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Infant Locomotor Skill Development in the Context of Mother-Infant Interactions

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To the Graduate Council:

I am submitting herewith a dissertation written by Sabrina Lynn Thurman entitled "Infant Locomotor Skill Development in the Context of Mother-Infant Interactions." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Psychology.

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Infant Locomotor Skill Development in the Context of Mother-Infant Interactions

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Abstract

The acquisition of locomotor skills and transitions within them leads to changes in infants' exploratory abilities and interactive behaviors, which affects several aspects of parent-infant exchanges. Here, we tracked how the onset of crawling and walking affected both infants' and mothers' spatial exploration, interactive behaviors, and use of postures in 10-minute free play sessions held in a laboratory setting. Thirteen infants and their mothers were followed longitudinally with biweekly sessions occurring from before crawling onset until infants had two months walking experience. We focused on two 6-session transition periods centered around the onsets of hands-and-knees crawling and walking. Behavioral data from the free play sessions were used to identify changes in spatial location coordinates, interactive behaviors, and postures within and across sessions. The use of location coordinates allowed us to derive measures of spatial exploration, including distance traveled, speed of travel, dispersion in the room, and distance between the mother and the infant. We related measures of spatial exploration to their interactive behaviors with toys, furniture and each other, their use of, and transitions between, postures, and the infants' postural stabilization during play as they moved about the room. Results showed that predominantly with the acquisition of hands-and-knees crawling, infants increased their spatial exploration of the room, which was associated with concomitant increases in their interactive behaviors and postural changes. Mothers, on the other hand, showed an increase in spatial displacement in the room, but this increase was not associated with increased interactive behaviors or postural changes. This indicated that mothers' spatial displacement was more likely driven by monitoring their child, and not active discovery of the room. As infants gained mobility, the distance between infant and mother increased. Mother-infant interactions and explorations therefore reorganized over time as infants gained motor skills.

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Part 1. Introduction

Portions of this work were previously published in the journal *Developmental Psychology*, authored by Sabrina L. Thurman and Daniela Corbetta [Thurman, S. L. & Corbetta, D. (2017). Spatial exploration and changes in infant-mother dyads around transitions in infant locomotion. *Developmental Psychology.* Advance online publication. doi: 10.1037/dev0000328]

> "By movement alone we learn about the existence of things which are not ourselves; and it is by our own movements alone that we gain the idea of extension."
>
> – Jean-Jacques Rousseau (1762, pg. 27)

There are few milestones in infancy that are as celebrated by parents as the onset of independent locomotion, in the forms of crawling and walking. Infants also show elatedness upon the discovery of their new skills (Mahler et al., 1975). This enthusiasm in both infants and their parents is understandable, because with the development of infant postural skills and the emergence of mobility, infants gain novel opportunities to explore their environments in ways they have never before experienced. The development of these new skills changes their interactions with objects and people in their environments (Campos et al. 2000), enabling them to begin to act on their worlds independently from their mothers, to whom they had previously relied on heavily. These advancements in turn allow them to gain new knowledge (Gibson, 1988, 2003; Piaget, 1936). In conjunction with these drastic changes taking place in infants, there are also many changes that occur in mothers and families surrounding the onset of infant locomotor skills (Campos et al., 2000; Whitney & Green, 2011).

Many notable theorists have emphasized that these early interactions infants experience with their physical and social environments are important for the development of sensorimotor schemata (Piaget, 1936), cognitive functioning and intellectual development (Jennings, Harmon, Morgan, Gaiter, & Yarrow, 1979), learning about environmental affordances (Gibson, 1988), and for breaking symbiosis with their mothers and developing a concept of self (Campos et al., 2000; Mahler et al., 1975; Neisser, 1991). Furthermore, early appearing infant-mother interactive behavior patterns also have the potential to affect individual behaviors and interactions in the long term. A recent study by Bernier, Calkins, and Bell (2016) showed that high-quality mother-infant interactions contribute to infants' brain development over the first two years of life. There is also evidence that strongly suggests that the ways mothers interact with their infants physically can affect several aspects of development. When caregivers altered how they handled and positioned their infants, significant changes in several infant motor behaviors were affected immediately, in the short term, and up to 12 months after experimental manipulations (Lobo & Galloway, 2012).

