

CASCADES OF LEARNING THROUGH PLAY: THE RELATION BETWEEN INFANT
MOVEMENT, ATTENTION, AND LANGUAGE PRODUCTION IN THE SECOND YEAR
OF LIFE

by

MARGARET TANKESLY FYAN

(Under the Direction of Janet E. Frick)

ABSTRACT

Motor development is not only a key foundation to how individuals engage in movement across the lifespan, but a means to learning and engagement in other developmental domains. Prior work has explored the relation between motor development and cognition through the lens of embodied cognition, linking movement to cognitive domains such as attention and language across various developmental periods in infancy. However, the relation between whole-body movement, attentional processes, and language development remains under-explored. The present study demonstrates that there are dynamic, moment-to-moment predictive relations between whole-body movement in toddlers and their attentional processes as well as their vocalizations. Unique combinations of movements across the whole body were found to predict vocal production and engaging in particular infant attentional states. Results are discussed in terms of how these three systems interact with one another and create potential developmental cascades within and across the domains of motor, attention, and language development.

Keywords: Movement Variability; Motor Development; Language; Attention; Joint Attention

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CHAPTER 1

INTRODUCTION

Motor development within the field of developmental psychology is a growing area of research. Much of what is known about normative motor development was established decades ago and was foundational to the motor developmental literature. Researchers such as Myrtle McGraw (1946), Arnold Gesell (1928), and Mary Shirley (1931) were instrumental in forming the current understanding of infant motor development, including the establishment of motor milestones. These milestones (see Appendix B) are still widely referenced and are updated by the World Health Organization (WHO; Martorell et al., 2006) as well as by the National Center on Birth Defects and Developmental Disabilities, Centers for Disease Control and Prevention (NCBDDD, 2024). Subsequently, research on motor development has sought to enhance the understanding of how infants gain and use their motor system.

Motor behaviors have also played an important role in the study of other developmental processes; for example, they have been central in perceptual studies of how infants perceive objects and events. A primary example of this is the “Visual Cliff” paradigm (Gibson & Walk, 1960), which measures visual depth perception by examining how infants respond to an apparent drop in a surface in front of them; infants’ motor behaviors are a key part of their response. Similar studies have focused on how infants perceive and navigate obstacles in their environments such as navigation of varying slopes or surfaces (Adolph et al., 1993; Adolph et

al., 2010). This literature has been foundational in understanding the interplay between motor and perceptual systems and has since been expanded to other domains of cognition.

The concept of embodied cognition characterizes how infant body movement informs cognition. Embodied cognition is an area of research focused on how our motor system impacts traditional cognitive domains, including perception, attention, language, memory, problem solving, and learning (Shapiro, 2019). Early infant movement is not exclusive of cognition. Thelen and colleagues (1987) demonstrated that early kicking behavior as early as 6-weeks of age shows similarities with models of more complex adult motor behaviors. Subsequently, Thelen (1994) demonstrated that by three months of age, infants are able to take patterns of coordinated kicking behaviors, such as alternating left and right legs or kicking both legs in the same direction at the same time, to accomplish a novel task (moving a mobile). Infants were able connect their movement to cognition, knowing that if they moved in a particular way, a certain action would causally happen. Other studies exploring the links between motor behavior and cognition have shown that as locomotion emerges, crawlers and walkers differ in how they approach novel environments. Crawling infants use an experiential approach (“learn by doing”) going in headfirst, while walkers take a longer time in deciding how to ascend and descend slopes (Adolph et al., 1993; Adolph et al., 2010). In addition, there have been numerous studies exploring how infant postural development facilitates changes in embodied experiences that then provide differing opportunities for learning (Soska et al., 2010; Kretch et al., 2022; Kretch et al., 2014). While much of the research on embodied cognition has focused on perception, there is extant literature applying the theory of embodied cognition to the cognitive domains of attention and language. Attention literature frequently refers to the relation between attention and motor development as embodied attention (Yu & Smith, 2012; Robertson & Johnson,

2009). Within the literature associated with language development, much of the literature has linked oral-motor development to the development of language and vocal production (Ejiri, 1998; Borjon et al., 2024).

While much is known about relations between motor development and the domains of cognition, there are still many unknowns. The current study seeks to understand how variability in whole-body infant movement, a relatively untapped aspect of infant movement in the second year of life, is related to attention and language.

Movement and Attention

The relation between motor behavior and attention is observed extremely early in infancy. One example of this is the phenomenon of “sticky attention”, a feature of early infant attention where an infant’s visual focus “sticks” to an object or event without the ability to quickly disengage. This phenomenon is thought to be due to immaturity of the motor system underlying visual shifts and saccades (Colombo, 2001). In infant attention paradigms ranging from habituation, to novelty preference, to violation of expectations, infant responses require the ability to move their heads and eyes toward peripheral stimuli (Frick et al., 2003; Oakes, 2010). Even further, the subsequent development of sustained attention months later, when an infant is able to attend to an object/event for a greater period of time, relies on infants' ability to orient and shift their visual attention towards preferred objects, as well as the ability to disengage from other objects (Colombo, 2001). This engagement and disengagement, while visual in nature, requires infants to have control over their head, neck, and saccadic back-and-forth eye movements to orient toward and away from stimuli (Johnson, 1994).

Additional work has examined this relation more directly and has discovered that sustained visual attention in young infants is linked to particular patterns of whole-body motor

movement (Robertson & Johnson, 2009). Using pressure sensors placed in car seats of infants between one and five months of age, researchers determined that infants with greater movement rebound (i.e., more uncontrolled movement above recorded baseline movement) engaged in less sustained visual attention, while infants who demonstrated less movement rebound (i.e., greater motor control) demonstrated higher levels of sustained attention. Early in infancy, it has been theorized that infant's looking behavior during visual foraging reflects coupling between fluctuations in motor activation, changes in saccadic eye and head movements, and attentional processes (Robertson & Johnson, 2009). These findings are important to understand how movement is related to attentional processes that develop and increase in complexity across infancy.

Additionally, prior research found longitudinal links between movement and attention; specifically, infants who had less suppression and greater rebound of motor behavior at the onset of looking at three months were reported by their parents to have more problems with attention and reported indicators of ADHD at 8 years of age (Friedman et al., 2007). The extent to which body movement is suppressed during gaze onset during the same free-looking task at three months (Robertson & Johnson, 2009) may reflect differences in motor-attention integration, which can have important implications for attention later in life (Friedman et al., 2007).

These established links between movement and sustained attention also may help support the establishment of joint attention with a social partner. Certain types of movement have been shown to support sustained attention. Bambach and Colleagues (2016) found that while infants manually play with toys, attending to the objects centered at the midline supports head and trunk stabilization and increases visual sustained attention to the objects compared to non-centered objects. Further, when infants are engaging, motor behaviors, such as object manipulation,

provide cues that can help to support the emergence of more complex forms of attention (Deak et al., 2018; Schroer & Yu, 2022). Thus, motor actions, such as holding and manipulation of an object at midline and object rotation, contribute to the development of shared attentional states such as joint attention.

Measurement of Attention and Motor Behavior

A variety of methods and tools of measurement have been used to study the relation between motor behavior and attention. Emerging research has begun to use head-mounted eye tracking (HMET) to understand caregiver-infant interactions within the context of the development of social, attentional, and language skills. The egocentric cameras in HMET provide insight into the infant's point of view, their body position, behavior, and objects or people in view (Bradshaw et al., 2023). In studies with infants under 12 months of age, researchers have used HMET methods for evaluating the relation between caregiver and infant movement and other developmental outcomes (Yu & Smith, 2012; Bradshaw et al., 2023; Slone et al., 2019).

Despite the promise of HMET, a small number of studies have evaluated motor-attention integration in the second year of life, examining how motor actions are related to visual attention and exploration (e.g. Abney et al., 2018; Borjon et al., 2021). However, many questions remain regarding how motor development and whole-body movement is related to the development of attention, particularly complex forms of attention.

Overall, there is strong evidence that attention is linked to motor development. Yet, there is limited information on the relation between forms of infant attention and motor behavior. Furthermore, there are currently no studies looking to address the relation between complex forms of infant attention (i.e. joint attention) that emerge near the end of the first year

of life and whole-body movement during motor development. Beyond the studies discussed, motor development and attention have not been studied concurrently. Given this lack of research in the area of movement and attention, there is a need to continue investigating this relation. Motor development has additionally been studied at various points in the infancy period with other domains of cognition such as language.

Movement and Language

In addition to attention, language is a domain of cognitive development that is inherently related to motor development. Language production itself is a motor act (Iverson, 2010). Physiologically, mandibular oscillations (opening and closing the mouth/mandible), oral-motor physiology, and vocal production aid in oral language development (Ejiri, 1998; Iverson, 2010). Developing the muscular control to produce and communicate language is imperative to successful integration of movement and language.

Motor and language development have been explored in tandem at various developmental points in language learning. At the transition into canonical babbling around five months of age, rhythmic stereotypies develop with a peak in frequency of rhythmic arm movements (e.g., shaking, swinging, and banging) at the emergence of this language milestone (Thelen, 1979; Iverson et al., 2007; Iverson, 2010). Changes in vocalization around motor milestones illustrate how they are coordinated systems. At the emergence of locomotion, infants with novice crawling experience are less likely to vocalize during crawling compared to infants with a month of crawling experience; similar findings were observed for the pull-to-stand motor milestone (Berger et al., 2017).

The gesture-speech system, a highly synchronous co-occurrence of gesture and speech (i.e., “talking with your hands”) that emerges in infancy, is a well-established concept that has

been studied in children and adults (Iverson & Fagan, 2004). Coordinated rhythmic limb movements that emerge at the onset of babbling between six and nine months of age is theorized to be a precursor to the adult gesture-speech system. Subsequently, as infants approach 12 months of age and produce their first word, vocal-motor coordination is well established (Iverson & Fagan, 2004).

Vocal production has additionally been explored in relation to oral-motor development and the recognizability of speech. One study in particular found that there are age-related increases in recognizability of vocalizations, as well as movement preceded vocalization (Borjon et al., 2024). While the precision (how soon prior to the onset of a vocalization) of these body movements was not found to be related to the recognizability of speech, infants still used extraneous body movements and co-occurring oral-motor articulators to produce speech, demonstrating the coordination of the motor system and verbal language development (Borjon et al., 2024).

Another well-established link between motor development and language is object manipulation and language learning. For example, in a dyadic lab task with an infant and their caregiver interacting with various objects, infants who engaged in greater amounts of object rotation (i.e. experiencing greater and more complex views of the full object) later showed greater vocabulary growth (Slone et al., 2019). Additionally, the relation between object label learning and manual object exploration has been replicated in the home setting with a caregiver, again showing that when infants are engaging in functional use of objects, they are better prepared to learn a new object label from their caregiver (West & Iverson, 2017). Complex manual manipulation and exploration of various objects, however, requires complex postural

development wherein infants can hold themselves upright in a seated position (West & Iverson, 2017; Soska et al., 2010; Yu & Smith, 2012).

Infants discover new information through various types of object interactions. Visual attention alone (looking without holding), manual action alone (holding without looking), and multimodal attention and action (looking and holding simultaneously) all produce different information. Researchers have demonstrated that the multimodal aspect of hand-eye coordination during an object labeling task is positively associated with object label learning during toy play when compared to visual attention and manual action on their own (Schroer & Yu, 2021; Schroer & Yu, 2023).

Taken together, it has been established that there is coordination between the motor and language system. Previous work on language development and movement in infancy has looked at key milestone periods for development in locomotion, crawling to walking, and manual action related vocal production and word learning. However, there is little insight into how overall body movement impacts vocal production and language learning in the second year of life.

In sum, motor behavior is linked to attention and language development in a few key ways. First, motor behaviors have been linked to attentional processes at multiple points in infant development, most notably within the first few months of life and importantly for the development of sustained attention, engagement, and disengagement (Robertson & Johnson, 2009; Friedman et al., 2007; Oakes, 2023; Abney et al., 2018). Second, the onset of vocal behaviors has been found to pair with movement, such as the onset of canonical babbling emerging in conjunction with rhythmic limb movements (Thelen, 1979), and locomotive behaviors predicting vocal production (Berger et al., 2017).

Gaps in Knowledge

What is currently known about the connection between movement and attention comes from a limited number of studies. These studies have used a variety of methods, mixing physiological with observational tools; however, many opportunities remain to evaluate how movement is related to the development of more complex forms of attention, such as joint attention. Additionally, there are important developmental windows that may be informative for how infant language and movement interact on a day-to-day basis, which is still relatively unexplored. Finally, most of the existing studies in this research domain have been conducted in laboratory settings. Further work in naturalistic environments may provide additional insights into how these domains interact in a child's everyday life.

The Present Study

The current study examines the relation between motor development, attention, and language in the second year of life using data from the Play and Learning Across a Year (PLAY) project. The study will evaluate complex forms of attention as measured by Bakeman and Adamson (1984), language production in the form of communicative utterances and global language knowledge collected using the MacArthur-Bates Communicative Inventories (M-BCDI; Fenson, 2007), and infant movement variability measured using postures (Adolph & Franchak, 2017; MacGraw, 1946) and head and trunk movement, adapted from the coding scheme of Iverson and Fagan (2004). This study will seek to answer the following three questions and hypotheses:

RQ1: Does movement variability differ between ages?

H1: It is expected that movement variability will significantly differ between age groups, with older age groups showing greater variability in movement.

RQ2: Does movement variability relate to aspects of overall language development?

H2: Movement variability will positively relate to vocal production during a dyadic play session, as well as to higher expressive vocabulary (overall language development), measured using the scores on the M-BCDI in 12-, 18-, and 24-month-olds, as previous literature has established relations between vocabulary growth and increased manual action and object interactions.

RQ3: How do moment-to-moment changes in infant movement relate to future infant engagement states?

H3: Various whole-body movements or combinations of movements will be predictive of entering the different infant engagement states.

CHAPTER 2

METHODS

Participants

The Play and Learning Across a Year (PLAY) project is a multi-site collaborative study consisting of in-home data collection of structured and naturalistic mother-child interactions collected across 30 North American Universities. The participant sample consisted of 31 mother- infant dyads in the state of Georgia. Using cross-sectional methods, mothers ($M = 32.62$, $SD = 3.81$) and their infants were recruited in three age groups: 12-month ($N = 11$; $M = 12.35$, $SD = 0.51$; 54.5% Female), 18-month ($N = 10$; $M = 17.87$, $SD = 0.45$; 70.0% Female), and 24-month ($N = 10$; $M = 23.93$, $SD = 0.52$; 60.0% Female) olds. Most participants (90.32%) identified as white. Three participants (9.67%) identified as more than one race. The majority (71%) of mothers held academic or professional degrees higher than a bachelor's degree. The average age of the mothers was 32.62 years old.

Participants had to meet extensive inclusion criteria, which were established prior to data collection through screening phone calls. All participating families spoke only English and/or Spanish in the home. Infants were typically developing with no cognitive, motor, auditory, or vision delays or disabilities. Additional inclusion criteria were that all participating infants must have been born full term - between 37 and 41 gestational ages - with no severe birth complications.

Materials

All experimental materials were consistent across PLAY project sites. Visits were recorded via a Panasonic HC-V770 full HD Video Camera Camcorder. A Lenovo 8 Tab 4 16GB Tablet with an external Dayton Audio IMM-6 Microphone decibel meter mic was used to track and collect environmental noise levels during the one-hour natural play segment of the home visit. The tablet was also used to record all questionnaire data. The toys provided for the five- minute structured play were from the Green Toys Dish Set with the following objects: yellow plastic forks, knives, and spoons (two of each); two purple plastic bowls; two blue plastic teacups; two green plastic plates; and two Munchkin Bath Bobbers. All toys were placed in a clear plastic tote and handed to the mother while she and her infant were seated on a provided Gaiam Essentials Thick Yoga Mat.

Procedures

Prior to any home visits, families received a recruiting phone call to screen for inclusion criteria, gather demographic information, and schedule a home visit. Once families decided on a visit date, the experimenter sent an email to the families to establish visit details, and then confirmed via phone call the day before.

Home visits consisted of five main parts. At the time of data collection, mothers and their participant child had to be home alone with no other family members present in the data collection area. Upon arrival at the home, the experimenter explained the study and gained consent from the mother. Then, the experimenter conducted video and noise measurements of the one hour of natural play. The one-hour natural play was video recorded by the experimenter with the infant in the frame at all times, ensuring that the child's whole body was visible on

camera. In this segment, the mother was not required to be in frame, and the experimenter did not interact or make eye contact with the infant.

Next, a video-recorded house walk-through and room measurements were conducted. This was done to evaluate the environments that each infant gets to explore throughout the day. The experimenter started at the entrance of the home and was instructed to audibly name each room and their function. The experimenter recorded from left to right, then panned to the floor and ceiling, capturing as much of the room as possible. The mother was asked about how much time the infant spends in each room, the infant's objects in the room (e.g., clothes, shoes, books, or toys), and sleeping arrangements.

A five-minute structured mother-child play session was then recorded. The yoga mat was placed in a clearing on the floor, and instructions were given to the mother of "Please sit next to [CHILD] on this mat. I'll give you a set of toys. Please play with [CHILD] however you like for 5 minutes". The experimenter then handed the mother the tote bag of toys and began recording so that both the mother and her infant's entire bodies were in view, and this continued for five minutes.

For the final segment of the home visit, the experimenter sat down with the mother to complete the questionnaires and final paperwork. The tripod with video camcorder was set up to capture both mother and experimenter in the recording. Paper copies of the questionnaires and Likert-scale definitions were provided for the mother to follow along during the questionnaire portion of the visit. The questionnaire segment of visits was recorded on the digital camcorder mounted on a tripod while the experimenter verbally asked the participant questions and recorded answers via the digital form on the tablet.

Mothers were surveyed on demographics, locomotor milestones, vocabulary inventories, health, temperament, media use, pets, household division of labor, and a typical day in the home. Visits ended with the experimenter providing information for how mothers could receive the gift cards for participation.

For the present study, behavioral coding will be used to analyze the five-minute structured play segment and a five-minute natural play segment from each mother-infant dyad. To obtain the five-minute natural play segment, the 60-minute natural play session was separated into five-minute segments where both mom and infant were in frame. One five-minute segment, which could have occurred anywhere in the 60-minutes, from each infant was randomly selected to be included in behavioral coding.

Measures

For the present study, the five-minute natural play and structured play segments were behaviorally coded for the following variables: one, infant movement variability using posture, head, and trunk movements, two, vocal production, and three, infant attention. Each video was coded three times, each variable separately. All videos were coded in Datavyu, a java-based, open-source software that allows for audio and video microcoding (datavyu.org). See Appendix for coding dictionary.

Prior to analysis, five-minute natural and structured play segments were behaviorally coded for Infant Engagement States, Postures and Head and Trunk movement, and Vocal Production. The complete coding dictionary and rule book used by coders can be found in Appendix A. Five-minute segments of the one-hour natural play sessions were isolated where both mother and infant were in the frame. Mothers could be out of frame for less than five seconds or the segment was excluded from potential coding. Each video was coded by trained

undergraduate research assistants who are blind to research aims and hypotheses to ensure reliable coding. Interrater reliability was evaluated using Intraclass Correlation Coefficients (ICC 2,1). Correlations of 0.8 or greater indicate good to excellent reliability (Koo & Li, 2016).

Movement Variability

A behavioral coding scheme was developed to identify movement variability through quantifying the frequency and duration of postures and head and trunk movements. Coding was conducted for seven postures: (1) *Prone*, laying on stomach; (2) *Supine*, laying on back; (3) *Sitting (supported and unsupported)*, seated on bottom; (4) *Crawl*, hands and knees propulsion forward; (5) *Walking (supported and unsupported)*, upright propulsion on two feet; (6) *Stand (supported and unsupported)*, upright on two feet; (7) *Kneeling*, upright on both knees. Torso movement was coded for five different movements: (1) *Bounce*, torso moves vertically up and down; (2) *Rock*, singular back-and-forth torso movement [can occur while reaching]; (3) *Left Torso*, torso twists toward the left side of the body (degree change of 45 or greater); (4) *Right Torso*, torso twists toward the right side of the body (degree change of 45 or greater); (5) *Center Torso*, Torso twists from right/left back to center (degree change of 45 or greater). Head movement was coded for five different movements: (1) *Roll side to side- shake*, Lateral rotation of head (similar to headshake); (2) *Roll front to back- nod (up or down)*, forward-backward movement (similar to head nod); (3) *Left Head*, head twists toward the left side of the body (degree change of 45 or greater); (4) *Right Head*, head twists toward the right side of the body (degree change of 45 or greater); (5) *Center Head*, head twists from right/left back to center (degree change of 45 or greater). Postures and head/trunk movement codes were adapted from Gesell (1928) motor milestones, Adolph and Franchack (2017), and Iverson and Fagan (2004). These codes were selected based on their use in the literature, as the positions from MacGraw

(1946) demonstrated in Adolph and Franchak (2017) are widely used to study early motor behavior and emerging locomotion. The head and trunk movements from Iverson and Fagan's (2004) codes have also been used to study the relation between movement and speech.

Infant Attention

Infant attention was coded using six infant engagement states. Infant Engagement States (IES) measure an infant's involvement with an object, event, or social partner. The six engagement states are as follows: (1) *Unengaged*, passively observing the environment without engaging with anyone or anything; (2) *Onlooking*, gazing over at an object, person, or event but not actively participating; (3) *Solo Object Play*, playing, approaching, and engaging with an object on their own; (4) *Social Engagement*, one-on-one interaction with just the infant and mother and no objects; (5) *Supported Joint Engagement*, infant interacting with an object with another person can be seen when the mother is scaffolding the infant's attention of that object or event; (6) *Coordinated Joint Engagement*, the dyad shares attention on the object and each other by coordinating eye gaze to each other and the object/event. IES codes were used from Montroy et al. (2024), adapted from Bakeman and Adamson (1984).

Vocal Production

Vocal production was measured using communicative utterances during the five minutes of dyadic play. Vocalizations note whether the infant makes a communicative noise, measuring both the duration and frequency of utterances. This informs how much verbal communication is happening during dyadic play, as well as at what point in an interactive play setting vocal communication is occurring. Methods from Iverson and Fagan (2004) will be used to determine the boundaries of utterance onset and offset of each for duration and frequency.

