-182).

Wängler, J. A. (2012). Normal Phonological Development. (4th ed.) *Articulatory and phonological impairments: a clinical focus* (112-155). Boston: Pearson.

Warren, J. E., Wise, R. J. S., & Warren, J. D. (2005). Sounds do-able: Auditory–motor transformations and the posterior temporal plane. Trends in Neurosciences, 28, 636–643.

Wilson, E. M., Green, J. R., & Weismer, G. (2012). A kinematic description of the temporal characteristics of jaw motion for early chewing: preliminary findings. *Journal of Speech, Language, and Hearing Research, 55,* 626-38. doi: 10.1044/109243882011/10-0236