Even more importantly, early motor skills can potentially lay the foundation for a cascade of other fundamental skills later in life. For instance, Libertus & Violi (2016) found that sitting skills may influence language learning opportunities. In their study, infants who sat independently at younger ages had higher receptive vocabularies at 10 and 14 months. Libertus & Violi (2016) explained that the onset of self-sitting may be important for further developmental outcomes in language because sitting frees the hands and exposes the infant to more visual information, which may facilitate the use of gestures and social interactions with caregivers.

Similarly, Bornstein, Hahn, and Suwalsky (2013) found that more motorically mature and exploratory competent 5-month-old infants tended to show higher levels of intellectual functioning at 4 and 10 years of age, and higher academic achievement at 10 and 14 years of age. Motor maturity and exploratory competence increases opportunities for interactions with objects, which expands learning opportunities. Furthermore, a few recent studies (Karasik, Tamis-LeMonda, & Adolph, 2014; Lobo and Galloway, 2012) suggest that motor skill levels in infants changes responsivity in parents, which may further contribute to subsequent outcomes. Therefore, infants possess and begin to display qualities early on that contribute to their own long-term development (Bornstein, et al., 2013). These studies provide evidence to support Thelen & Smith's (1994) claim that rudimentary skills provide ground work from which subsequent capacities are expanded.

Thus, there are useful applications that can be derived from understanding the dynamics of mother-infant interactions during infancy. There are obvious links to parenting, but this research is also crucial for understanding how infants' socio-emotional, motor, and cognitive development is affected by early locomotor interactions with caregivers. Even though these interrelationships are so important, the literature on these topics lacks a great deal of information characterizing how mothers and infants use their postures and mobility to explore and interact with their environments and one another within play sessions and through the course of motor development in the first two years of the infants' life.

Through the last several centuries, many prominent researchers and theorists have attempted to address aspects of these phenomena, ranging from the complex changes in infants' expanding repertoire of postural and locomotor skills, and the dynamic changes in mother-infant interactions throughout development. A literature review of these perspectives will describe where these ideas originated and where they have gone in recent years.

Historical background and theoretical orientations

One of the earliest theorists to set the stage for studying how infant learning and discovery is tied to movement was Jean-Jacques Rousseau. His work, fixed in the mid-1700s, stemmed from John Locke's view that infants were fundamentally different from adults, but unlike Locke, Rousseau did not place any value on the social environment in development (Rousseau, 1762). He instead emphasized that society should do everything possible to facilitate the role of nature in children's growth and development. He described that during infancy, children use their senses to explore their worlds to gain new information, and that movement of the infants' own body plays a crucial role in this process (Rousseau, 1762).

Similar to his predecessor, Rousseau, James Mark Baldwin also was committed to understanding how movement patterns in infancy contribute to other developmental changes. His characterization of development as a dynamic and hierarchical process was one of the most influential of his propositions (Baldwin, 1897). Through accommodative processes, he explained, an organism adapts to stimulation from the environment by performing increasingly complex functions, such as gaining motor skills. He also recognized the role of self-stimulative experiences in infancy by describing both sensory and motor components of learning, and argued that advancements in one competent would strengthen the other. He described that heredity is a foundation, and developmental growth continues during infancy, but only through infants' actions on their worlds. Baldwin's (1897) writings were therefore some of the earliest introductions describing the link between infant sensorimotor development and learning.

In addition to delineating the importance of sensorimotor foundations of mental advancements in infancy, Baldwin also emphasized that the child's emerging sense of self is a product of many reciprocal interactions with others in the environment (Baldwin, 1897). Modern theorists tend to group Baldwin with ecological, contextual, or cross-cultural theorists (Thelen & Smith, 2006), some of which will be discussed further in the paragraphs below.

Maria Montessori had similar ideas to Rousseau and Baldwin about how children have active roles in their own learning processes, but she was one of the first developmentalists who committed herself to actually teaching children. Although most of her work was applied to early education settings, she also made enormous strides in progressing developmental theories. She argued that children learn through their own active interactions, from maturational forces (Montessori, 1936a), and they learn differently than adults (Montessori, 1936b). Although the role of self-stimulative experiences in development were popularized by Montessori, they were first emphasized by Rousseau (1762) and Baldwin (1896).