Vocalizations are determined by any time an infant makes a verbal noise such as a coo, babble, sound, word, string of words, etc. Vocalizations are separated by a breath or no repeat of utterance for greater than one second, which marks the offset of an individual utterance. The duration and frequency will be recorded. Non-communicative sounds, such as a cough, will not be counted toward language production. Additionally, recognizability of speech was also coded for, where four research assistants listened to each vocalization for each participant and assigned a 1 if they could understand a word (and then listed the word they heard), and a 0 if they could not make out a word. Each vocalization was then assigned a recognizability score made up of the sum of the responses from the four raters (0 = completely unrecognizable, 4 = completely recognizable).

MacArthur-Bates Communicative Development Inventories

The MacArthur-Bates Communicative Development Inventories (M-BCDI) was collected during the questionnaire section of the home visit during the PLAY study. The M-BCDI is a parent-report which captures information about children's language development. For 12-month-olds, parents completed either the English, Spanish or Bilingual short form of the M-BCDI in which parents read 165 different words (270 for bilingual), and response options are "understands" or "understands and says" (Fenson, 2007). If neither of these two categories apply, the word is left blank. M-BCDI were scored prior to analyses. For the 18- and 24-month-old participants, parents were asked to respond yes or no to whether their child said any of the following 176 (276 for bilingual) listed words by the researcher.

Data Analytic Plan

To address the research questions, various data analysis procedures were performed. RQ1 seeks to evaluate whether movement variability is different between the three age groups, 12-,

18-, and 24-month-olds. A two-way ANOVA was used to determine if there are any significant group differences in movement variability across the three age groups and two play settings. Frequency distribution, mean, standard deviation, and range of movement variability was also calculated. Shannon Entropy (H) was also calculated as a value for each participant's movement variability. It was expected that movement variability would significantly differ between age groups, with older age groups showing greater variability in movement.

RQ2 examines the relation between aspects of language development, such as receptive and expressive vocabulary knowledge (measured using the M-BCDI), communicative vocal production (measured using frequency and duration of utterances), and movement variability. A regression analysis with movement variability as the predictor, using the entropy value (H) for movement variability, and overall language scores from the M-BCDI as the outcome while controlling for age was conducted to examine this relationship. A categorical sequential analysis using multiple logistic regression (Weiß, 2018; Weiß and Göb, 2008) was also run to evaluate whether vocal production corresponds to body movements. It was expected that while controlling for age, movement variability would positively predict overall vocabulary knowledge, and that certain body movements would be related to greater instances of vocal production during the play sessions. This will further the understanding of the temporal relation between movement variability and how it is related to aspects of language development through verbal production and vocabulary knowledge.

RQ3 addresses how moment-to-moment changes in infant movement are related to different infant engagement states. Transitional probability matrices and categorical sequential analyses using multiple logistic regression were implemented to evaluate how infant movement variability over the second year of life influences different infant engagement states. Additionally, to answer this question, a linear regression analysis with movement variability as

the predictor and infant engagement states as the outcome while controlling for age was performed to determine the relationship between movement variability and infant attention over the second year of life. It was expected that there will be temporal relations between infant movement variability and attention. While controlling for age, it was expected that movement variability will positively predict infant engagement states. This aids the understanding of moment-to-moment changes in movement and attention, especially how movement variability relates to complex forms of attention, such as joint attention.

Data Reduction and Processing

During initial data coding, 27% ($n = 17$) of videos were coded for interrater reliability. Interrater reliability was calculated using Intraclass Correlation Coefficients (ICC 2,1). ICC values of 0.8 and above were accepted as sufficiently reliable (Koo & Li, 2016). Average ICC values for each coded variable are as follows: movement variability (ICC = 0.95), vocalizations (ICC = 0.98), and infant engagement states (ICC = 0.95).

For movement variability, the frequency of each different type of movement was calculated. Postures from the movement variability variable were also measured for duration spent in each position. Additionally, aggregate variables of each body segment (head, torso, and postures) and overall movement were created. Total and average movement durations for each participant, as well as a sum and average durations of each of the body segments for head, torso, and postural movement were also calculated. Movement variability for both variables (frequency and duration) was relatively normally distributed, so no additional transformations were needed. Shannon entropy, a measure of how predictable an individual's movement is (H; Shannon, 1946), was also calculated for each participant. High entropy indicated greater variability across

all types of measured body movements, while lower entropy indicated less variability across all types of body movement.

The frequency and duration of each vocalization bout was calculated. Vocalization duration was log transformed to account for a large right skew in the values. Using methods from Borjon et al. (2024), vocalizations were coded for recognizability by having research assistants rate if the vocalization they heard was a recognizable English word. Four research assistants completed this task for each participant. Each vocalization was then assigned a recognizability score made up of the sum of the responses from the four raters (0 = completely unrecognizable, 4 = completely recognizable).

M-BCDI data was evaluated for normality. There was a large right skew in the expressive vocabulary scores. To address the non-normality of the M-BCDI scores, a log transformation was performed for the expressive language scores. Twelve-month-olds were given a slightly different set of words for receptive vs. expressive vocabulary, whereas 18- and 24-month-olds were not tested on receptive vocabulary, but were given one set of words to test expressive vocabulary. As a result, there were unequal numbers of words given to 12-month-olds compared to 18- and 24-month-olds. To address this, a proportion of words known for expressive language was calculated for each age so everything would be on the same scale.

The duration of each Infant Engagement State (IES) was calculated, along with proportions of each engagement state (see Table 20 for full proportion data). IES was normally distributed with no excessive skewness or kurtosis.

Movement variability, vocalizations, and IES variables were then transformed into a time series format. Each individual movement, engagement state, and vocalization was dichotomized and placed over the time series from 0 to 300 seconds. This resulted in 23 variables for

movement variability, 6 variables for IES, and 1 variable for vocalizations each coinciding with the time variable from 0 to 300. This time series formatted data was used for the logistic regressions to evaluate the temporal relation between movement, attention, and language production. cs were added in the logistic regression to assess lead-lag relationships between movement, attention, and language.

Much of the previous research pertaining to lagged analyses had examined interpersonal synchrony or dyadic interactions (Somers et al., 2022; Northrup & Iverson, 2020; Margolis et al., 2019; Dowd & Tronick, 1986; Tronick et al., 1980). To determine an appropriate lag for the variables, previous research was consulted, although there was no consensus on a particular lag across articles from dyadic or interpersonal interactions. Many of the lags were set between one and three seconds of time, and so to help determine a specific lag time across the variables assessed in the study, Chi Square Tests of Independence were performed between concurrent (zero second lag) and lagged movement variables at one, two, three, and four second lags. Across all movements, a two second lag on each variable yielded the most significance. Based upon this information, a two second lag was used for all lag sequential analyses.

Multiple logistic regressions were included in the analyses for research questions two and three. Stepwise multiple logistic regressions were tested using each individual movement to predict concurrent vocalization and infant engagement states, as well as vocalization and infant engagement states following movements two seconds prior. Vocal production and infant engagement states, and individual movements were dichotomized over the time series. Controlling for time, age, and play setting (structured versus natural), all possible movements were added stepwise into the regression models. At each step, a significant likelihood ratio X^2 test was used to evaluate if the model fit better with the added predictors. Similarly, at each

step, the Hosmer-Lemeshow (H-L) test was done to assess model fit. Each model was fit only to where the significant likelihood ratio X^2 test was significantly contributing to the prediction of the outcome. First, a logistic regression was fit with the controls of time, age, and play setting. Time, age, and play setting were all significant predictors, and the significant likelihood ratio X^2 test collectively contributed to the prediction of vocal production compared to the null model. However, the H-L test revealed a poor model fit ($p > 0.05$). To address this, forward stepwise variable selection was used to find good model fit. This revealed that the variable of age caused the poor model fit in the H-L test, whereas when only the covariates of time and play settings were in the model, good model fit was found ($p = 0.95$). Despite this, age was a primary covariate in the overall study design and thus was included in all of the following logistic regression models. All likelihood ratio X^2 tests and H-L goodness of fit test results can be found at the bottom of each logistic regression table in Appendix C for each variable tested.

All statistical tests assessed the appropriate assumptions for each analysis. Assumptions of ANOVA (normality and homogeneity), bivariate regression (independence, normality, linearity, homoscedasticity, and absence of multicollinearity), and logistic regression (multicollinearity, linearity with the log odds, and outliers), were all tested. No significant issues emerged with the assumptions of each test.

CHAPTER 3

RESULTS

Research Question 1: Movement and Age

Overall, infants made a total of 8,834 changes in movement. Between the structured and natural play settings, infants differed in the number of changes between the two play settings. Of all total movements made by infants, 4,948 were made in the natural play setting (56%) while 3,886 (44%) were made in the structured play setting. Across age groups, infants in the natural play made greater amounts of changes across all types of movements. Twelve-month-olds made an average of 164 changes in movement in the natural play compared to 105 in the structured play, with an average of 24 postural changes during natural play compared to 8 in the structured play. Eighteen-month-olds made an average of 155 changes in movement in the natural play compared to 132 in the structured play, with an average of 23 postural changes in the natural play compared to 9 in the structured play. Infants in the 24-month-old group made an average of 160 changes in movement in the natural play compared to 141 in the structured play, with an average of 19 postural changes in the natural play compared to 4 in the structured play. See Table 2 for full descriptives on movement changes across play settings. See Tables 2, 3, and 4 for average frequencies of movement by age (Table 2), natural play (Table 3), and structured play (Table 4).

A two-way ANOVA was performed to address the first research question of whether movement variability differs between ages. There was a marginally significant main effect of age on movement variability ($F(1, 58) = 3.19, p = 0.07$). However, a significant interaction between

Age x Condition on movement variability was found ($F(1, 58) = 22.46, p < 0.001$; see Table 5). Post hoc comparisons using the Tukey HSD test revealed 12-month-olds in the natural play had greater movement variability compared to the same 12-month-olds in the structured play setting ($p < 0.001$, 95% CI = -94.99, -22.82), 18-month-olds in natural play had greater movement variability compared to 12-month-olds in structured play ($p = 0.003$, 95% CI = -86.49, -12.55), and 24-month-olds in natural play had greater movement variability compared to 12-month-olds in structured play ($p < 0.001$, 95% CI = -91.39, -17.44; see Figure 1 for Age x Condition interaction).

To examine differences in individual body segment movement (head, trunk, and postures) by age, a one-way ANOVA revealed one-way ANOVA revealed a significant main effect of condition (structured versus natural play) on head movements ($F(1, 60) = 7.63, p = 0.007$; see Table 6). Post hoc comparisons using the Tukey HSD test revealed greater head movements in the natural play compared to the structured play settings ($p < 0.001$, CI = -30.92, -4.95). For trunk movements, a two-way ANOVA revealed a significant Age x Condition interaction ($F(1, 58) = 5.04, p = 0.029$). See Table 7. Post hoc comparisons using the Tukey HSD test revealed 18-month-olds in structured play moved their torsos significantly more compared to 12-month-olds in the structured play setting ($p = 0.09$, CI = 1.09, 23.03). Lastly, for postural changes, one-way ANOVA revealed a significant main effect of condition (structured versus natural play) only ($F(1, 58) = 53.55, p < 0.0001$; see Table 8). Post hoc comparisons using the Tukey HSD test revealed greater postural changes in the natural play compared to the structured play between natural play and structured play settings ($p < 0.001$, CI = -19.52, -11.12).

Research Question 2: Movement Variability and Language

Infants vocalized a total of 1,762 times. See Table 9 for breakdown of frequency of vocalizations. The average duration of all vocalizations was 1.20 seconds ($M = 1.20$, $SD = 0.9$). Within each age group, 12-month-olds had an average vocalization duration of 1.42 seconds ($M = 1.42$, $SD = 1.5$), the average duration of a vocalization for 18-month-olds was 1.1 seconds ($M = 1.10$, $SD = 0.8$), and the average vocalization duration for 24-month-olds was 1.18 seconds ($M = 1.18$, $SD = 0.7$). There was no main effect of age on duration of vocalizations ($F(1,1760) = 2.67$, $p = 0.10$). See Table 10 for full vocalization durations.

The overall average of recognizability (scored 0 = not recognizable at all to 4 = completely recognizable) for all infants was 0.61 ($M = 0.61$, $SD = 0.68$). The average recognizability for the 12-month age group was 0.12 ($M = 0.12$, $SD = 0.24$), the 18-month age group was 0.67 ($M = 0.67$, $SD = 0.64$), and the 24-month age group was 1.08 ($M = 1.08$, $SD = 0.70$; see Table 11 for full recognizability breakdown). The highest recognizability score was 2.5 and the lowest was 0. The results of a one-way ANOVA revealed a significant main effect of age on the recognizability scores of vocalizations ($F(1,60) = 3.27$, $p < 0.001$; see Figure 2). Post hoc comparisons using the Tukey HSD test revealed the greatest differences in recognizability in speech between the 12- and 18-month-old groups ($p < 0.001$, 95% CI = 0.13, 0.58), where 18-month-old speech was significantly more recognizable than the 12-month-old speech, and the 12- and 24-month-old groups ($p < 0.001$, 95% CI = 0.35, 0.79), where 24-month-old speech was significantly more recognizable than that of the 12-month-olds speech.

Expressive Language was assessed in all three age groups. The overall average of words the infant could understand and say was 46 words ($M = 45.77$, $SD = 40.7$). For the 12-month-old group, the average proportion of words they could say and understand was about 3% ($M = 2.73$, $SD = 1.5$). In the 18-month-old group, the average proportion was approximately 10% of words

($M = 10.4$, $SD = 4.6$). For the 24-month-old age group, the average proportion was about 50% of words ($M = 49.6$, $SD = 25.8$; see Table 12 for M-BCDI Descriptives). The results of a one-way ANOVA indicated a significant effect of age group on the expressive language percentage scores ($F(2, 59) = 19.16$, $p < 0.001$). See Table 13 and Figure 3 for expressive language ANOVA.

The second research question asked whether movement variability relates to aspects of overall language development, as measured using vocal production as well as expressive and receptive language skills using the M-BCDI. First, a linear regression was run between movement variability, using Shannon Entropy (H), and expressive language on the M-BCDI while controlling for age. There was no significant relation between expressive language and movement variability ($b = -0.34$, $t = -1.47$, $p = 0.145$). See Table 14 and Figure 4 for the regression between movement variability and expressive language. As exploratory analyses, linear regressions between expressive language and the individual body segments and positions were run. There were no significant findings between frequency of All movements, head movements, trunk movements, and postural movements and expressive language. Additionally, vocal production was not found to be correlated with either expressive or receptive language in this sample (Expressive: $r = 0.08$, $p = 0.54$; Receptive: $r = 0.14$, $p = 0.52$) nor was recognizability of speech ($r = 0.20$, $p = 0.37$).

Next, to address another aspect of overall language development, the relation between movement variability and vocal production during the dyadic play session, transitional probabilities were calculated between each type of movement and vocalizations. All transitional probabilities were extremely low due to the fact that, as discussed earlier, infants vocalized very little over the five minutes, see Table 10. Due to this, the greatest probability of movement and vocalizations were for sitting unsupported (1200 instances, $p = 0.0064$) and centered head (289

instances, $p = 0.0013$). Lagged transitional probabilities by two seconds followed relatively the same pattern as the concurrent transitions. With this, the greatest probability of movement two seconds prior to vocalization were for sitting unsupported (1202 instances, $p = 0.0064$) and centered head (276 instances, $p = 0.0012$). See Table 15 full transitional probabilities and Table 16 for lagged transitional probabilities.

In order to better understand these temporal relations between movement and the onset of vocalizations, an exploratory analysis where six second time windows were identified around the onset of a vocalization: three seconds prior to the onset of a vocalization, and three seconds following the onset of a vocalization. This was completed to identify prominent body movements that are leading up to and following vocalizations and was calculated across all 1,762 vocalizations recorded. In the three seconds leading up to a vocalization, infants were most frequently in an unsupported seated position ($n = 8,263$) and most frequently turned their head to the center ($n = 1,595$). Looking at the immediate one second prior to the onset of a vocalization, infants most frequently turned their head to the center ($n = 966$), followed by nodding their head down ($n = 733$). In the three seconds following the onset of a vocalization, changes in movement decreased. In the three seconds following the onset of a vocalization, infants were still most frequently in an unsupported seated position ($n = 214$), and if they did move within that three second period of the onset, the greatest change was turning their heads to the center ($n = 43$) and nodding their heads up ($n = 26$). Addressing changes in movement following the offset of a vocalization (when the infant finished their vocalization), infants were still most likely to be in a seated position ($n = 8,244$), turning their head to the center ($n = 1,624$) and nodding their heads down ($n = 1,244$).

To address the second part of research question two of how movement variability related to overall language development, the temporal relation between movement variability and vocal production was tested. A stepwise multiple logistic regression was tested using each individual movement to predict concurrent vocalization as well as vocalization following movements two seconds prior. For the concurrent movement and vocalization findings, based on the likelihood ratio X^2 test, variables at each step were found to significantly contribute to the prediction of vocalization. As reported in Table 17, there were a number of significant predictors of concurrent vocalization. A combination of head, trunk, and postural movements each predicted concurrent vocalization. A total of eight movements were significant predictors of vocalization, with the greatest predictor of each of these being the head movement of shaking back and forth, with a log odds increase of 1.45 to concurrent vocalization ($b = 1.45, p = 0.004$). See Table 17 for full findings.

Addressing the movements predicting vocalization two seconds later, based on the likelihood ratio X^2 test, variables at the step of contributing trunk movements were not found to contribute significantly to the lagged prediction of vocalization and were only fit to the steps of contributing head and postural movements. As reported in Table 18, a total of three movements significantly contributed to vocalization two seconds after the movements. Of these, being in a supine position was the greatest predictor with a log odds increase of 0.68 to vocalization ($b = 0.68, p = 0.01$). See Table 18 for full findings. Additionally, Figures 5 and 6 display odds ratio forest plots for vocalizations and lagged vocalizations by each movement.

Research Question 3: Movement Variability and Attentional States

Infants overall spent the greatest amount of time in supported joint engagement (38%), followed by solo object play (36%), and then coordinated joint engagement (16%). See Table 20

for full infant engagement states proportions. However, addressing the average duration spent in each engagement state, the greatest average duration was for solo object play, with a mean duration of 13 seconds ($M = 13.06$, $SD = 13.10$), followed very closely by supported joint engagement with an average duration of 12.6 seconds ($M = 12.61$, $SD = 12.39$), and then social engagement with an average duration of 9 seconds ($M = 9.20$, $SD = 7.40$). See Tables 19 and 20 for descriptives on duration and proportion of time spent in infant engagement states.

To address the third research question of how infant movement related to infant engagement states, a series of linear regressions, transitional probabilities, and multiple logistic regressions were performed. First, linear regression analyses between each infant engagement state and movement variability (using Shannon Entropy) were performed while controlling for age. Both social engagement ($b = 8.89$, $t = 3.74$, $p < 0.001$) and the unengaged state ($b = 2.91$, $t = 3.42$, $p = 0.001$) were significantly predicted by movement variability (see Figure 7). The linear regression between supported joint engagement and movement variability approached significance ($b = 5.42$, $t = 1.78$, $p = 0.079$; see Figure 8). As an exploratory analysis, linear regressions were run between each infant engagement state and individual body segment movements. No significant results emerged, (see Table 21 for full regression findings).

The question of the temporal relations between attention and movement asked in research question three, transitional probabilities were calculated between types of movement and infant engagement states. All probabilities of events overlapping were very small, as we were measuring 23 individual movements across six engagement states. The highest transitional probability was for sitting unsupported transitioning into supported joint engagement ($p = 0.019$). This was followed by the transitional probability of sitting unsupported transitioning into solo object play ($p = 0.016$) and then sitting unsupported transitioning into coordinated joint

engagement ($p = 0.0088$). In coordinated joint engagement, the highest non-postural transition was nodding down ($p = 0.001$). In supported joint engagement, the highest non-postural transition was centering head ($p = 0.0024$). In solo object play, the highest non-postural transition was also centering head ($p = 0.0023$). social engagement, onlooking, and unengaged had the lowest amount of time spent in them, and therefore, the least amount of transitions within. All three engagement states followed the same pattern as above, where the greatest postural transition was sitting unsupported followed by centering head. See Table 15 for full transitional probabilities.

Looking at the transitional probabilities with a two second lag on infant movement predicting engagement state two seconds later, little changed overall. The highest transitional probabilities remained as sitting unsupported transitioning into supported joint engagement ($p = 0.019$). This was followed by the transitional probability of sitting unsupported transitioning into solo object play ($p = 0.016$) and then sitting unsupported transitioning into coordinated joint engagement ($p = 0.0088$). The number of instances changed marginally, and not significantly enough to change the probability of these events (see Tables 15 and 16 for comparative values). In coordinated joint engagement, the highest non-postural transition changed from nodding down to centering head ($p = 0.0088$). In supported joint engagement, the highest non-postural transition remained centering head ($p = 0.0024$). In solo object play, similarly the highest non-postural transition remained centering head ($p = 0.0024$). As for the previous transitional probabilities, the engagement states of social engagement, onlooking, and unengaged had the lowest amount of time spent in them, and the least amount of transitions within. These engagement states followed the same pattern as above where the greatest postural transition was sitting unsupported followed

by centering one's head to be the next greatest transitional probability. See Table 16 for lagged transitional probabilities.

To address research question three predictively and sequentially, the temporal relation between movement variability and each infant engagement state was tested. Stepwise multiple logistic regressions were tested using each individual movement to predict concurrent engagement state as well as engagement states following movements two seconds prior. Each engagement state is reported as concurrent and lagged results in descending order from most complex form of attention to least (e.g. most: coordinated joint engagement, least: unengaged). Findings for the engagement states of social engagement, onlooking, and unengaged can be found in Tables 28 - 33 and Figures 15 - 20 and will not be discussed in the text as they do not pertain specifically to research question three, but were still analyzed.

As reported in Table 22 and from the likelihood ratio X^2 test, variables at each step were significant contributors to the prediction of concurrently being in coordinated joint engagement. Eleven different movements across all three body segments were found to significantly predict being in coordinated joint engagement. Many of these movements were found to positively predict being in coordinated joint engagement, such as walking unsupported ($b = 0.82, p = 0.003$) and nodding down ($b = 1.31, p < 0.001$), while others were found to negatively predict being in coordinated joint engagement, such as walking supported ($b = -0.79, p = 0.05$) and rocking one's torso back and forth ($b = -0.51, p < 0.001$).

Addressing the lagged movements predicting coordinated joint engagement two seconds later, eleven different movements across all three body segments were found to significantly contribute to the prediction of being in coordinated joint engagement. As reported in Table 23, standing unsupported was found to be the greatest postural predictor two seconds prior with a log

odds increase of 1.13 ($b = 1.13, p < 0.001$), while nodding up was the greatest head movement predicting being in coordinated joint engagement ($b = 1.56, p < 0.001$). See Tables 22 and 23 for full findings on coordinated joint engagement and lagged coordinated joint engagement. Additionally, Figures 9 and 10 display odds ratio forest plots for coordinated joint engagement and lagged coordinated joint engagement by each movement.

Moving into supported joint engagement, as reported in Table 24 and from the likelihood ratio X^2 test, variables at each step were significant contributors to the prediction of concurrently being in supported joint engagement. A total of fourteen different movements were found to be predictive of concurrently being in supported joint engagement. The majority of these findings were movements positively predicting being in supported joint engagement, such as walking supported, which had a log odds increase of 1.11 to supported joint engagement ($b = 1.11, p < 0.001$). Of movements that significantly decreased the likelihood of being in supported joint engagement, nodding down was found to have a log odds decrease of -0.47 to supported joint engagement ($b = -0.47, p < 0.001$).

The lagged movements predicting supported joint engagement two seconds later, found based on the likelihood ratio X^2 test, variables at the step of trunk movements were found not to significantly contribute to the prediction of supported joint engagement, and were only fit to the steps of contributing head and postural movements. As reported in Table 25, thirteen movements across the head and postural movements were found to significantly predict supported joint engagement two seconds later. The postures were overall found to positively predict supported joint engagement two seconds later, while head movements were found to decrease the likelihood of being in supported joint engagement two seconds later. walking supported was found to be the greatest positive predictor of supported joint engagement with a log odds

increase of 1.09 ($b = 1.09, p < 0.001$). Conversely, nodding up was found to significantly decrease the likelihood of being in supported joint engagement with a log odds decrease of -0.67 ($b = -0.67, p < 0.001$). See Tables 24 and 25 for full findings on supported joint engagement and lagged supported joint engagement. Additionally, Figures 11 and 12 display odds ratio forest plots for supported joint engagement and lagged supported joint engagement by each Movement.

Based on the likelihood ratio X^2 test, variables at all steps were found to be significant contributors to the prediction of concurrent solo object play. As reported in Table 26, twelve movements were found to significantly predict being in solo object play. All postural movements were found to be significant predictors of being in solo object play, while only nodding up and down were found to be predictive across all head and torso movements. Being in a prone position was found to be the greatest predictor of being in solo object play, with a log odds increase of 1.87 ($b = 1.87, p < 0.001$), followed by crawling with a log odds increase of 1.74 ($b = 1.74, p < 0.001$). Both nodding up and down were found to decrease the likelihood of being in solo object play with a log odd decrease of -0.34 for nodding up ($b = -0.34, p < 0.001$), and a log odds decrease of -0.59 for nodding down to being in solo object play ($b = -0.59, p < 0.001$).

For the lagged movements into solo object play, as reported in Table 27 and based on the likelihood ratio X^2 test, variables at the step of torso movements did not significantly contribute to the prediction of being in solo object play two seconds later, and were only fit to the steps of contributing head and postural movements. Across the head and postural movements, fourteen movements were found to be significantly predictive of being in solo object play two seconds later. Nearly all postural movements were found to positively predict being in solo object play, except for the position of supine, which significantly decreased the likelihood of being in solo object play two seconds later. nodding up and nodding down were still found to decrease the

likelihood of being in solo object play while centering one's head and turning one's head to the right were both found to positively predict being in solo object play two seconds later. Of postural movements, prone was the greatest predictor of being in solo object play two seconds later with a log odds increase of 1.89 ($b = 1.89, p < 0.001$), followed by crawling with a log odds increase of 1.73 ($b = 1.73, p < 0.001$). nodding up contributed a log odds decrease of -0.48 ($b = -0.48, p < 0.001$) to being in solo object play while turning one's head to the right found a log odds increase of 0.19 ($b = 0.19, p = 0.02$). See Tables 26 and 27 for full findings on solo object play and lagged solo object play. Additionally, Figures 13 and 14 display odds ratio forest plots for solo object play and lagged solo object play by each movement.

CHAPTER 4

DISCUSSION

This study explored the relation between attentional processes, language outcomes, and motor behavior in the second year of life. Through three primary research questions and hypotheses, a number of unknowns about these relations were answered. First, there was a significant interaction effect of age and play setting on movement variability; however, no main effect of age itself on movement variability was observed. Second, there was no significant relation between vocabulary outcomes and movement variability, although individual movements did predict vocal production. Finally, movement variability was found to be related to specific infant engagement states and there were many predictive findings between movement variability and various infant engagement states. Each hypothesis is discussed more fully below.

Research Question One: Age Changes in Movement Variability

The first research question investigated whether movement variability differed between ages. It was hypothesized that movement variability would significantly differ between age groups, with older age groups showing greater variability in movement. This hypothesis was partially supported, as there was a significant main effect of play setting on movement variability and a marginally significant main effect of age on movement variability. These main effects were qualified by a significant interaction between age and play setting on movement variability. Within this sample, movement variability was found to be context dependent; between the

structured and natural play settings, infants differed greatly in their movements. However, with each age group increase, movement variability became more similar across the two contexts (see Figure 1), with 12-month-olds' motor behaviors looking very different between the play settings, while the 18- and 24-month-olds looked more similar across the play settings.

The ways in which infants move their bodies are influenced by the play settings they are in, but also potentially by the type of play they are engaging in. The interaction effect between age and play setting may suggest that infants are moving differently in the two environments due to what is in the environments. This could potentially be related to the standardization of instructions in the structured play, that all infants and their caregivers were asked to sit on the mat and play with a given set of toys. This could have potentially limited the changes in movement the infants could have made compared to free play in any area of the home. Even so, the interaction between age and play setting on movement variability may also be affected by how the infants are engaging with the items in each environment (Soska et al., 2010). Twelve-month-olds had the greatest differences between settings, and with each subsequent increase in age, movement variability became more similar across the settings. In the structured play, the 12- and 18-month-olds may have let caregivers drive the interaction with novel items and followed their lead compared to 24-month-olds who may have taken more of a leading role in the interaction. Further research should seek to elucidate the discrepancies between the play settings, such as using familiar toys during a structured play task or integrating novel toys into the familiar (naturalistic) environment.

Research Question Two: Movement Variability and Language Development

Research question two sought to answer whether movement variability relates to aspects of overall language development. It was hypothesized that while controlling for age, movement

variability would positively predict overall vocabulary knowledge, and that certain body movements would be related to greater instances of vocal production during the play sessions. This hypothesis was tested in a number of different ways, and through a variety of analyses, was partially supported.

Movement Variability and Vocabulary Knowledge

The first part of this hypothesis was not supported; movement variability was not related to overall expressive vocabulary outcomes in this sample. Previous studies examining infant movement and language outcomes also used the same language outcome measure of the M-BCDI; however, the ways in which movement has previously been measured and operationalized are different from the present study (Slone et al., 2019; Schroer & Yu, 2021; Schroer & Yu, 2023). Additionally, prior research has looked at more than just how movement impacts language and has focused more on manual action and object interaction from the perspective of motor behavior. Previous studies also employed object labeling events, where an infant and caregiver are interacting with an object and the caregiver provides the name of or label for the object that is in the interaction (Schroer & Yu, 2023), which was not a part of the methods in the present study. The present study's methods only looked at changes in whole body movement. The null findings of the current study might change if only one of the play settings over the other were to be evaluated or if movement were examined over a longer period of time than the five minutes that were used in the present study. As reported previously, the current study found age related differences when looking at movement variability across the two play settings. One possible explanation for the lack of vocabulary-related findings in our sample may be that movement needs to be studied within the context of activities that are known to be related to language and vocabulary outcomes such as object labeling events, manual action, and object

interaction, as opposed to looking at a more global relation between movement and language outcomes (Schroer & Yu, 2023; Slone et al., 2019).

Whole-Body Movement and Vocal Production

In exploration of the relation between whole-body movement and vocal production, individual movements were evaluated both concurrently and lagged two seconds prior to vocalization using transitional probabilities. For the concurrent relation, it was found that the greatest probability of movement co-occurring with a vocalization took place when infants were sitting unsupported. This is consistent with previous literature that has evaluated infant vocal production during locomotor transitions; Berger and colleagues (2017) found that infants were less likely to vocalize as novice walkers and crawlers compared to infants who had prior experience with these locomotor milestones. With the second year being a primary transition period for advancing locomotion and beginning to learn to walk, the finding that infants are vocalizing most in a mastered, unsupported seated position is consistent with the previous literature. Additional support for this interpretation comes from the next two greatest likelihood probabilities of vocalization co-occurring with standing unsupported and walking unsupported. The mastery of various positional and locomotor abilities allows infants to devote more attentional resources to other cognitive processes such as verbal communication.

Infants were also more likely to turn their heads back to the center across all head and trunk movements while vocalizing. Orienting oneself back to the center can be interpreted as a variety of different things, such as orienting oneself to another person or centering one's body at the midline during play. Infants are most stable with their head and trunk at the midline, so if infants are engaging in both object play and either sustained or joint attention, attentional processes are likely strongest at the midline (Bambach et al., 2016). As the play sessions were

dyadic in nature and communication is social in nature (Fogel, 1992), infants changing their head position during or leading up to a vocalization may indicate that they were reorienting to an object or a person for the vocalization; this question could be addressed through additional coding in future studies. It has been conceptualized in the embodied cognition literature that movement takes attentional resources, and while developing new motor skills, those resources go to maintaining stability and body position rather than other cognitive processes, such as vocalizations (Berger et al., 2017; 2018). Mastery of these motor behaviors can create opportunities to utilize different cognitive skills when much less of the focus is on maintaining posture and stability.

Predictive Concurrent Findings of Whole-Body Movement and Vocal Production

Whole-body movements were categorized into three domains: postural changes, head movements, and trunk movements. A number of whole-body movements were predictive of vocalization using multiple logistic regressions. First, looking at just postural changes, supine and prone were the only significant predictors of vocalization (see Table 17 and Figure 5). Supine was not a common position for infants to be in during the play sessions, but while infants were in a supine position, data indicated that vocalization was likely. For the domain of head and trunk movements, shaking one's head and nodding were significant predictors of a vocalization as well. As mentioned before, vocal production is social in nature, and these head movements may indicate that infants were using gestural communication in addition to verbal communication (Iverson & Fagan, 2004). This could provide evidence for the development of the gesture speech system that emerges early in infancy, and which becomes more complex as infants increase in motor and verbal abilities (Iverson & Fagan, 2004). Finally, in the domain of trunk movements, turning one's torso to the left or right was predictive of the onset of a

vocalization. This may be more evidence of using one's body as a mode of gestural communication in tandem with verbal communication, and progressing the gesture speech system, although additional coding would be needed to confirm this interpretation. The integration of motor and vocal behaviors is important into adulthood as the gesture-speech system as well as facial affect are important to social communication and social learning (Iverson & Fagan, 2004). Development of these complex abilities starts in infancy, and is an important facet of how infants coordinate communication in their developing world and systems.

Predictive Lagged Findings of Whole-Body Movement and Vocal Production

Looking at the two seconds prior to vocalization, being in a prone position was a significant negative predictor of vocalization. Similar to Berger and colleagues (2017), infants very rarely were in a prone position. However, those who were in a prone position vocalized less. This may be due to what infants were doing (or not doing) in this prone position, and that they were not physically in a position to have an opportunity to vocalize. Additionally, of the head and trunk positions, only nodding up two seconds prior to the onset of a vocalization was predictive of the future vocalization. One possible interpretation of this orientational head movement is that potentially, infants were looking up two seconds prior to vocalizing to orient to an object or the other individual in the dyadic play session. Coordinating movement and vocalization means that infants may be using their bodies to reference things in their environment. Looking left and right, or turning one's head and torso, may be movements that infants use to guide their social partner to what they want or are attending to. As infant's recognizability of speech increases with age, gestures and body movements become increasingly important to successful communication of wants and needs for infants to their caregivers and social partners. The use of coding for whole-body movement and orientations of position has the

potential to enhance future studies exploring the relation between gesture and speech, as not all nonverbal gestures are coordinated only by limb movement. Looking at the whole body and the ways in which infants orient their bodies may give insight into how preverbal infants use their bodies to communicate with caregivers and social partners.

Research Question Three: Movement Variability and Attentional Processes

Research question three asked how moment-to-moment changes in infant movement related to future infant engagement states. It was hypothesized that particular movements would be predictive of infants being in different engagement states. Through a series of analyses, this hypothesis was supported.

There was a positive relation between movement variability and social engagement. Social engagement is largely communicative, and so having greater variability and complexity in movement may open more opportunities for greater instances of communication, compared to other forms of engagement that are characterized by focused or joint attention. This finding is similar to the significant relation between movement variability and vocal production in research question 2. This presents a unique developmental cascade (Masten & Cicchetti, 2010) between infant movement, attentional states, and language where promoting a variety of movements may strengthen not only their motor skills, but attentional and social capabilities as well.

Movement variability was also found to be related to the engagement state of unengaged. Across the entire sample, only six infants were in an unengaged state at any point in time, however, these infants had higher entropy values of movement variability. One possible explanation for this finding comes from evidence from the physical therapy literature. Not only too little, but also too much movement has been found to have a negative impact on other developmental outcomes (Dusing, 2016). The state of unengaged is where an infant is passively

observing the environment without engaging with anyone or anything. Unengaged is less than even a simple form of attention, it is where the infant is exhibiting no specific focused or sustained attention at all. As suggested in the physical therapy literature, it may be that some of the infants high in movement variability could be moving their bodies more out of lack of motor control rather than an increasing complexity in movements that make up the greater variability. A deeper qualitative look into what types of movements these infants were engaging in would provide further evidence to evaluate this interpretation.

The relation between supported joint engagement (which is a complex form of attention) and movement variability was found to approach significance. This could potentially suggest that the relation between movement variability and complex forms of attention may start to emerge at the end of the second year and continue to develop into toddlerhood. The fact that the relation between supported joint engagement and movement variability approached significance may be due to supported joint engagement not being fully joint attention nor focused attention. Joint interactions are dynamic, which may encourage a wider variety of movements compared to a more focused attentional state. Because supported joint engagement is not a full joint interaction nor solo focused attention, the finding approaching significance may be indicative of how infants are moving their bodies related to the emerging joint attention capabilities.

This motor-attention coordination, at the whole-body movement level, was not found in the full triadic interaction of coordinated joint engagement. A possible explanation for these results could be delineated by how movement variability was measured using entropy. As stated previously, Shannon Entropy (H) is used as a measure of how predictable an individual's movement is, where high entropy indicates greater variability across all types of measured body movements, while lower entropy indicated less variability across movements. However, when

addressing the engagement states and what may be required to be in specific engagement states, repetitive movements may be more characteristic of some engagement states, such as coordinated joint engagement. The triadic interaction in coordinated joint engagement is distinguished by the infant looking to the caregiver, then to the object, and back to the caregiver. These repetitive head movements may potentially drive down the entropy score, indicating a higher frequency of fewer types of movements. Which movements are affording certain opportunities for engaging in specific attentional states may be dependent on the operational definition of each engagement state.

Whole-Body Movement and Engagement States

Certain movements occurred concurrently or prior to each engagement state. Most of the engagement states followed similar patterns to each other as demonstrated by the transitional probabilities. Sitting unsupported was the most common body position to transition into each engagement state concurrently as well as two seconds prior. This was not surprising, as the development of independent sitting starts earlier than 12 months, so infants by their second year of life should have a fair amount of experience sitting upright on their own.

For most of the engagement states, the highest probability body movement was centering head. This differed for coordinated joint engagement which most commonly occurred with nodding down. Coordinated joint engagement is defined as where the dyad shares attention on an object and each other by coordinating eye gaze to each other and the object/event (Bakeman and Adamson, 1984). This triadic interaction going between the infant, social partner, and an object requires head control and the ability to use head movements to coordinate visual attention and eye gaze from the social partner to the object, and back to the social partner. The use of nodding down could be a signifier of this coordination between movement and attention, where the infant

is looking from their caregiver to the object and back to the caregiver. The transitional probabilities with a two second lag were largely similar to the concurrent findings. The majority of transitions stayed the same with one notable change being again in coordinated joint engagement. Two seconds prior to coordinated joint engagement, the greatest non-postural movement transitional probability was centering one's head, as compared to the concurrent finding of nodding down. Again, along the same lines of what coordinated joint engagement is defined as, the centering of one's head is likely related to engaging with the social partner and/or object on the other side of the interaction.

Predictive Concurrent and Lagged Findings of Whole-Body Movement and Infant Engagement States

Overall, combinations of certain movements were found to be predictive of engagement states, sometimes increasing the likelihood and sometimes decreasing the likelihood of being in each state. This is the case for findings both assessed concurrently and with a lag (see Tables 34 and 35). These unique combinations of movements that are indicative of being in different engagement states largely fit with how each engagement state is defined. For example, while in coordinated joint engagement, the postural movements of sitting, standing, and walking unsupported were found to increase the likelihood of infants being in coordinated joint engagement. One possible explanation for this relation is more complex locomotive movement is positively coordinated with more complex forms of attention. Additionally, complex head and trunk movements were also positive predictors of being in coordinated joint engagement, such as the torso movement of rocking and the head movements of shake, nodding up, and nodding down.

Movements were not mutually exclusive, and so infants could be moving their heads, torsos, and/or changing position at the same time. Rocking back-and-forth is mainly expressed

through infants reaching for objects from several different postures. Infants are able to propel their torsos forward while reaching for an object. However, this developmental ability has frequently been tied to the development of sitting, and trading stability to reach for an object (Berger et al., 2018; Harbourne et al., 2013). Looking at the two seconds prior to coordinated joint engagement, the lagged findings are largely similar to the concurrent findings, providing support that the specific combination of movements are related to this specific engagement state (see Tables 34 and 35).

Similarly, supported joint engagement found significant predictive relations between head, trunk, and postural movements. While all the postural movements were found to significantly increase the likelihood of being in supported joint engagement, head movements predicted decreasing the likelihood of being in supportive joint engagement. Understanding what movements are representative of being in each engagement state tells a great deal about what attentional skills are required for being in such attentional states. Infants in supported joint engagement are not fully acknowledging the social partner's presence in the interaction. Moving one's head overall was found to decrease the likelihood of being in supported joint engagement possibly because head movements are not required for the interaction (see Table 34). This could be compared to coordinated joint engagement, where the triadic interaction between infant, the object, and the social partner are all important to the interaction and characterized by the infants' eye contact with their social partner and the object. The use of nodding up and down, nodding, and shaking one's heads are all movements that indicate that the infant is responding to and acknowledging their caregiver in that interaction. As noted with coordinated joint engagement, the lagged predictions to supported joint engagement remain largely the same as the concurrent findings (see Table 35).

All postural movements except for supine were found to increase the likelihood of being in solo object play. In addition to supine, both nodding up and nodding down were also found to decrease the likelihood of being in solo object play. Solo object play is characterized by focused attention, an interaction only between the infant and an object. While complex postural movements were found to increase the likelihood of being in solo object play, less complex postural movements, such as prone and crawling, were actually stronger predictors of this relation. A possible explanation for these findings is that there is a wider variety of ways of being in solo object play; infants likely don't have to be in a specific postural position to be engaged solely with an object. This potentially opens a wider variety of opportunities to engage in solo object play. However, when comparing solo object play to supported and coordinated joint engagement, the opportunities to be in supported or coordinated joint engagement tighten as there are more requirements to meet to be in these engagement states as supported and coordinated joint engagement are contingent on another person in the interaction (coordinated more so than supported).

In contrast to the lagged findings discussed previously, the two seconds prior to solo object play may play a different but important role in terms of which movements best set up solo object play. The orientational head movements (left, right, and center) were found to significantly increase the likelihood of being in solo object play two seconds later. A possible explanation for this could be that prior to being in solo object play, infants could have been exiting a previous engagement state, potentially transitioning from a more complex form of attention to solo object play, which is largely individual focused attention. Another possibility could be that infants were surveying their visual field, looking for what to engage with next. Further coding could help to clarify these possibilities.

By the second year of life, infant movement is more deliberate as infants begin to move and locomote in ways that aid in exploration and social learning and development (Kretch et al., 2014; 2022). These deliberate movements may potentially aid in the understanding of what movements are most useful for engaging in both more simple forms of attention, such as sustained attention, as well as complex forms of attention, such as joint attention, which are both important parts of attentional processes in the second year of life (Bakeman & Adamson, 1984; Yu & Smith, 2012). As infants expand their motor capabilities, they can better use their bodies to respond to cues from caregivers and social partners. As a result, infants are able to use these complex motor skills to engage in more complex forms of attention and sustain their attention for greater amounts of time.

A Developmental Cascades Interpretation of Movement Variability

The development of different cognitive domains, such as language and attention, is not exclusive from each other nor from other areas of development, such as motor development. The framework of developmental cascades can be implemented to explain the substantial interplay between several developmental processes. Developmental cascades are a series of unidirectional and bidirectional processes of developmental behaviors and events that are cumulative in nature, and that shape and drive future developmental choices, events, and milestones (Oakes & Rakison, 2019). Cascades are the collective consequences for development of the interactions and transactions happening in a developing system. The effects of such interactions and transactions across levels, domains, and even different systems can have both unidirectional and bidirectional cascading effects, resulting in direct and indirect pathways to alter the course of human development (Masten & Cicchetti, 2010). Understanding the interplay between domains

of development can identify developmental “tipping points” leading to potential positive and negative cascading effects in development.

In the current study, the unique combinations of body movements that were found to be predictive of each engagement state as well as vocal production point to how whole-body movements contribute to the development of motor and cognitive abilities within language and attention. The developmental cascades framework is helpful for examining the importance of whole-body movements as they relate to different attentional processes as well as vocal production.

These findings help to demonstrate the unique dynamics that are at play during different attentional states and in language development. The predictive findings in this study expand on previous research (Borjon et al., 2021) that head movements and the development of head stabilization are important to the development of complex attentional skills. Both postural control and head stabilization in infancy are connected to the domains of both language and attention. Expanding upon work from both Berger and colleagues (2017) and Iverson and Fagan (2004), the use of complex movements and locomotor skills are linked to vocal production and are predictive of when infants vocalize.

These distinctive processes of developing complex language and attentional skills may be bidirectionally related to motor development during infancy, providing potential building blocks across domains. While there are aspects of each domain that are mutually exclusive, the established links between attention, language, and whole-body movement show interconnections of how movement can lead to vocal production and engaging in various attentional processes.

The role that movement plays in vocalization may largely be related to attention. The development of complex movements and locomotor behaviors may allow for infants to spend

less attentional resources on movement itself and be able to engage in vocal production to verbally communicate their thoughts, wants, and needs. The current study found age-related increases in speech recognizability, which is supported by Borjon and colleagues (2024), who previously established the development of oral-motor skills used to articulate speech. This allows for speech to become increasingly recognizable. As infants develop specific motor abilities, for example oral-motor development, language and motor development are coupled, demonstrating their interdependent processes (Borjon et al., 2024).

While spending less attentional resources on the movement pieces, infants are able to communicate in increasingly complex ways with caregivers and social partners. This may include multimodal communication components such as combining movements, with vocal production, and visual attention leading to a combination of all three domains of development. Promoting infant whole-body movement encourages cascading effects that can have positive impacts both physically and cognitively through transactions with language, communication, attentional skills, and a combination of the three where they are able to engage with a social partner effectively.

Limitations

While the requirements of the PLAY project were that all infants were typically developing with no noted differences regarding birthing problems, hearing, vision, cognition or other developmental issues, this research may be more beneficial and well suited for a developmentally diverse population of infants. Much of the literature within the realm of developmental psychology has addressed similar questions to this in only typically developing populations (e.g., Thelen, 1979; Iverson & Fagan, 2004; Slone et al., 2019). While this allows us to have a deeper understanding about normative developmental trajectories within the domains

of motor and cognitive development, the need to understand these processes from a developmental cascade (Masten & Cicchetti, 2010) perspective can aid in the identification of developmental tipping points that may lead to delay or early identification of neurodevelopmental disorders.

It would be remiss not to address sampling considerations related to the participants in our study. The large majority of our sample was white, highly educated mothers, who all spoke English. The sample of dyads that was collected was doubly noteworthy in the way that they welcomed researchers into their homes for multi-hour video recorded home visits where the dyad were the only individuals present in the home. It is important to take into account the willingness, trust, and understanding of an individual to welcome a researcher into one's space and video record all aspects of an individual's home, especially with an infant. Additionally, having the resources to be able to accommodate a multi-hour home visit with no one else present in the home is another factor that may play into the sample that was gathered. These sample characteristics could be expected to affect the generalizability of the results, and further examination of the links between motor development, attention and language in a more diverse population would be beneficial.

Future Research

Each of the research questions posed in this study was aimed at addressing how movement variability was related to the domains of attention and language. Future research should address the relation of all three in tandem, as to how motor behavior, attention, and language impact one another in the same analyses. One possible way to do this is using perievent time histograms, which are histograms that specify the number of co-occurring target events that happen around the “trigger” or onset of an event, such as the onset of a vocalization (Blumberg

et al., 2013). Perievent time histograms could be created to demonstrate the time-related coupling between movement and infant attention. Using methods from Blumberg et al. (2013), each event histogram would indicate the total frequency of the target event, the movement that co-occurred with the trigger event, and the engagement state, within a 50ms bin around the trigger. This would allow for a quantitative analysis of what is happening moment-to-moment within an individual infant's motor and attentional behaviors during the play sessions.

An important area for future research is to understand lagged and leading effects at the within-person level. As noted in the methods, there is not currently a consistent lag or lead time across developmental literature; further, the majority of the research using these tools is looking at *interpersonal* synchrony (synchrony between two or more people; Somers et al., 2022; Northrup & Iverson, 2020; Margolis et al., 2019; Dowd & Tronick, 1986; Tronick et al., 1980). However, the need to understand these coordinated systems calls for the use of *intrapersonal* synchrony to identify behaviors and cognitions that precede one another in the same individual. For example, Bloch and colleagues (2019) addressed intrapersonal synchrony and dissynchrony of interactions in a population of children with autism spectrum disorder (ASD). Researchers posited that it may not be the quantity of signals (communicative gestures) that lead some children with ASD to communication difficulties, rather that the quality of the signal from the communicative gesture may not fit into the interactional flow (intrapersonally), leading to difficulties with communication. More work into understanding intrapersonal synchrony and the implications of the coordination between movement, attention, and language is needed. This can aid in the development of methods to measure intrapersonal synchrony across other domains of cognition and areas of development.

Future research should explore an understanding of how these processes may alternately play out in developmentally diverse infants, such as those with ASD, motor, language, or cognitive delays, which may have critical impact on understanding developmental tipping points that happen during the infant period. Previous studies addressing developmentally diverse populations in the infancy period have used a developmental cascades framework to understand the interplay between different domains of development and outcomes (Iverson, 2021; Iverson et al., 2023; Heymann et al., 2018; Bradshaw et al., 2022). However, there has been no previous work addressing how whole-body movement impacts language and attentional development, nor in developmentally diverse, or elevated likelihood samples of infants. Therefore, a future direction would be to address the gap in knowledge of understanding how these coordinated systems impact one another as well as how they may play into early identification of neurodevelopmental disorders in infants and toddlers.

Additionally, sampling a population of individuals that are more representative of diverse characteristics across race, education, SES, geographic location, and parental sexual orientation, will allow for a more representative sample. This could allow for greater generalization of findings, which could ultimately be important for developing policies and practices that benefit a larger segment of the population.

Lastly, evaluating these variables over a greater time period may enhance the findings. To match the allotted time for the structured play event, natural play videos were trimmed to five-minute segments as well. Having longer observation periods for both the structured and natural play events would not only present the opportunity for greater observation period of each variable, but also allow for more opportunity to view a variety of different behaviors within the infants. Increasing the amount of time would aid in the understanding of typical daily movement

and activity of infants throughout the day, rather than the small snapshot of time the five-minute segments permitted.

Conclusion

Overall, this study's exploration into the relation between movement, attention, and language development in the second year of life revealed that infant movement variability was found to be age and context dependent with differences across the play settings where infants overall moved more in the natural play, but differences between play setting decreased with each subsequent age group. Infant movement variability was not found to be predictive of vocabulary outcomes; however, individual movements were found to be related to vocal production. Lastly, movement variability was found to be a significant predictor of social engagement, with the more important findings that individual head, trunk, and postural movements were individually and collectively predictive of being in various infant engagement states that were unique from one another (see Tables 34 and 35). The use of a developmental cascades framework allows for the identification of particular movements and attentional processes that are highly coordinated and impact one another, and that also coincide with the development of language and vocal production. These findings demonstrate that both whole-body movement and individual movements on a moment-to-moment basis are coordinated with attentional and language processes and are important to the development of one another. The results point to a number of important future directions, perhaps most importantly the need to examine these questions in both typically developing and developmentally diverse samples of infants.

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APPENDIX A

Movement Variability

Behavioral Coding Dictionary

General rules:

1. Download the Datavyu template for this project. This will ensure all of the columns are named the same.
2. Watch the video once fully through at full speed before even beginning to code for behaviors
3. Every video should be exactly 5 minutes long. If the video starts at 00.00.00, it should end at 05.00.00. If you start at 00.13.00, the video should end at 05.13.00.
4. Once you finish your video, watch it with cell highlighting to ensure accuracy before you save and upload your files.

Postural Codes:

	Movement	Description
Postures	Prone (Pr)	Laying on stomach
	Supine (Su)	Laying on back
	Sit (Si) • Supported (s) • Unsupported (u)	Seated on bottom
	Crawl/scoot (C)	Hands and knees or other form of propulsion forward
	Walk (Wa) • Supported (s) • Unsupported (u)	Upright propulsion forward on 2 feet
	Stand (St) • Supported (s) • Unsupported (u)	Upright on 2 feet
	Kneel (K)	Upright on both knees
	Unusable (X)	
Torso	Bounce (B)	Torso moves up and down.
	Rock / reach (R)	Singular back-and forth torso movement [can occur while reaching]

	Left turn (LT)	Torso twists toward left side of body (degree change of 45 or greater)
	Right turn (RT)	Torso twists toward right side of body (degree change of 45 or greater)
	Center torso (CT)	Torso twists from right/left back to center (degree change of 45 or greater)
Head	Roll side to side- shake (S)	Lateral rotation of head (similar to headshake).
	Roll front to back- nod (N) • Up (u) • Down (d)	Forward-backward movement (similar to head nod)
	Left turn (LH)	Head turns toward left side of body (degree change of 45 or greater)
	Right turn (RH)	Head turns toward right side of body (degree change of 45 or greater)
	Center head (CH)	Head turns from right/left back to center (degree change of 45 or greater)

Notes:

- Think about where center of pressure is for some positions
 - Prone: center of pressure is on stomach
 - Standing: center of pressure is in the feet
- Head rotation in the direction of the side of the body doesn't mean the head is always oriented to that side of the body (i.e. you can have a right head turn and the head still be on the left side of the body)
- Can have two head movements in the same direction in a row (ex. LH LH)
- For walking to go into standing, wait three seconds and if they do not take another step switch it into standing

Utterances

Anytime an infant makes a verbal noise- coo, babble, word, sound, etc set onset and when infant has completed making sound, set offset (duration). All noted as VOC in datavyu.

- Any communicative sounds
- If the sound is not communicative, then don't count it (ie. cough)

Infant engagement states

(u) **Unengaged:** passively observing the environment without engaging with anyone or anything. The infant does not appear to be engaged or occupied with any object or thing. If the infant is looking around the room but is not focusing on one thing, then still code “u.”

- Non-social, no communication (physically or verbally), not holding anything

(o) **Onlooking:** gazing over at an object, person, or event but not actively participating. If the mother is engaging with an object but the infant is not engaged but is just looking at her or the object then code “o”. The infant is simply observing with no role in interacting with the mother or object. Observing

- No reaching behaviors, no social or nonsocial communication

(p) **Solo Object Play:** playing, approaching, and engaging with an object on their own. The mother is not participating in the interaction. The infant is playing or exploring objects on their own.

- Baby’s attention is on an object they’re playing with and does not include mom or accept mom’s social bid to join.
- Think of baby and toy in their own world.
- If the mom is trying to join and the baby doesn’t accept/acknowledge the mom, keep the mindset of the baby’s point of view. (we will code for Mom separately.)

(e) **Social Engagement:** one-on-one interaction with just the mom and no objects. Does not have to include eye contact or talking, but can include those things.

- Mom is holding the baby and talking; no objects
- Typical face-to-face interaction

(s) **Supported joint engagement:** The infant interacting with an object with another person can be seen when the mother is scaffolding the infant’s attention of that object or event. The infant does not fully acknowledge the mother’s involvement in the object but interacts with an object the mother led to them. uses an object with the mother’s help but doesn’t look to or acknowledge the mom, and a significant part of the interaction

- The child and mother are actively involved with the same object or event, but the child is not actively acknowledging the mother’s participation.
- The child and mother are engaged with the same referent, and there is evidence that the child is actively attending to symbols, but the child is not explicitly attending to the mother; for example, the mother might be helping a child name and point letters on an alphabet book but not ever referencing mom.
- reaches or tries to reach for the object, proffered by the adult, or is physically directed by the adult

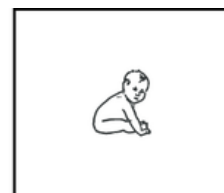
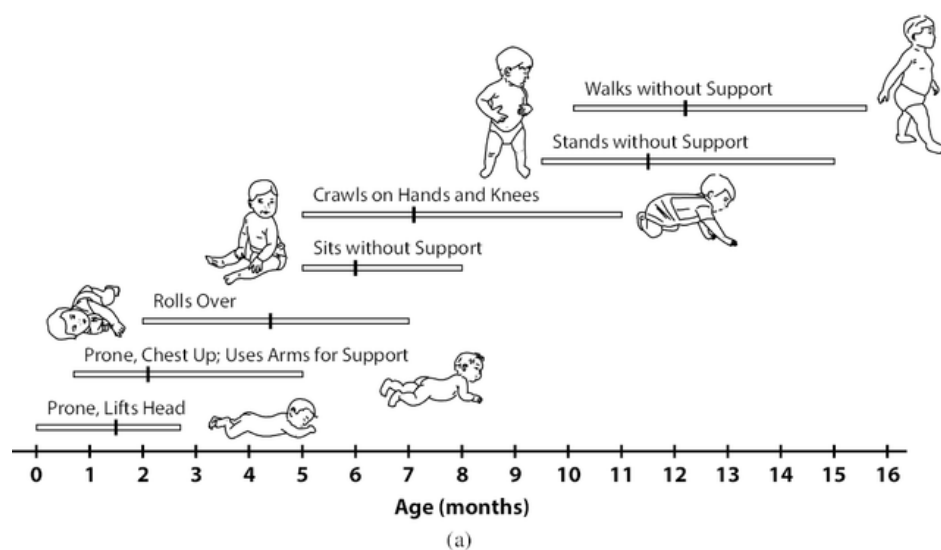
(c) **Coordinated joint engagement:** the dyad shares attention on the object and each other by coordinating eye gaze to each other and the object/event. The infant clearly demonstrates shared meaningful attention to both the mother and the object/event. Classic Joint Attention.

- the child is actively and repeatedly acknowledging the mother’s participation, likely by visually referencing the mother at critical points in the interaction

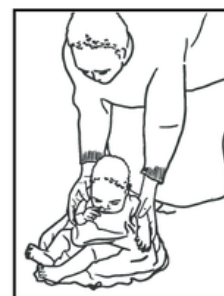
- Example: If the mom is helping a child name and point letters on an alphabet book, but the child is referencing mom by saying “Mom, your turn” or looking at mom
- Eye contact/looks at mom will be the biggest determinant of this.
- Dyad is acting in a coordinated manner; turn-taking (i.e., wobbling a toy back and forth, throwing a ball), conversational turn-taking involving words, gestures, or the meaningful imitation of sound.

(n) **Not usable:** child is fussy, or for some reason, we can’t use this portion, out of frame

APPENDIX B



(b)



(c)

APPENDIX C

TABLES AND FIGURES

Table 1.*Participant Demographic Characteristics*

Characteristic	<i>n</i>	%
Child Age		
12	11	35.5
18	10	32.2
24	10	32.3
Child Gender		
Female	13	41.9
Male	18	58.1
Mother Age		
20-29	1	3.2
30-39	27	87.1
40-49	3	9.7
Child Race		
White	27	87.1
More than one	3	9.7
Other	1	3.2
Child Ethnicity		
Hispanic or Latino	6	19.4
Non-Hispanic or Latino	25	80.6
Mother Race		
White	29	90.3
More than one	2	6.5
Other	1	3.2
Mother Ethnicity		
Hispanic or Latino	4	12.9
Non-Hispanic or Latino	27	87.1
Language Spoken		
English	28	90.3
English and Spanish	3	9.7
Highest level of education		
Some college	2	6.5
Bachelor's	5	16.1

Graduate or professional school but no degree	1	3.2
Master's	11	35.5
Professional degree after bachelor's (MD; DDS; JD, LLB; etc.)	2	6.5
Doctorate degree (PhD, EDd)	10	32.2
Employment Status		
Employed	29	93.5
Unemployed	2	6.5

Table 2.*Average Frequency of Movements by Child Age*

	Total Frequency		Head Movement		Trunk Movement		Postural Changes	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
12-months	134.6	38.0	85.5	26.4	33.7	10.4	15.5	10.2
18-months	143.3	25.1	89.9	17.8	37.4	7.9	16.0	13.4
24-months	150.3	37.8	103.0	32.5	35.7	10.6	11.6	10.1

Table 3.*Average Frequency of Movements by Child Age in Natural Play*

	Total Frequency		Head Movement		Trunk Movement		Postural Changes	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
12-months	164.1	25.3	101.6	21.8	38.6	8.7	23.8	6.3
18-months	154.7	29.8	96.5	19.7	35.0	10.3	23.2	14.9
24-months	159.6	31.6	106.4	27.9	34.2	11.7	19.0	7.8

Table 4.*Average Frequency of Movements by Child Age in Structured Play*

	Total Frequency		Head Movement		Trunk Movement		Postural Changes	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
12-months	105.2	22.0	69.3	20.4	28.7	9.9	7.2	5.0
18-months	131.9	12.3	83.3	13.5	39.7	3.7	8.8	6.3
24-months	141.0	42.8	99.0	37.8	37.2	9.8	4.2	5.8

Table 5.*Movement Variability, Age, and Condition ANOVA*

	<i>F</i> (1, 58)	<i>p</i>	η^2
Age	3.19	0.079	0.036
Condition	22.49	< 0.001***	0.25
Age x Condition	5.39	0.024*	0.061

Note. 0 '***' 0.001 '**' 0.01 '*'

Table 6.*Head Movement, Age, and Condition ANOVA*

	<i>F</i> (1, 58)	<i>p</i>	η^2
Age	5.38	0.024*	0.072
Condition	8.43	0.005**	0.11
Age x Condition	2.94	0.09	0.039

Note: 0 '****' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 7.*Trunk Movement, Age, and Condition ANOVA*

	<i>F</i> (1, 58)	<i>p</i>	η^2
Age	0.51	0.48	0.0081
Condition	0.18	0.67	0.0029
Age x Condition	5.04	0.029*	0.079

Note: 0 '****' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 8.*Postural Movement and Condition ANOVA*

	<i>F</i> (1, 58)	<i>p</i>	η^2
Condition	53.55	< 0.001***	0.47

Note. 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 9.*Frequency of Vocalizations by Age and Condition*

	Frequency of Vocalizations	Structured Play	Natural Play
Overall	1762	696	1066
12-months	350	76	274
18-months	556	178	378
24-months	856	414	442

Table 10.*Average Duration of Vocalizations by Age and Condition*

	Vocalization Duration (Seconds)		Structured Play		Natural Play	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Overall	1.2	0.9	1.1	0.9	1.3	1.0
12-months	1.4	1.5	1.0	1.6	1.5	1.4
18-months	1.1	0.8	1.1	0.8	1.1	0.8
24-months	1.2	0.7	1.2	0.7	1.2	0.7

Table 11.*Average Recognizability of Vocalizations by Age and Condition*

	Vocalization Recognizability		Structured Play		Natural Play	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Overall	0.6	0.7	0.6	0.7	0.6	0.6
12-months	0.1	0.2	0.1	0.3	0.1	0.2
18-months	0.7	0.6	0.6	0.6	0.7	0.8
24-months	1.1	0.7	1.1	0.9	1.0	0.5

Table 12.*M-BCDI Proportion Descriptives*

	<i>M</i>	<i>SD</i>	Range
Expressive Vocabulary			
12-months	2.7	1.5	1-5
18-months	10.4	4.6	5-20
24-months	49.6	25.8	11-93
Overall	20.3	25.3	1-93
Receptive Vocabulary	17.6	10.8	2-36

Table 13.*Expressive Language and Age ANOVA*

	<i>F</i> (2, 59)	<i>p</i>	η^2
Age	141.5	< 0.001***	0.83

Table 14.*Movement Variability and Expressive Language Regression*

	Estimate	SE	<i>t</i>	<i>p</i>
Intercept	-0.172	0.82	-0.21	0.84
Movement Variability	-0.34	0.23	-1.48	0.15
Age	0.21	0.012	16.62	< 0.001***

Note: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 15.*Transitional Probabilities*

Movements	Vocalizations	Coordinated Joint Engagement	Supported Joint Engagement	Solo Object Play	Social Engagement	Onlooking	Unengaged
Sitting Unsupported	0.006	0.009	0.02	0.02	0.0009	0.003	0.0002
Standing Unsupported	0.002	0.002	0.005	0.002	0.0003	0.0006	0.00001
Walking Unsupported	0.002	0.0007	0.001	0.001	0.0002	0.0003	0.00004
Sitting Supported	0.002	0.001	0.004	0.004	0.0009	0.0008	0.00004
Standing Supported	0.001	0.0006	0.0009	0.001	0.0004	0.0005	0.00002
Walking Supported	0.0002	0.00003	0.003	0.0003	0.00004	0.00	0.00
Supine	0.0003	0.00	0.0002	0.00008	0.00004	0.00005	0.00003
Prone	0.0002	0.00008	0.0001	0.001	0.0004	0.00001	0.00
Crawling	0.0006	0.00008	0.0003	0.002	0.0001	0.0002	0.00
Kneeling	0.001	0.0006	0.003	0.003	0.0002	0.0003	0.00001
Shake	0.00003	0.00002	0.00001	0.00	0.00	0.00	0.00
Rock	0.0009	0.0002	0.0009	0.0001	0.0001	0.0002	0.00003
Bounce	0.0001	0.00007	0.00008	0.002	0.00003	0.00	0.00
Nod	0.00003	0.00002	0.00002	0.00	0.00	0.00	0.00
Nod Up	0.001	0.0008	0.0008	0.001	0.0002	0.0003	0.00003
Nod Down	0.0009	0.001	0.0008	0.001	0.0002	0.0003	0.00002
Center Torso	0.0005	0.0002	0.0005	0.001	0.0001	0.0001	0.00
Left Torso	0.0003	0.0001	0.0003	0.0005	0.00008	0.00007	0.00001
Right Torso	0.0003	0.00009	0.0002	0.0005	0.00004	0.00007	0.00
Center Head	0.001	0.0007	0.002	0.002	0.0003	0.0004	0.00004
Left Head	0.0009	0.0005	0.0008	0.002	0.0003	0.0003	0.00004
Right Head	0.0007	0.0004	0.0007	0.001	0.0002	0.0003	0.00003

Table 16.*Lagged Transitional Probabilities*

Movements	Vocalizations	Coordinated Joint Engagement	Supported Joint Engagement	Solo Object Play	Social Engagement	Onlooking	Unengaged
Sitting Unsupported	0.006	0.009	0.019	0.016	0.0009	0.003	0.0001
Standing Unsupported	0.002	0.002	0.005	0.002	0.0003	0.0007	0.00
Walking Unsupported	0.002	0.0007	0.001	0.001	0.0002	0.0003	0.00005
Sitting Supported	0.002	0.001	0.004	0.004	0.0008	0.0008	0.00004
Standing Supported	0.001	0.0006	0.0009	0.001	0.0004	0.0005	0.00001
Walking Supported	0.0002	0.00003	0.0003	0.0003	0.00004	0.00	0.00
Supine	0.0003	0.00	0.0001	0.00009	0.0004	0.00005	0.00002
Prone	0.0002	0.00008	0.0002	0.001	0.00004	0.00	0.00001
Crawling	0.0006	0.00008	0.0003	0.001	0.0001	0.0002	0.00
Kneeling	0.001	0.0006	0.003	0.003	0.0002	0.003	0.00001
Shake	0.000009	0.00002	0.00001	0.00002	0.00	0.000004	0.00
Rock	0.0007	0.0002	0.0009	0.002	0.0001	0.0002	0.00002
Bounce	0.00008	0.00007	0.00008	0.0001	0.00003	0.000004	0.00
Nod	0.00003	0.00002	0.00002	0	0.00	0.00001	0.00
Nod Up	0.0009	0.0006	0.0008	0.001	0.0002	0.0003	0.00002
Nod Down	0.0009	0.001	0.0008	0.001	0.0001	0.0002	0.00002
Center Torso	0.0004	0.0002	0.0005	0.0009	0.0001	0.0001	0.00001
Left Torso	0.0003	0.0001	0.0003	0.0005	0.0001	0.00009	0.000009
Right Torso	0.0002	0.00009	0.0002	0.0004	0.00004	0.00007	0.000004
Center Head	0.006	0.009	0.019	0.016	0.0009	0.003	0.0001
Left Head	0.002	0.002	0.005	0.002	0.0003	0.0007	0.00
Right Head	0.002	0.0007	0.001	0.001	0.0002	0.0003	0.00005

Table 17.*Multiple Logistic Regression between Movement and Vocal Production*

	Estimate	Odds Ratio	SE	Wald's X^2	df	p
Intercept	-3.41	0.03	0.24			< 0.001***
Sitting Unsupported	-0.004	1.00	0.23	0.00	1	0.98
Standing Unsupported	-0.145	0.86	0.23	0.39	1	0.53
Walking Unsupported	0.26	1.29	0.24	1.18	1	0.28
Sitting Supported	-0.018	0.98	0.23	0.01	1	0.94
Standing Supported	-0.028	0.97	0.24	0.01	1	0.91
Walking Supported	-0.010	0.99	0.29	0.00	1	0.973
Supine	1.10	2.99	0.28	3.13	1	< 0.001***
Prone	-1.02	0.36	0.29	0.02	1	0.0005**
Crawling	0.44	1.55	0.25	12.26	1	0.077
Kneeling	0.03	1.03	0.24	15.42	1	0.89
Shake	1.45	4.27	0.51	7.96	1	0.004**
Rock	0.40	1.50	0.81	3.78	1	< 0.001***
Bounce	1.04	2.83	0.23	23.93	1	< 0.001***
Nod	0.96	2.61	0.49	1.01	1	0.052
Nod Up	0.94	1.48	0.81	1.33	1	< 0.001***
Nod Down	0.085	1.09	0.84	1.60	1	0.31
Center Torso	0.29	1.33	0.11	0.58	1	0.0099**
Left Torso	0.44	1.55	0.14	20.69	1	0.001**
Right Torso	0.23	1.26	0.16	21.95	1	0.13
Center Head	0.086	1.09	0.075	6.64	1	0.25
Left Head	0.11	1.11	0.085	9.70	1	0.21
Right Head	0.072	1.07	0.095	2.20	1	0.45
Time	0.0007	1.00	0.0002	9.32	1	0.002**
Age	0.094	1.10	0.0046	423.26	1	< 0.001***
Play Setting	-0.57	0.56	0.049	136.59	1	< 0.001***

Note. 0 '***', 0.001 '**', 0.01 '*',

Significant Likelihood X^2 test: $X^2(5) = 58.50, p < 0.001$

H-L test of goodness fit: $X^2(8)$ of 119.45, $p < 0.001$

Table 18.*Multiple Logistic Regression between Lagged Movement and Vocal Production*

	Estimate	Odds Ratio	SE	Wald's X^2	df	p
Intercept	-3.16	0.04	0.22			<0.001***
Sitting Unsupported	-0.11	0.90	0.22	0.25	1	0.60
Standing Unsupported	-0.27	0.76	0.22	1.49	1	0.22
Walking Unsupported	0.08	1.08	0.22	0.13	1	0.73
Sitting Supported	-0.15	0.86	0.22	0.46	1	0.47
Standing Supported	-0.21	0.81	0.23	0.85	1	0.35
Walking Supported	-0.19	0.83	0.28	0.46	1	0.48
Supine	0.68	1.98	0.27	6.28	1	0.01*
Prone	-1.07	0.34	0.28	15.22	1	<0.001***
Crawling	0.26	1.30	0.24	1.24	1	0.27
Kneeling	-0.07	0.94	0.22	0.09	1	0.74
Shake	-0.36	0.70	0.77	0.22	1	0.65
Nod	0.74	2.09	0.50	2.17	1	0.15
Nod Up	0.27	1.31	0.08	10.42	1	0.001**
Nod Down	0.09	1.09	0.08	1.02	1	0.32
Center Head	0.09	1.09	0.07	1.37	1	0.26
Left Head	-0.15	0.86	0.09	2.70	1	0.10
Right Head	0.13	1.13	0.09	1.86	1	0.17

Note. 0 '***' 0.001 '**' 0.01 '*'

Significant Likelihood X^2 test: $X^2(7) = 20.52, p < 0.005$

H-L test of goodness fit: $X^2(8)$ of 151.62, $p < 0.001$

Table 19.*Average Duration Spent in Each Engagement State*

	Overall		12-months		18-months		24-months	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Coordinated Joint Engagement								
Overall	8.42	7.34	8.50	5.35	7.76	7.70	8.99	8.64
Structured Play	8.09	7.10	8.96	5.83	6.94	6.78	8.74	8.14
Natural Play	8.83	7.64	8.09	4.89	9.17	8.24	9.30	9.29
Supported Joint Engagement								
Overall	12.61	12.39	11.64	11.07	12.61	12.89	13.55	13.13
Structured Play	11.49	10.61	10.37	8.46	11.12	11.72	13.13	11.58
Natural Play	13.95	14.15	13.50	13.90	14.33	14	14	14.60
Solo Object Play								
Overall	13.06	13.11	13.77	12.37	12.80	12.84	12.48	13.31
Structured Play	12.21	12.88	13.49	11.32	10.64	9.89	12.70	17.61
Natural Play	14.08	13.33	14.07	13.53	15.98	15.79	12.25	10.04
Social Engagement								
Overall	9.20	7.40	9.21	7.22	9.37	6.34	8.99	9.14
Structured Play	7.03	4.21	5.10	NA	7.23	3.85	7.34	6.26
Natural Play	9.49	7.69	9.33	7.29	9.97	6.84	9.29	9.72
Onlooking								
Overall	6.44	4.21	7.01	4.41	6.45	4.61	5.35	2.94
Structured Play	6.60	4.30	6.88	4.26	6.69	4.78	5.82	3.43
Natural Play	6.16	4.07	7.21	4.70	5.83	4.23	4.84	2.27
Unengaged								
Overall	6.35	2.45	7.09	3.30	5.93	1.80	5.33	1.13
Structured Play	6.29	1.96	NA	NA	7.17	1.75	4.53	NA
Natural Play	6.37	2.73	7.09	3.30	4.69	0.76	6.13	NA

Table 20.*Proportion Spent in Each Engagement State*

	Overall	12-months	18-months	24-months
Coordinated Joint Engagement	0.16	0.14	0.16	0.19
Supported Joint Engagement	0.38	0.37	0.44	0.34
Solo Object Play	0.36	0.30	0.35	0.38
Social Engagement	0.04	0.03	0.04	0.05
Onlooking	0.06	0.04	0.06	0.09
Unengaged	0.01	0.00	0.00	0.00
Unusable	0.00	0.00	0.01	0.00

Table 21.*Movement Variability and Infant Engagement States Regressions*

	Estimate	SE	t	p
Coordinated Joint Engagement				
Intercept	14.41	7.18	2.01	0.049
Movement Variability	-1.45	2.01	-0.73	0.47
Age	-0.11	0.11	-1.02	0.31
Supported Joint Engagement				
Intercept	-8.73	10.88	-0.80	0.43
Movement Variability	5.42	3.04	1.78	0.079
Age	0.23	0.17	1.41	0.16
Solo Object Play				
Intercept	-1.53	11.14	-0.14	0.89
Movement Variability	5.05	3.11	1.62	0.11
Age	-0.10	0.17	-0.61	0.55
Social Engagement				
Intercept	-23.87	8.50	-2.81	0.0067**
Movement Variability	8.89	2.38	3.74	< 0.001***
Age	-0.06	0.13	-0.48	0.63
Onlooking				
Intercept	1.76	6.48	0.27	0.79
Movement Variability	2.52	1.81	1.39	0.17
Age	-0.25	0.099	-2.53	0.014*
Unengaged				
Intercept	-9.25	3.04	-3.04	0.0035

Movement	2.91	0.85	3.42	0.0011
Variability				
Age	0.014	0.046	0.32	0.75

Note: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 22.

Multiple Logistic Regression between Movement and Coordinated Joint Engagement

	Estimate	Odds Ratio	SE	Wald's X ²	df	p
Intercept	-2.86	0.06	0.27			< 0.001***
Sitting Unsupported	0.64	1.90	0.27	5.79	1	0.02*
Standing Unsupported	0.76	2.13	0.27	7.82	1	0.005**
Walking Unsupported	0.82	2.27	0.27	9.02	1	0.003**
Sitting Supported	-0.091	0.91	0.27	0.11	1	0.74
Standing Supported	-0.0018	1.00	0.28	0.00	1	0.99
Walking Supported	-0.79	0.45	0.28	3.99	1	0.05*
Supine	-0.13	0.87	0.40	3.78	1	0.90
Prone	-0.11	0.90	0.011	5.41	1	0.74
Crawling	-0.62	0.54	0.32	0.11	1	0.052
Kneeling	0.64	1.89	0.32	0.01	1	0.020
Shake	1.54	4.65	0.27	9.01	1	0.003**
Rock	-0.51	0.60	0.51	4.46	1	< 0.001***
Bounce	1.15	3.14	0.11	150.14	1	< 0.001***
Nod	1.02	2.76	0.23	365.68	1	0.04*
Nod Up	0.90	2.46	0.074	0.00	1	< 0.001***
Nod Down	1.31	3.69	0.068	0.04	1	< 0.001***
Center Torso	-0.37	0.69	0.13	1.80	1	0.005**
Left Torso	0.092	1.10	0.16	24.72	1	0.56
Right Torso	-0.20	0.82	0.19	22.22	1	0.28
Center Head	-0.0047	1.00	0.074	7.82	1	0.95
Left Head	0.017	1.02	0.087	0.34	1	0.84
Right Head	-0.13	0.88	0.097	1.16	1	0.18
Time	0.00074	1.00	0.00024	9.69	1	0.002**
Age	0.022	1.02	0.0044	24.68	1	< 0.001***
Play Setting	0.094	1.10	0.047	4.00	1	0.05*

Note. 0 '***' 0.001 '**' 0.01 '*'

Significant Likelihood X2 test: X2(5) = 57.81, $p < 0.001$

H-L test of goodness fit: X2(8) of 82.92, $p < 0.001$

Table 23.*Multiple Logistic Regression between Lagged Movement and Coordinated Joint Engagement*

	Estimate	Odds Ratio	SE	Wald's X^2	df	p
Intercept	-3.15	0.04	0.31			< 0.001***
Sitting	0.95	2.58	0.30	9.72	1	0.002**
Unsupported						
Standing	1.13	3.1	0.31	13.57	1	< 0.001***
Unsupported						
Walking	1.07	2.93	0.31	11.96	1	< 0.001***
Unsupported						
Sitting	0.18	1.2	0.31	0.35	1	0.56
Supported						
Standing	0.35	1.42	0.32	1.24	1	0.27
Supported						
Walking	-0.57	0.56	0.43	1.75	1	0.19
Supported						
Supine	-12.96	0.00	110.90	0.01	1	0.91
Prone	0.35	1.41	0.35	0.98	1	0.32
Crawling	-0.20	0.82	0.35	0.32	1	0.57
Kneeling	0.90	2.47	0.31	8.47	1	0.004**
Shake	1.29	3.63	0.52	6.05	1	0.01*
Rock	-0.72	0.49	0.12	36.70	1	< 0.001***
Bounce	1.08	2.94	0.24	21.02	1	< 0.001***
Nod	1.24	3.47	0.47	6.91	1	0.01**
Nod Up	1.56	4.75	0.07	507.99	1	< 0.001***
Nod Down	1.06	2.89	0.07	221.95	1	< 0.001***
Center Head	-0.07	0.93	0.08	0.97	1	0.32
Left Head	0.09	1.09	0.09	1.11	1	0.29
Right Head	-0.16	0.85	0.10	2.82	1	0.09
Center Torso	-0.33	0.72	0.13	6.12	1	0.01*
Left Torso	-0.23	0.8	0.18	1.62	1	0.20
Right Torso	-0.11	0.89	0.18	0.38	1	0.54
Time	0.00	1	0.00	5.71	1	0.01*
Age	0.02	1.02	0.00	22.27	1	< 0.001***
Play Setting	0.11	1.12	0.05	5.40	1	0.02*

Note. 0 '***', 0.001 '**', 0.01 '*',

Significant Likelihood X^2 test: $X^2(3) = 8.64$, $p < 0.03$

H-L test of goodness fit: $X^2(8)$ of 70.05, $p < 0.001$

Table 24.*Multiple Logistic Regression between Movement and Supported Joint Engagement*

	Estimate	Odds Ratio	SE	Wald's X^2	df	p
Intercept	-1.76	0.17	0.18			< 0.001***
Sitting	0.96	2.61	0.18	28.34	1	< 0.001***
Unsupported						
Standing	0.74	2.10	0.18	16.30	1	< 0.001***
Unsupported						
Walking	0.64	1.90	0.19	11.77	1	0.0006***
Unsupported						
Sitting	0.83	2.30	0.18	20.74	1	< 0.001***
Supported						
Standing	0.54	1.72	0.19	8.45	1	0.0037**
Supported						
Walking	1.11	3.03	0.22	26.41	1	< 0.001***
Supported						
Supine	0.65	1.91	0.24	7.33	1	0.0068**
Prone	0.08	1.08	0.22	0.14	1	0.71
Crawling	0.12	1.13	0.20	0.38	1	0.54
Kneeling	0.96	2.62	0.19	26.96	1	< 0.001***
Shake	-0.26	0.77	0.51	0.27	1	0.60
Rock	0.18	1.20	0.068	7.20	1	0.0073**
Bounce	-0.18	0.83	0.22	0.70	1	0.40
Nod	-0.26	0.77	0.47	0.31	1	0.58
Nod Up	-0.31	0.73	0.069	20.35	1	< 0.001***
Nod Down	-0.47	0.62	0.069	47.09	1	< 0.001***
Center	0.048	1.05	0.093	0.27	1	0.60
Torso						
Left Torso	-0.23	0.79	0.12	3.58	1	0.058
Right Torso	-0.098	0.91	0.13	0.57	1	0.44
Center Head	-0.16	0.85	0.059	7.08	1	0.0078**
Left Head	-0.27	0.76	0.07	15.65	1	< 0.001***
Right Head	-0.22	0.80	0.075	8.54	1	0.0035**
Time	0.00018	1.00	0.00018	1.01	1	0.31
Age	0.037	1.04	0.0033	124.48	1	< 0.001***
Play Setting	-0.29	0.75	0.035	65.69	1	< 0.001***

Note. 0 '****' 0.001 '***' 0.01 '**'

Significant Likelihood X^2 test: $X^2(5) = 11.51$, $p = 0.04$

H-L test of goodness fit: $X^2(8)$ of 94.28, $p < 0.001$

Table 25.*Multiple Logistic Regression between Lagged Movement and Supported Joint Engagement*

	Estimate	Odds Ratio	SE	Wald's X^2	df	p
Intercept	-1.71	0.18	0.18			< 0.001***
Sitting	0.94	2.55	0.18	27.43	1	< 0.001***
Unsupported						
Standing	0.71	2.03	0.18	15.02	1	< 0.001***
Unsupported						
Walking	0.67	1.93	0.19	12.63	1	< 0.001***
Unsupported						
Sitting	0.81	2.25	0.18	19.93	1	< 0.001***
Supported						
Standing	0.43	1.54	0.19	5.44	1	0.02*
Supported						
Walking	1.09	2.96	0.22	25.47	1	< 0.001***
Supported						
Supine	0.64	1.90	0.24	7.28	1	0.007**
Prone	0.10	1.11	0.21	0.22	1	0.65
Crawling	0.24	1.27	0.20	1.41	1	0.21
Kneeling	0.97	2.64	0.18	27.83	1	< 0.001***
Shake	-0.55	0.59	0.54	1.00	1	0.30
Nod	-0.05	0.96	0.46	0.01	1	0.91
Nod Up	-0.67	0.51	0.07	81.97	1	< 0.001***
Nod Down	-0.36	0.70	0.07	27.93	1	< 0.001***
Center Head	-0.12	0.89	0.06	4.48	1	0.04*
Left Head	-0.21	0.81	0.07	9.03	1	0.003**
Right Head	-0.23	0.79	0.07	9.63	1	0.002**
Time	0.00	1.00	0.00	0.13	1	0.77
Age	0.04	1.04	0.00	123.00	1	< 0.001***
Play Setting	-0.29	0.75	0.04	67.72	1	< 0.001***

Note. 0 '***' 0.001 '**' 0.01 '*'

Significant Likelihood X^2 test: $X^2(10) = 779.84, p < 0.001$

H-L test of goodness fit: $X^2(8) = 73.51, p < 0.001$

Table 26.*Multiple Logistic Regression between Movement and Solo Object Play*

	Estimate	Odds Ratio	SE	Wald's X^2	df	p
Intercept	-1.09	0.32	0.19			< 0.001***
Sitting	0.61	1.84	0.18	11.29	1	< 0.001***
Unsupported						
Standing	0.74	2.10	0.19	15.98	1	< 0.001***
Unsupported						
Walking	0.78	2.18	0.19	16.95	1	< 0.001***
Unsupported						
Sitting	0.82	2.28	0.19	19.71	1	< 0.001***
Supported						
Standing	1.06	2.87	0.19	31.38	1	< 0.001***
Supported						
Walking	1.25	3.48	0.22	33.06	1	< 0.001***
Supported						
Supine	-1.03	0.36	0.33	9.70	1	< 0.001***
Prone	1.87	6.48	0.21	77.54	1	< 0.001***
Crawling	1.74	5.70	0.20	78.20	1	< 0.001***
Kneeling	0.73	2.08	0.19	15.16	1	< 0.001***
Shake	-1.29	0.27	0.76	2.91	1	0.09
Rock	0.15	1.16	0.07	4.72	1	0.03
Bounce	-0.47	0.63	0.24	3.71	1	0.05
Nod	-1.55	0.21	0.75	4.21	1	0.04
Nod Up	-0.34	0.71	0.07	22.55	1	< 0.001***
Nod Down	-0.59	0.56	0.07	63.53	1	< 0.001***
Center	0.21	1.23	0.09	4.91	1	0.03
Torso						
Left Torso	0.12	1.13	0.12	1.02	1	0.31
Right Torso	0.21	1.24	0.13	2.78	1	0.10
Center Head	0.07	1.08	0.06	1.52	1	0.22
Left Head	0.13	1.14	0.07	3.57	1	0.06
Right Head	0.15	1.17	0.07	4.28	1	0.04
Time	0.00	1.00	0.00	12.92	1	< 0.001***
Age	-0.03	0.97	0.00	73.59	1	< 0.001***
Play Setting	0.25	1.28	0.04	45.90	1	< 0.001***

Note. 0 '***' 0.001 '**' 0.01 '*'

Significant Likelihood X^2 test: $X^2(8) = 278.11, p < 0.001$

H-L test of goodness fit: $X^2(8) = 95.11, p < 0.001$

Table 27.*Multiple Logistic Regression between Lagged Movement and Solo Object Play*

	Estimate	Odds Ratio	SE	Wald's X^2	df	p
Intercept	-1.13	0.32	0.19			< 0.001***
Sitting	0.70	2.01	0.19	14.25	1	< 0.001***
Unsupported						
Standing	0.78	2.18	0.19	16.99	1	< 0.001***
Unsupported						
Walking	0.86	2.37	0.19	20.12	1	< 0.001***
Unsupported						
Sitting	0.92	2.51	0.19	23.85	1	< 0.001***
Supported						
Standing	1.16	3.17	0.19	36.32	1	< 0.001***
Supported						
Walking	1.37	3.93	0.22	38.65	1	< 0.001***
Supported						
Supine	-0.74	0.48	0.31	5.47	1	0.02*
Prone	1.89	6.61	0.22	77.10	1	< 0.001***
Crawling	1.73	5.66	0.20	75.28	1	< 0.001***
Kneeling	0.79	2.20	0.19	17.00	1	< 0.001***
Shake	-0.48	0.62	0.58	0.68	1	0.41
Nod	-0.13	0.00	0.12	0.01	1	0.91
Nod Up	-0.74	0.48	0.08	90.27	1	< 0.001***
Nod Down	-0.36	0.70	0.07	26.00	1	< 0.001***
Center Head	0.15	1.16	0.06	6.93	1	0.008**
Left Head	0.02	1.02	0.07	0.11	1	0.74
Right Head	0.17	1.19	0.07	5.79	1	0.02*
Time	0.00	1.00	0.00	8.44	1	0.004**
Age	-0.03	0.97	0.00	70.37	1	< 0.001***
Play Setting	0.24	1.28	0.04	45.89	1	< 0.001***

Note. 0 '****' 0.001 '***' 0.01 '**'

Significant Likelihood X^2 test: $X^2(8) = 218.18, p < 0.001$

H-L test of goodness fit: $X^2(8)$ of 58.70, $p < 0.001$

Table 28.*Multiple Logistic Regression between Movement and Social Engagement*

	Estimate	Odds Ratio	SE	Wald's X^2	df	p
Intercept	-1.05	0.35	0.21			< 0.001***
Sitting	-2.12	0.12	0.19	130.10	1	< 0.001***
Unsupported						
Standing	-2.43	0.09	0.22	121.17	1	< 0.001***
Unsupported						
Walking	-2.44	0.09	0.24	99.91	1	< 0.001***
Unsupported						
Sitting	-1.22	0.29	0.18	43.88	1	< 0.001***
Supported						
Standing	-1.95	0.14	0.20	90.70	1	< 0.001***
Supported						
Walking	-2.82	0.06	0.39	51.15	1	< 0.001***
Supported						
Supine	0.69	1.99	0.23	9.01	1	0.002**
Prone	-2.83	0.06	0.42	44.38	1	< 0.001***
Crawling	-1.96	0.14	0.25	61.77	1	< 0.001***
Kneeling	-2.32	0.10	0.23	97.75	1	< 0.001***
Shake	1.14	3.13	0.91	1.59	1	0.21
Nod	-0.12	0.88	0.21	0.33	1	0.56
Nod Up	0.00	1.00	0.43	0.00	1	0.99
Nod Down	1.51	4.51	0.79	3.62	1	0.06
Center Head	0.07	1.08	0.17	0.19	1	0.66
Left Head	0.22	1.24	0.16	1.82	1	0.18
Right Head	0.34	1.41	0.14	6.23	1	0.01*
Time	0.41	1.51	0.15	7.65	1	0.006**
Age	0.20	1.22	0.18	1.24	1	0.27
Play Setting	0.00	1.00	0.00	29.23	1	< 0.001***

Note. 0 '***' 0.001 '**' 0.01 '*'

Significant Likelihood X^2 test: $X^2(5) = 21.31, p = 0.01$

H-L test of goodness fit: $X^2(8) = 37.21, p < 0.001$

Table 29.*Multiple Logistic Regression between Lagged Movement and Social Engagement*

	Estimate	Odds Ratio	SE	Wald's X ²	df	p
Intercept	-0.94	0.39	0.21			<0.001***
Sitting Unsupported	-2.05	0.13	0.18	123.62	1	<0.001***
Standing Unsupported	-2.30	0.10	0.22	112.07	1	<0.001***
Walking Unsupported	-2.23	0.11	0.24	88.62	1	<0.001***
Sitting Supported	-1.25	0.29	0.18	45.38	1	<0.001***
Standing Supported	-1.71	0.18	0.20	73.97	1	<0.001***
Walking Supported	-2.91	0.05	0.42	49.01	1	<0.001***
Crawling	-2.30	0.10	0.28	68.17	1	<0.001***
Kneeling	-2.11	0.12	0.23	86.61	1	<0.001***
Prone	-2.80	0.06	0.42	43.50	1	<0.001***
Supine	0.66	1.93	0.23	8.28	1	0.004**
Time	0.00	1.00	0.00	25.05	1	<0.001***
Age	-0.02	0.98	0.01	3.91	1	0.05*
Play Setting	-2.17	0.11	0.14	234.21	1	<0.001***

Note. 0 '***' 0.001 '**' 0.01 '*'

Significant Likelihood X2 test: X2 (3) = 21.31, $p < 0.001$

H-L test of goodness fit: X2 (8) of 43.63, $p < 0.001$

Table 30.*Multiple Logistic Regression between Movement and Onlooking*

	Estimate	Odds Ratio	SE	Wald's X^2	df	p
Intercept	-0.37	0.69	0.24			0.13
Sitting	-1.14	0.32	0.23	23.61	1	< 0.001 ***
Unsupported						
Standing	-0.89	0.41	0.25	12.77	1	< 0.001 ***
Unsupported						
Walking	-0.91	0.40	0.26	11.83	1	< 0.001 ***
Unsupported						
Sitting	-0.78	0.46	0.24	10.47	1	0.001**
Supported						
Standing	-0.20	0.82	0.25	0.68	1	0.41
Supported						
Walking	-3.40	0.03	1.03	10.97	1	< 0.001 ***
Supported						
Supine	-0.30	0.74	0.40	0.58	1	0.45
Prone	-2.39	0.09	0.75	10.28	1	0.001**
Crawling	-1.07	0.34	0.28	14.32	1	< 0.001 ***
Kneeling	-1.61	0.20	0.26	37.12	1	< 0.001 ***
Shake	-12.77	0.00	346.30	0.00	1	0.97
Rock	-0.32	0.73	0.15	4.29	1	0.04*
Bounce	-12.58	0.00	144.50	0.01	1	0.93
Nod	0.58	1.79	0.77	0.56	1	0.45
Nod Up	-0.11	0.89	0.14	0.67	1	0.41
Nod Down	-0.25	0.78	0.14	3.12	1	0.08
Center	-0.33	0.72	0.22	2.25	1	0.13
Torso						
Left Torso	-0.13	0.88	0.27	0.23	1	0.63
Right Torso	-0.12	0.89	0.27	0.19	1	0.67
Center Head	0.10	1.11	0.12	0.75	1	0.39
Left Head	0.19	1.21	0.13	2.09	1	0.15
Right Head	0.36	1.43	0.13	7.30	1	0.006**
Time	-0.01	0.99	0.00	197.26	1	< 0.001 ***
Age	-0.07	0.93	0.01	102.95	1	< 0.001 ***
Play Setting	1.01	2.73	0.08	162.74	1	< 0.001 ***

Note. 0 '***' 0.001 '**' 0.01 '*'

Significant Likelihood X^2 test: $X^2(5) = 17.48, p = 0.003$

H-L test of goodness fit: $X^2(8) = 116.16, p < 0.001$

Table 31.*Multiple Logistic Regression between Lagged Movement and Onlooking*

	Estimate	Odds Ratio	SE	Wald's X^2	df	p
Intercept	-0.36	0.70	0.24			0.13
Sitting	-1.22	0.30	0.23	27.69	1	<0.001***
Unsupported						
Standing	-0.85	0.43	0.24	12.10	1	<0.001***
Unsupported						
Walking	-1.06	0.35	0.26	16.01	1	<0.001***
Unsupported						
Sitting	-0.85	0.43	0.24	12.50	1	<0.001***
Supported						
Standing	-0.28	0.76	0.24	1.30	1	0.25
Supported						
Walking	-0.15	0.00	0.02	0.004	1	0.95
Supported						
Supine	-0.35	0.70	0.39	0.80	1	0.37
Prone	-1.49	0.00	0.02	0.05	1	0.94
Crawling	-1.07	0.34	0.28	14.79	1	<0.001***
Kneeling	-1.66	0.19	0.26	40.45	1	<0.001***
Shake	0.02	1.02	1.04	0.0005	1	0.98
Nod	1.09	2.97	0.66	2.74	1	0.09
Nod Up	-0.18	0.84	0.14	1.49	1	0.22
Nod Down	-0.42	0.66	0.15	7.52	1	0.006**
Center Head	0.07	1.07	0.16	0.32	1	0.57
Left Head	0.22	1.24	0.13	2.73	1	0.09
Right Head	0.42	1.53	0.13	10.78	1	0.001**
Time	-0.01	0.99	0.00	183.58	1	<0.001***
Age	-0.07	0.93	0.01	98.90	1	<0.001***
Play Setting	1.00	2.72	0.08	160.18	1	<0.001***

Note. 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Significant Likelihood X^2 test: $X^2(5) = 17.48, p = 0.003$

H-L test of goodness fit: $X^2(8) = 116.16, p < 0.001$

Table 32.*Multiple Logistic Regression between Movement and Unengaged*

	Estimate	Odds Ratio	SE	Wald's X^2	df	p
Intercept	-2.19	0.11	0.34			< 0.001***
Sitting	-2.68	0.07	0.37	51.46	1	< 0.001***
Unsupported						
Standing	-4.27	0.01	0.76	31.47	1	< 0.001***
Unsupported						
Walking	-2.42	0.09	0.45	28.75	1	< 0.001***
Unsupported						
Sitting	-2.93	0.05	0.47	38.20	1	< 0.001***
Supported						
Standing	-3.43	0.03	0.64	28.59	1	< 0.001***
Supported						
Walking	-16.94	0.00	657.44	0.00	1	0.98
Supported						
Supine	-3.73	0.02	1.04	12.87	1	< 0.001***
Prone	-3.74	0.02	0.76	23.98	1	< 0.001***
Crawling	-16.77	0.00	576.47	0.00	1	0.98
Kneeling	-0.59	0.55	0.51	1.38	1	0.24
Time	0.00	1.00	0.00	2.52	1	0.11
Age	-0.83	0.44	0.31	7.18	1	0.007**
Play Setting	-2.19	0.11	0.34	51.46	1	< 0.001***

Note. 0 '***' 0.001 '**' 0.01 '*'

Significant Likelihood X^2 test: $X^2(5) = 77.11, p < 0.001$

H-L test of goodness fit: $X^2(8) = 32.74, p < 0.001$

Table 33.*Multiple Logistic Regression between Lagged Movement and Unengaged*

	Estimate	Odds Ratio	SE	Wald's X^2	df	p
Intercept	-1.00	0.37	0.52			0.06
Sitting	-2.93	0.05	0.37	61.80	1	<0.001***
Unsupported						
Standing	-18.72	0.00	626.40	0.00	1	0.98
Unsupported						
Walking	-2.04	0.13	0.46	19.95	1	<0.001***
Unsupported						
Sitting	-2.86	0.06	0.45	40.42	1	<0.001***
Supported						
Standing	-3.94	0.02	0.75	27.31	1	<0.001***
Supported						
Walking	-19.18	0.00	1,792.00	0.00	1	0.99
Supported						
Crawling	-19.13	0.00	1,180.00	0.00	1	0.99
Kneeling	-3.91	0.02	0.76	26.49	1	<0.001***
Prone	-2.01	0.13	0.81	6.16	1	0.01*
Supine	-1.05	0.35	0.58	3.32	1	0.07
Time	0.00	1.00	0.00	4.04	1	0.04*
Age	-0.06	0.94	0.03	4.47	1	0.03*
Play Setting	-0.64	0.53	0.31	4.20	1	0.04*

Note. 0 '***' 0.001 '**' 0.01 '*'

Significant Likelihood X^2 test: $X^2(3) = 103.02, p < 0.001$

H-L test of goodness fit: $X^2(8)$ of 41.33, $p < 0.001$

Table 34.*Significant Odds Ratios of Movements Predicting Engagement State*

Infant Engagement State	Increases Likelihood (OR)	Decreases Likelihood (OR)
Coordinated Joint Engagement	Sitting Unsupported (1.9) Standing Unsupported (2.13) Walking Unsupported (2.27) Shake (4.65) Nod (2.76) Nod Up (2.46) Nod Down (3.69) Bounce (3.14)	Walking Supported (0.45) Rock (0.6) Center Torso (0.69)
Supported Joint Engagement	Sitting Unsupported (2.61) Standing Unsupported (2.1) Walking Unsupported (1.9) Sitting Supported (2.3) Standing Supported (1.72) Walking Supported (3.03) Supine (1.91) Kneeling (2.62) Rock (1.7)	Nod Up (0.73) Nod Down (0.62) Center Head (0.85) Left Head (0.76) Right Head (0.8)
Solo Object Play	Sitting Unsupported (1.84) Standing Unsupported (2.1) Walking Unsupported (2.18) Sitting Supported (2.28) Standing Supported (2.87) Walking Supported (3.48) Prone (6.48) Crawling (5.8) Kneeling (2.08)	Supine (0.36) Nod Up (0.71) Nod Down (0.56)
Social Engagement	Supine (1.99) Right Head (1.41)	Sitting Unsupported (0.12) Standing Unsupported (0.09) Walking Unsupported (0.09) Sitting Supported (0.29) Standing Supported (0.14) Walking Supported (0.06) Prone (0.06) Crawling (0.14) Kneeling (0.10)

Onlooking	Right Head (1.43)	Sitting Unsupported (0.32) Standing Unsupported (0.41) Walking Unsupported (0.40) Sitting Supported (0.46) Standing Supported (0.82) Walking Supported (0.03) Supine (0.74) Prone (0.09) Crawling (0.34) Kneeling (0.20) Rock (0.73)
Unengaged		Sitting Unsupported (0.07) Standing Unsupported (0.01) Walking Unsupported (0.09) Sitting Supported (0.05) Standing Supported (0.03) Supine (0.02) Prone (0.02)

Table 35.*Significant Odds Ratios of Lagged Movements Predicting Engagement State*

Infant Engagement State	Increases Likelihood (OR)	Decreases Likelihood (OR)
Coordinated Joint Engagement	Sitting Unsupported (2.58) Standing Unsupported (3.1) Walking Unsupported (2.93) Kneel (2.47) Shake (3.63) Bounce (2.94) Nod (3.47) Nod Up (4.75) Nod Down (2.89)	Rock (0.49) Center Torso (0.72)
Supported Joint Engagement	Sitting Unsupported (2.55) Standing Unsupported (2.03) Walking Unsupported (1.93) Sitting Supported (2.25) Standing Supported (1.54) Walking Supported (2.96) Supine (1.90) Kneeling (2.64)	Nod Up (0.51) Nod Down (0.70) Center Head (0.89) Left Head (0.81) Right Head (0.79)
Solo Object Play	Sitting Unsupported (2.01) Standing Unsupported (2.18) Walking Unsupported (2.37) Sitting Supported (2.51) Standing Supported (3.17) Walking Supported (3.93) Prone (6.61) Crawling (5.66) Kneeling (2.20)	Supine (0.48) Nod Up (0.48) Nod Down (0.70) Center Head (1.16) Right Head (1.19)
Social Engagement	Supine (1.93)	Sitting Unsupported (0.13) Standing Unsupported (0.10) Walking Unsupported (0.11) Sitting Supported (0.29) Standing Supported (0.18) Walking Supported (0.05) Prone (0.06) Crawling (0.10) Kneeling (0.12)

Onlooking	Right Head (1.53)	Sitting Unsupported (0.30) Standing Unsupported (0.43) Walking Unsupported (0.35) Sitting Supported (0.43) Crawling (0.34) Kneeling (0.19) Nod Down (0.66)
Unengaged		Sitting Unsupported (0.05) Walking Unsupported (0.13) Sitting Supported (0.06) Standing Supported (0.02) Kneeling (0.02) Prone (0.13)

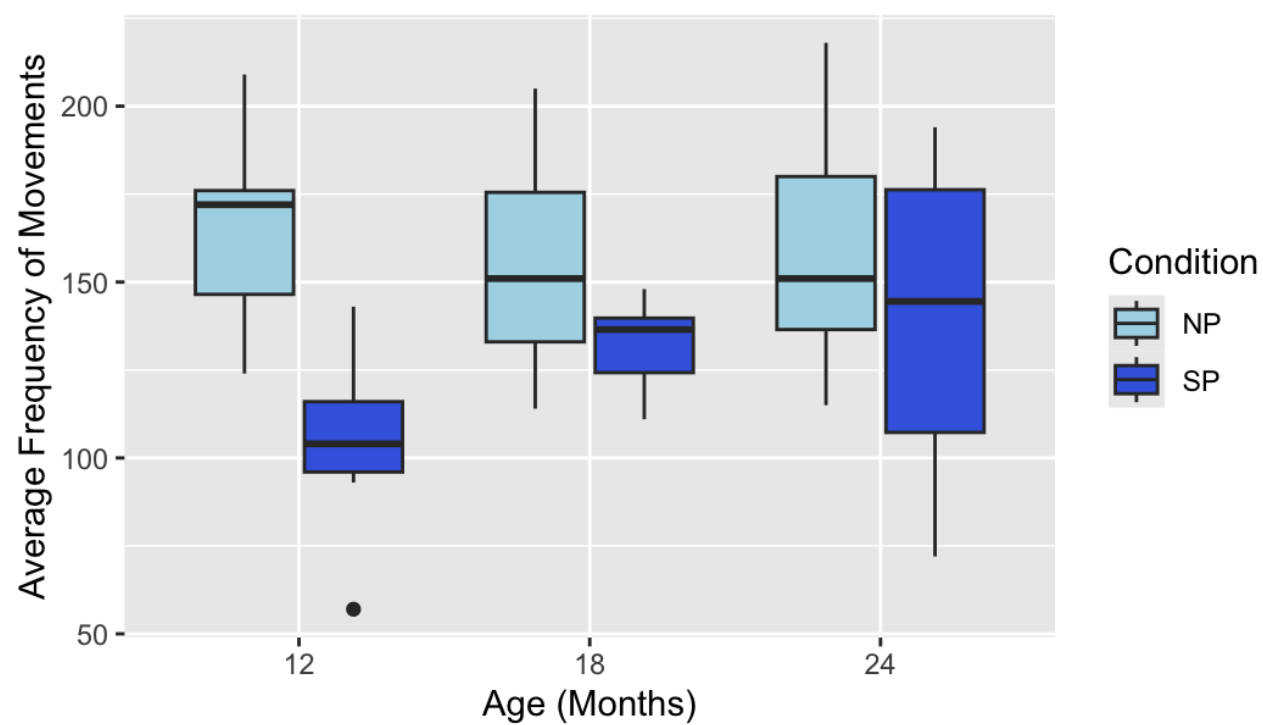
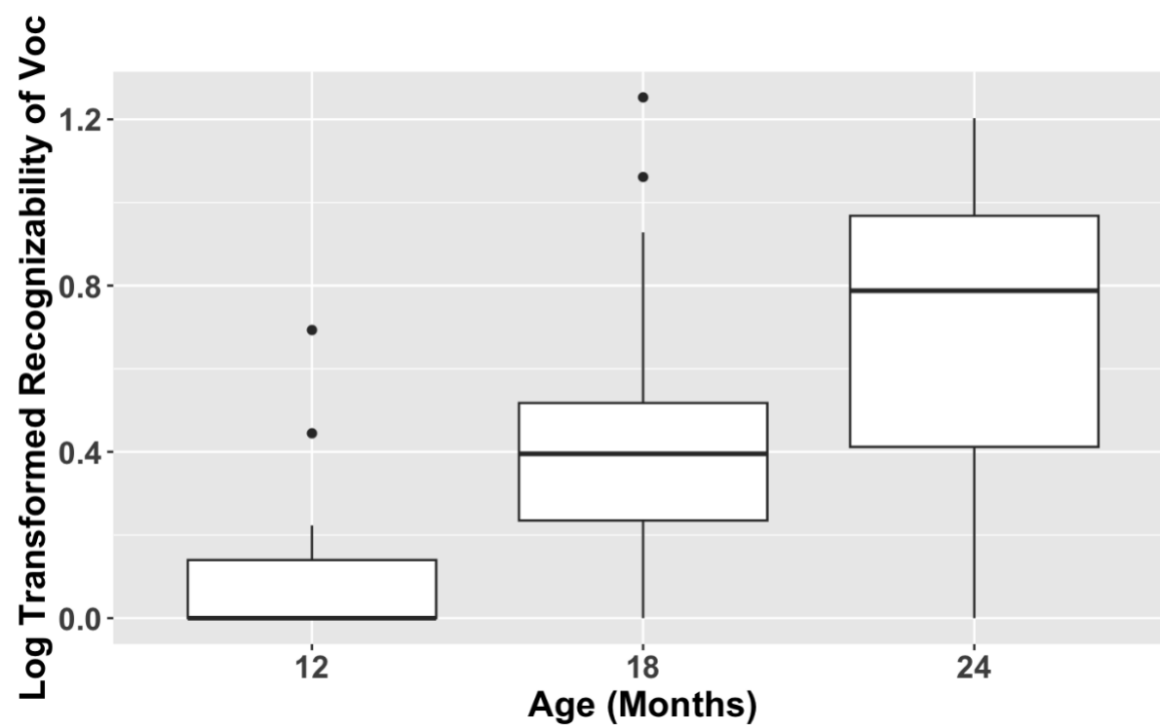
Figure 1.*Movement Variability by Age and Play Setting***Figure 2.***Vocalization Recognizability and Age*

Figure 3.

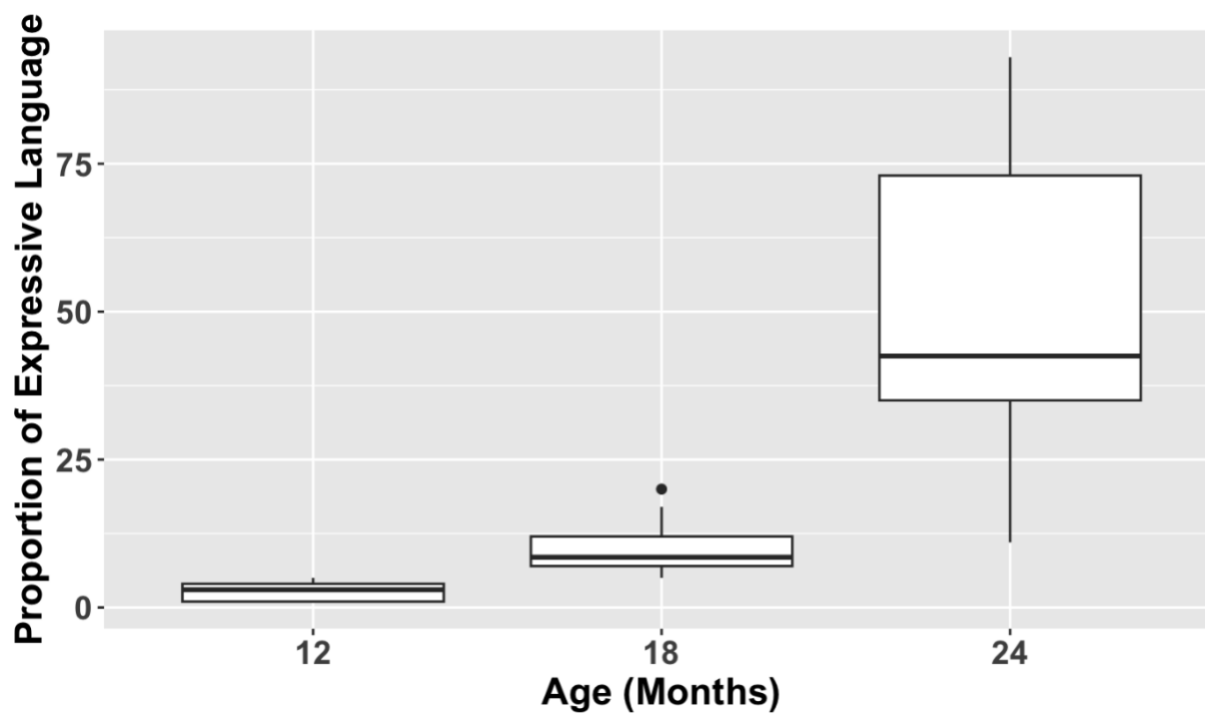
Expressive Language and Age

Figure 4.

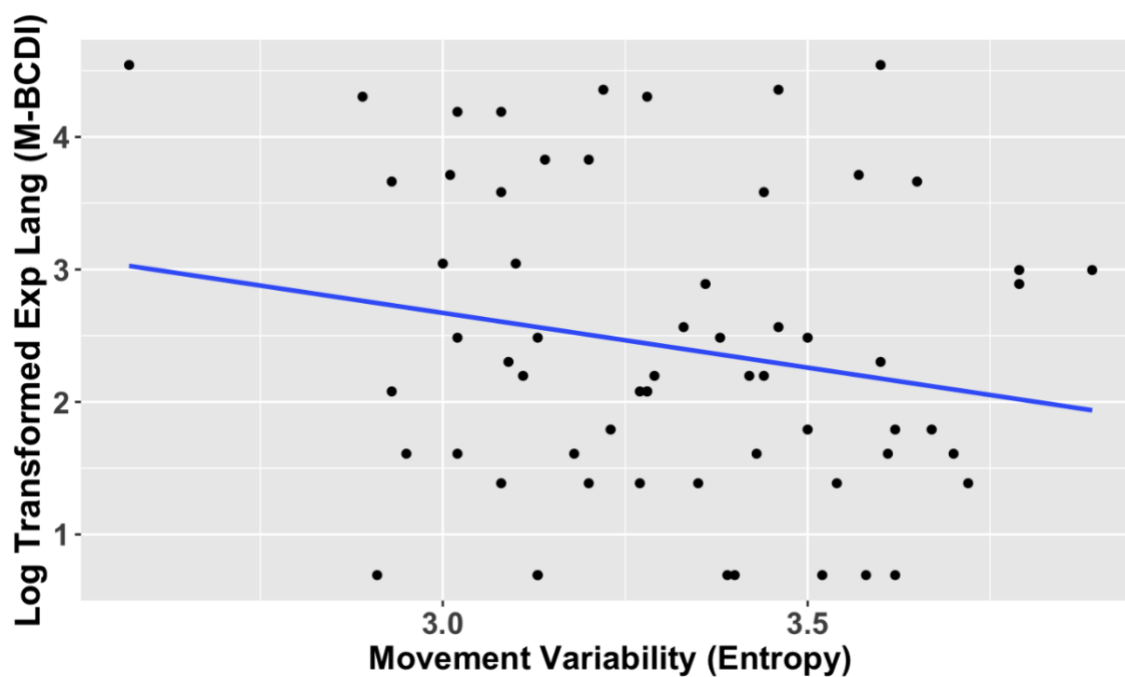
Movement Variability and Expressive Language (M-BCDI)

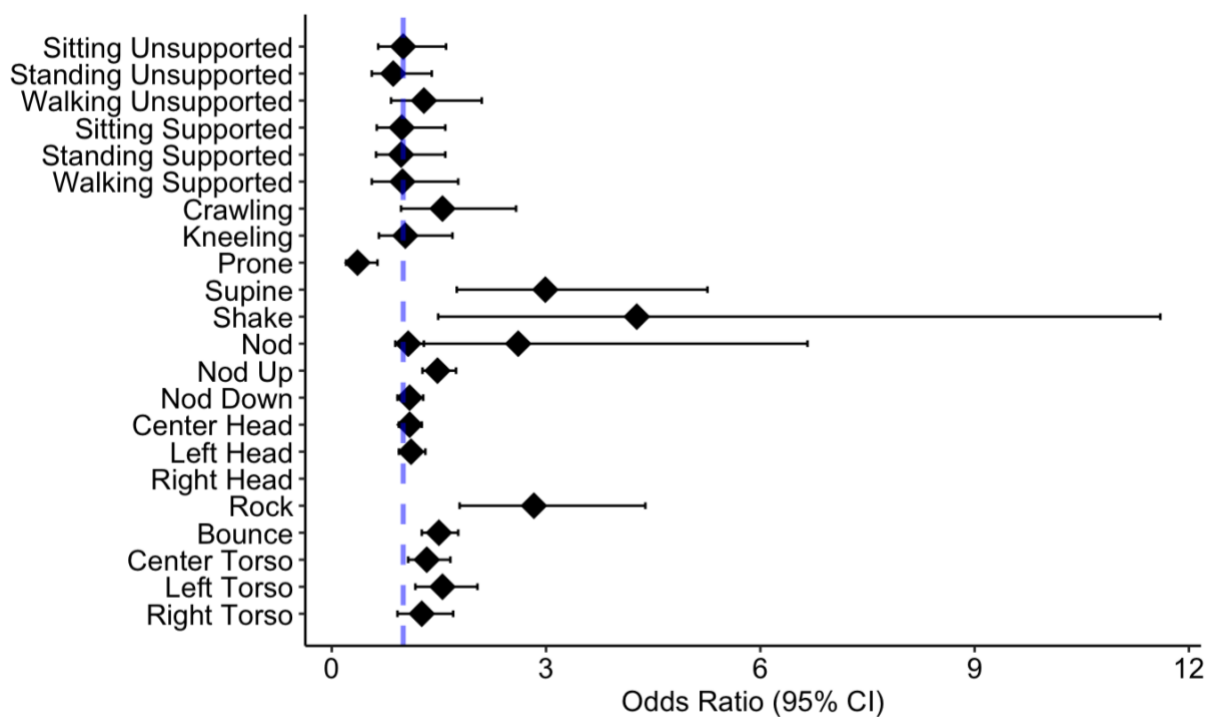
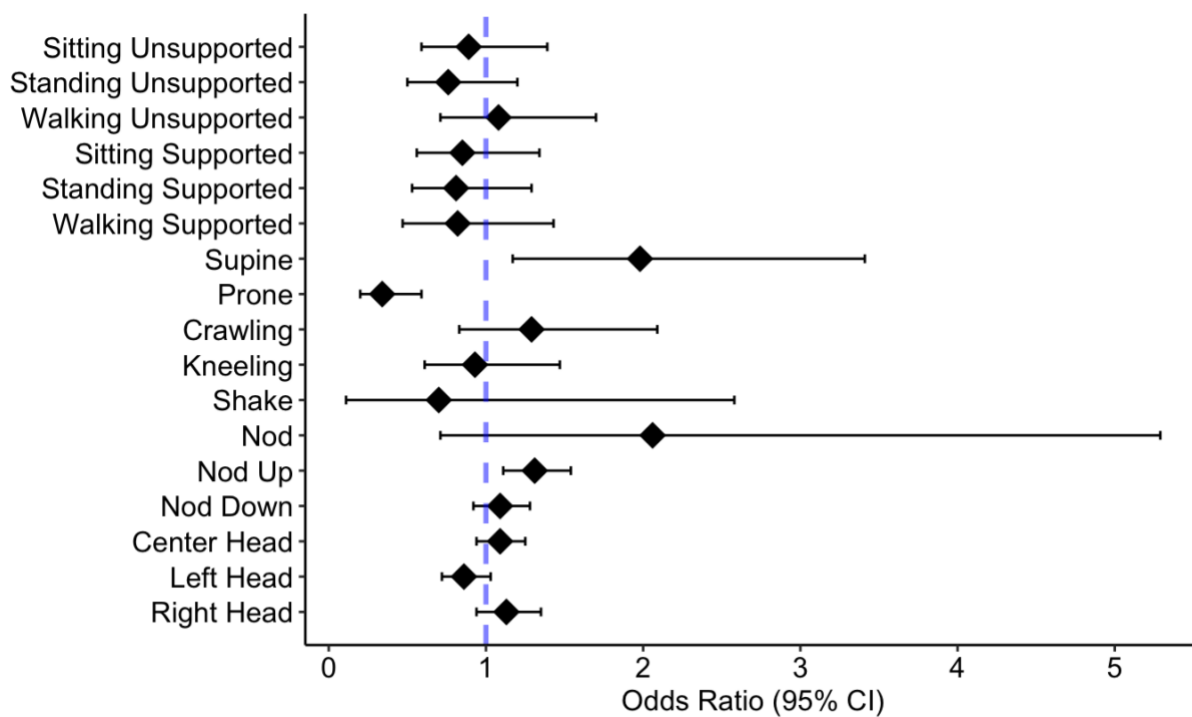
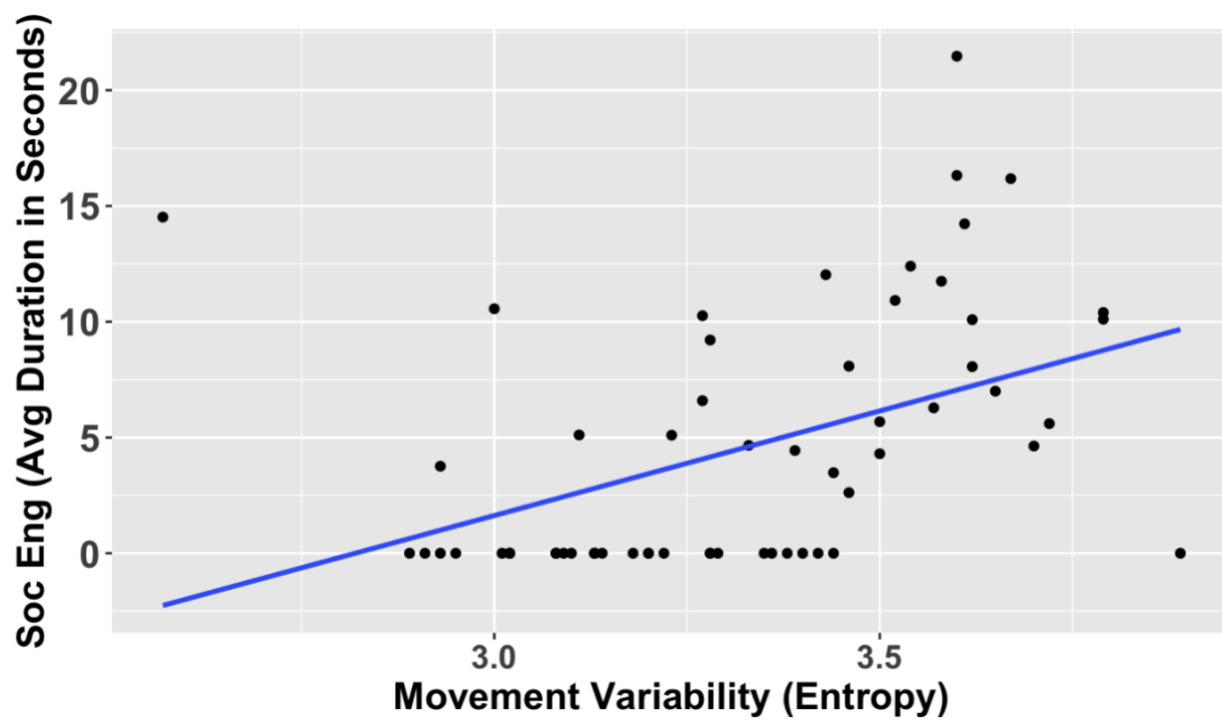
Figure 5.*Associations to Vocal Production***Figure 6.***Lagged Associations to Vocal Production*

Figure 7.

Movement Variability and Social Engagement

**Figure 8.**

Movement Variability and Supported Joint Engagement

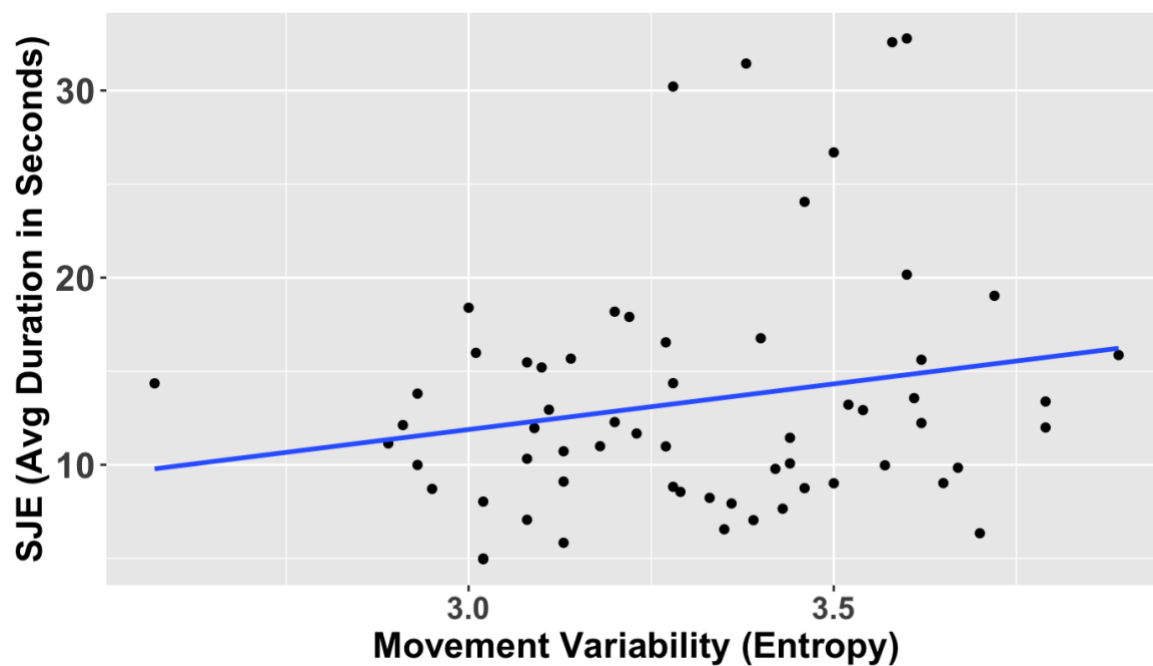


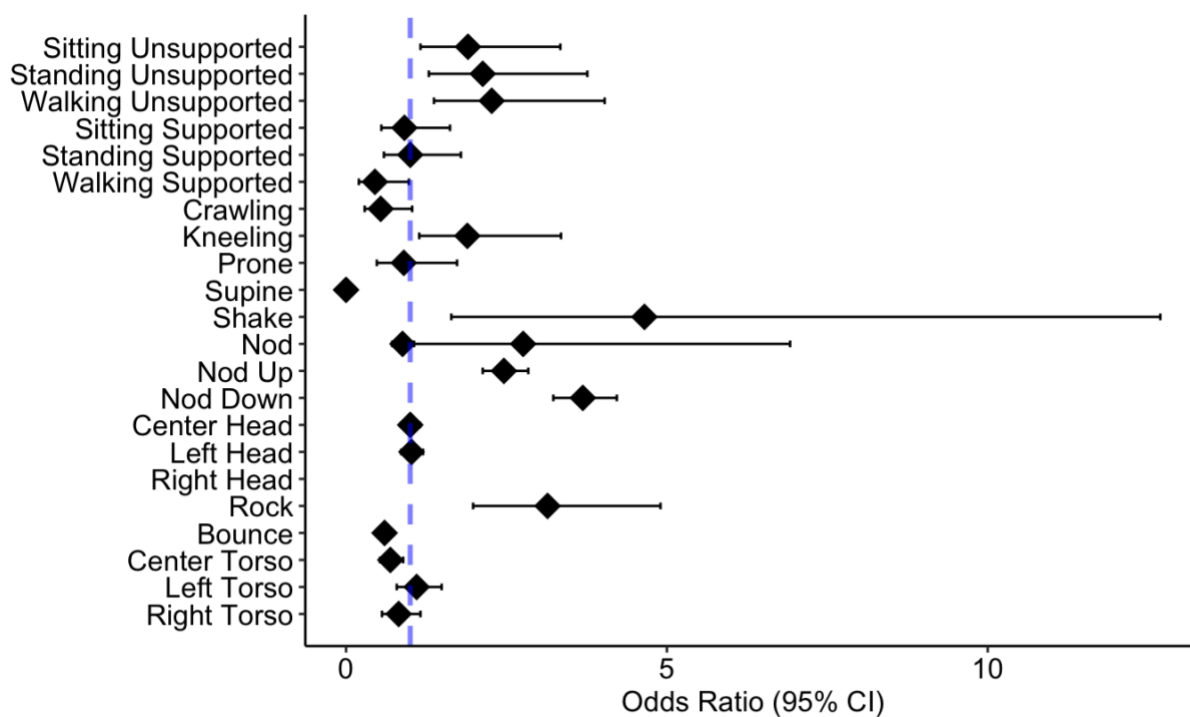
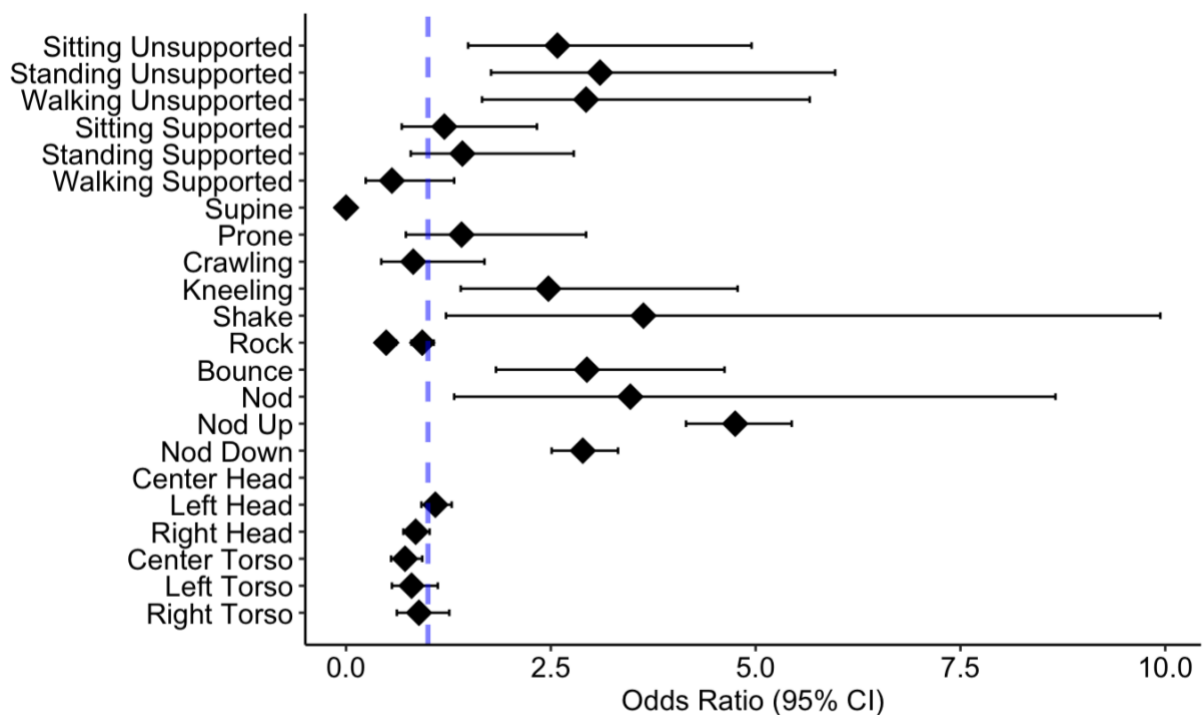
Figure 9.*Associations to Coordinated Joint Engagement***Figure 10.***Lagged Associations to Coordinated Joint Engagement*

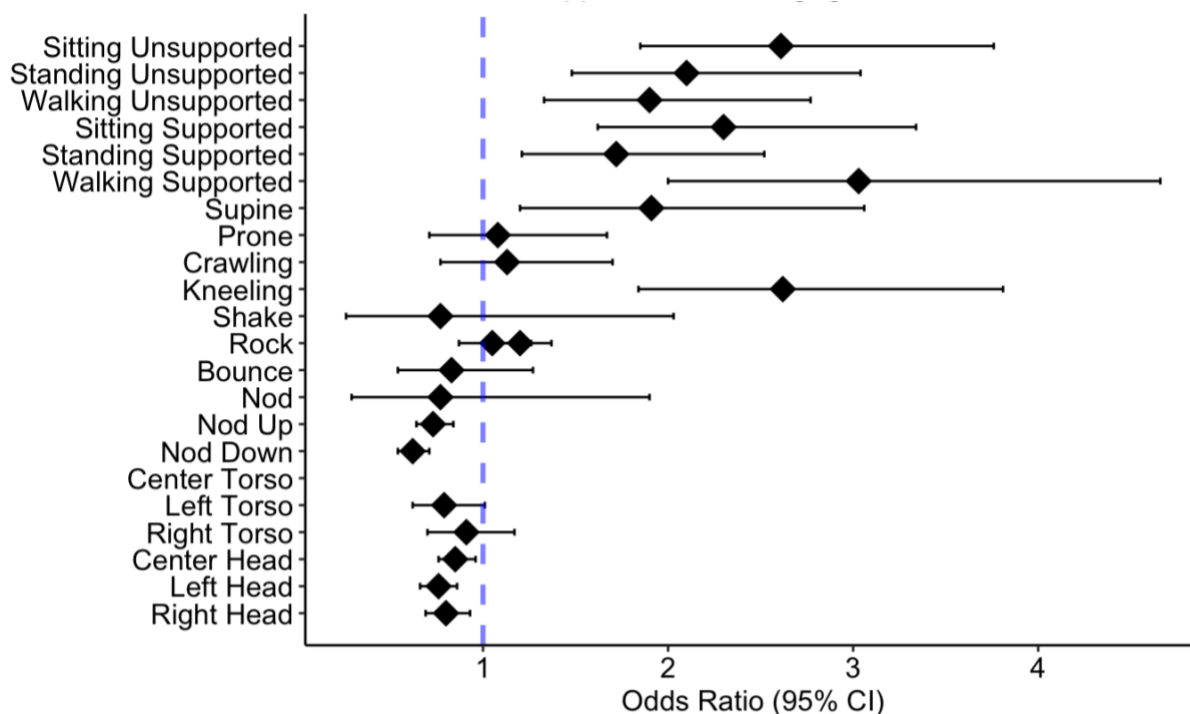
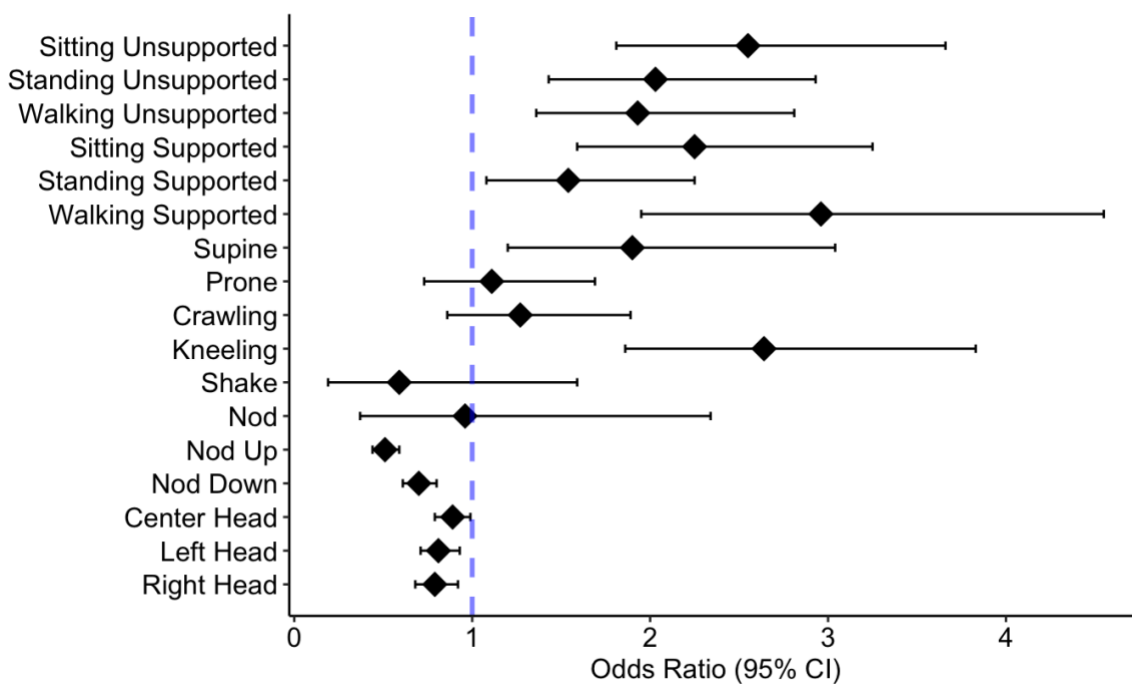
Figure 11.*Associations to Supported Joint Engagement***Figure 12.***Lagged Associations to Supported Joint Engagement*

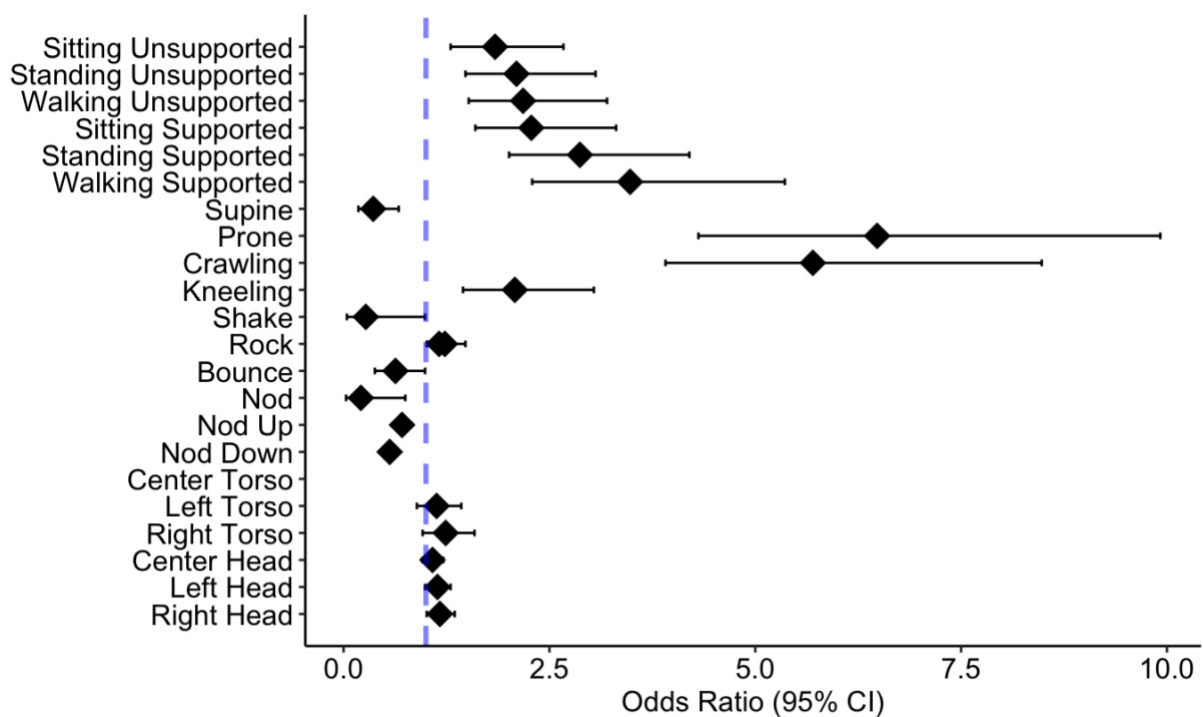
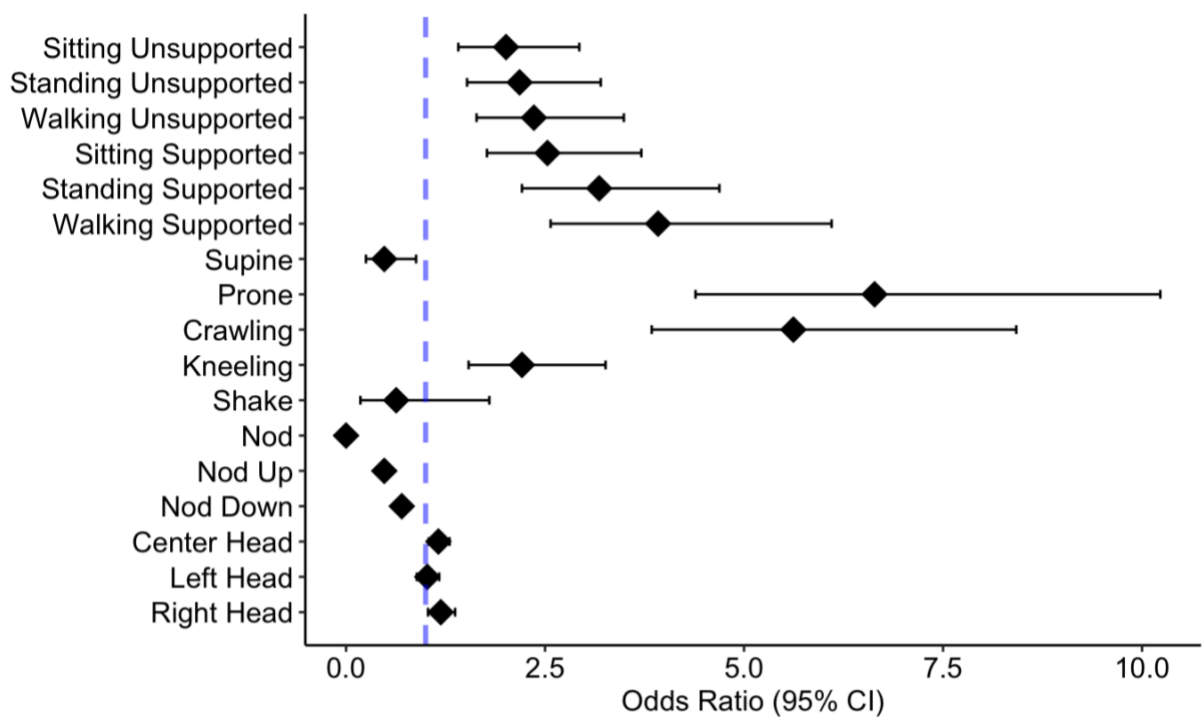
Figure 13.*Associations to Solo Object Play***Figure 14.***Lagged Associations to Solo Object Play*

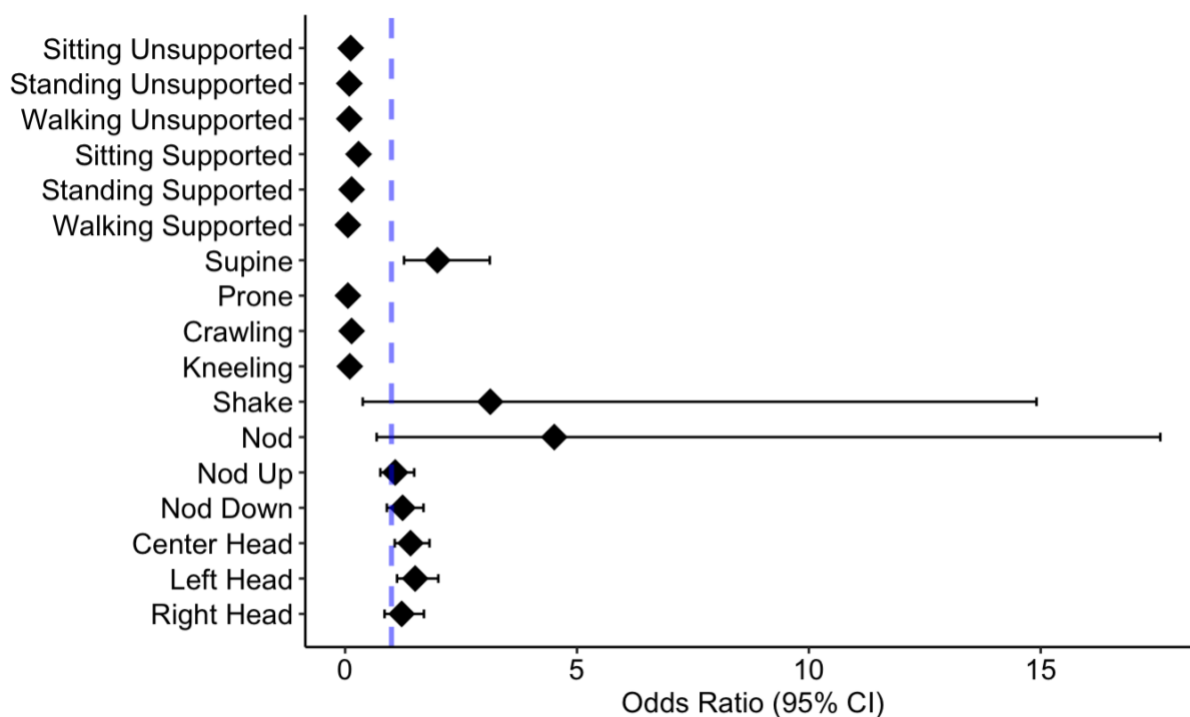
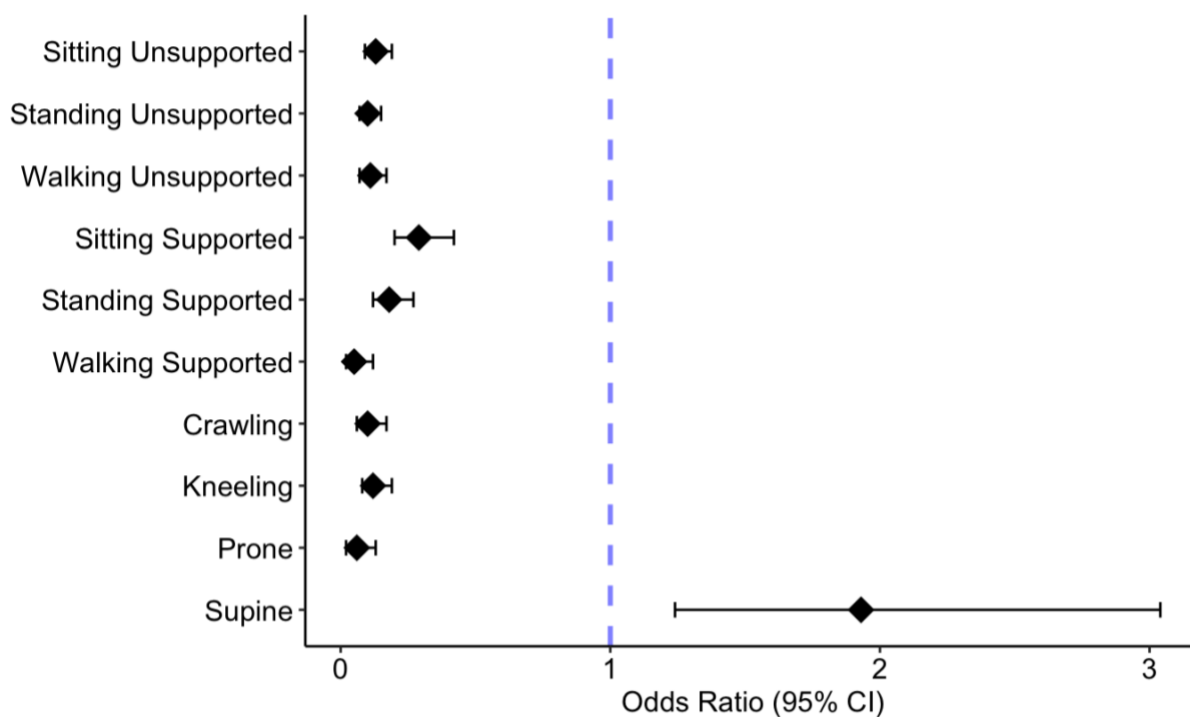
Figure 15.*Associations to Social Engagement***Figure 16.***Lagged Associations to Social Engagement*

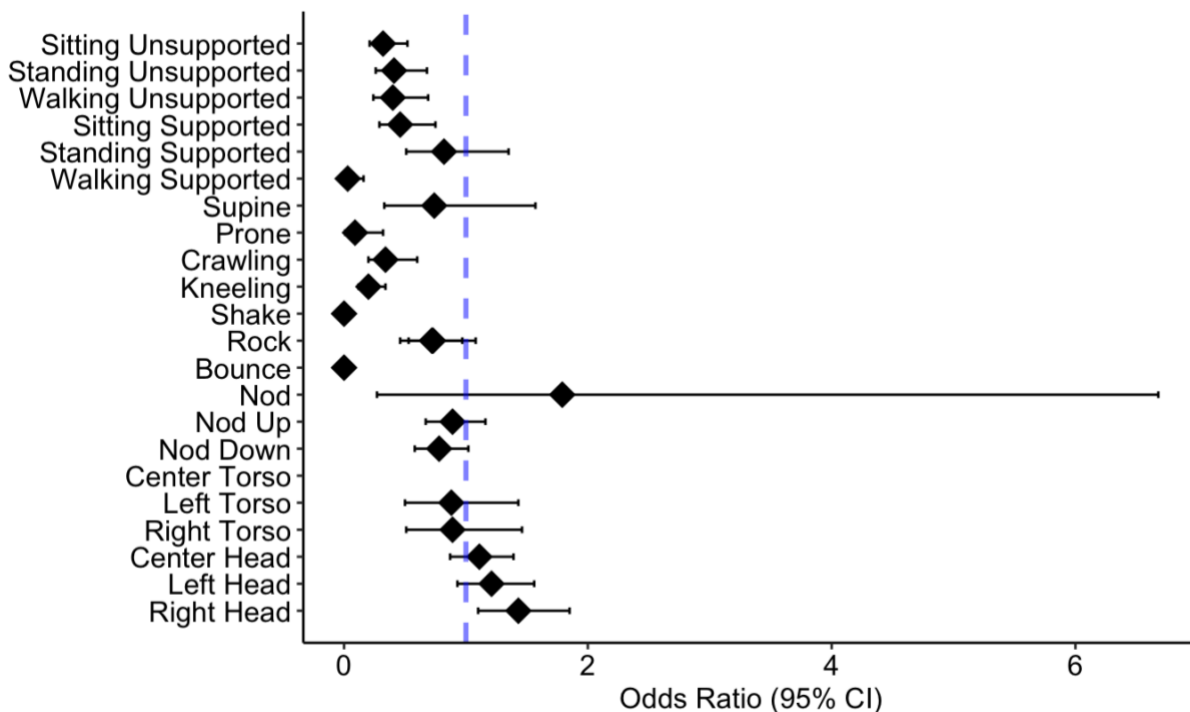
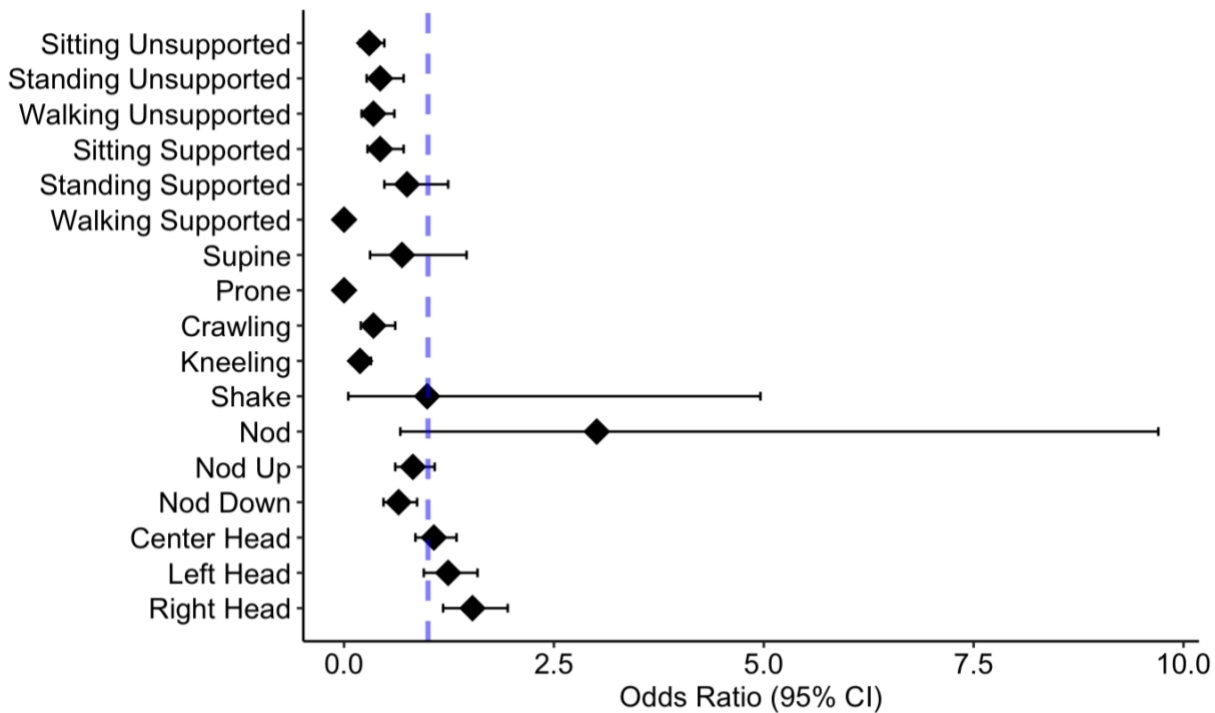
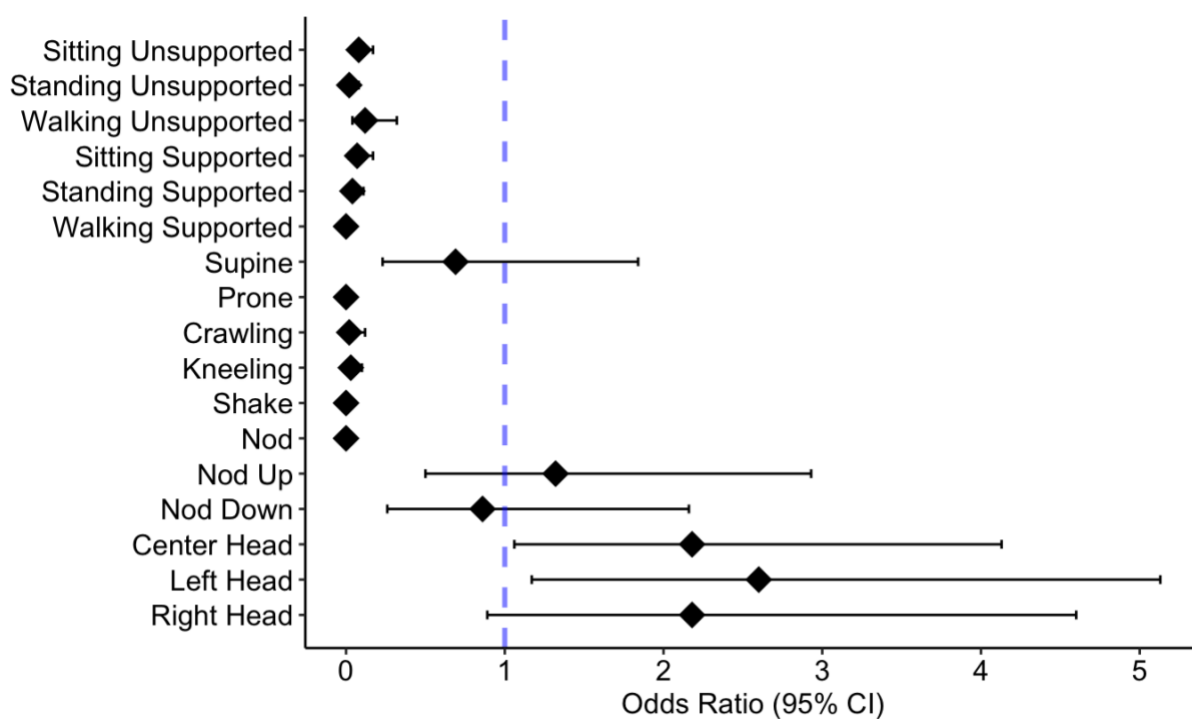
Figure 17.*Associations to Onlooking***Figure 18.***Lagged Associations to Onlooking*

Figure 19.*Associations to Unengaged***Figure 20.***Lagged Associations to Unengaged*