Montessori believed that certain significant behaviors were learned during sensitive periods, which to her, were pre-programmed periods when the child was especially eager to master a particular task, such as walking. If the child did not learn the task during its sensitive period, the child's eagerness to learn it would diminish, which would affect development in the long term. In the case of walking, Montessori described the acquisition of upright locomotion as a second birth for the child because of the passage to becoming an active rather than passive being (Montessori, 1936b). During this time, and for much of the child's early life, the role of the caregiver was simple – to provide opportunities to stimulate their child's interests. Montessori described that some mothers enjoy following their newly walking infants and take pride in watching their child's discoveries. However, she claimed that some mothers may become anxious about where their child will now venture on their own, or attempt to help their child walk or pick up their child to help the child get to his or her goal faster. Montessori claimed that the ways parents respond to their infants learning to walk impacted the infants' feelings about their own independence (1936b). In this way, Montessori was one of the first theorists to address potential changes in the parent-infant relationship in the context of infant locomotor skill development.

Although much of Montessori's work was applied to early educational settings, she still possessed a theoretical position that, in part, was strongly influenced by Rousseau. Rousseau emphasized that development occurs as a result of guidelines set forth by nature. This explanation is known by modern developmentalists as biological maturation. Among other maturational theorists like Myrtle McGraw, Arnold Gesell was one of the most influential in the realm of motor development (Thelen & Adolph, 1992). For Gesell, the most important factors in development were hard-wired maturational forces from within the child, which were under control of the genes. Development occurred, according to him, in a fixed sequence, but children varied in rates of development. One of Gesell's main foci during his career was to describe developmental norms for motor achievements, and his time period became known for those goals. He wrote at length about the stages and ages of motor development milestones such as reaching, crawling, and walking (Gesell, 1928; 1946; Gesell & Ilg, 1943; Gesell & Thompson, 1938). This approach focused predominately on answering "what" and "when" questions, without much consideration of environmental characteristics, infant motivations, or perception-action links. For Gesell and his fellow maturational theorist Myrtle McGraw, what started out as descriptives for general milestones in the development of motor skills eventually became how he explained the cause, as he relied increasingly on the role of genetics (Thelen & Adolph, 1992).

Gesell's motor cataloguing efforts and incomplete and deterministic theory gave way to a new type of research focused on the variables that cause motor development to happen.

Maturational views of motor development quickly declined in popularity with the increasing favor to Piagetian notions, which emphasized sensorimotor exploration and play as primary mechanisms through which children gained knowledge about the world (Piaget, 1936). Important for motor development, Piaget believed that at each stage, children constantly move around their environments, exploring and interacting. Through this process, they make sense of their surroundings and construct increasingly comprehensive mental structures to function effectively in their environments (Piaget 1947). Although William James first described the interrelationships between consciousness and self-movement (James, 1892), Piaget was one of the first to posit that through exploration and learning, children constructed their developmental stages themselves, which, unlike maturational theorists before him, emphasized an active role of the child in its own development. Piaget therefore extended the study of development to answer "how" development may occur. Similar to Gesell and other maturational theorists, Piaget maintained that children move through stages of development in an invariant order. He, however, did not believe that his proposed stages of development were genetically programmed (Piaget, 1936).

Piaget characterized infancy as a sensorimotor period, in which infants actively construct different movements and action structures, called schemas. Piaget claimed that once infants develop a scheme, they must use it (Piaget, 1936). He characterized several stages in infancy that outlined the infants' developing understanding of the role of their own actions in creating interesting changes in the environment. Through those processes, developing primary, secondary, and tertiary reactions, infants gradually learn to vary their actions to observe different results within themselves and their environment (Piaget, 1947). Piaget acknowledged that the environment is important for development, but only in the sense that the environment should interest and stimulate the child to explore and act on it, in order for the child to construct his or her own cognitive structures (Piaget, 1936). This idea seemed to stem from Baldwin, who was minimally credited for originating many ideas used in Piaget's writings. Nearly four decades earlier, Baldwin (1897) wrote at length about the role of the environment in shaping adaptations of organisms. Beyond the role of the physical environment, in Piaget's mind, and similar to Rousseau and Montessori, parents and educators did not play significant roles in teaching children (Montessori 1936a; Rousseau, 1762). This was because to him, learning came from the child, through his or her own discoveries (Piaget, 1936, 1947). Therefore, as infants explore and manipulate their environments, they assimilate and accommodate new information, which leads to advancements in intellectual development.

Unlike many of his predecessors, Piaget's theory did not emphasize the role of the parents in children's early development. Some of the first theorists to consider the holistic role of mothers in infants' early social-emotional development were ethologists. John Bowlby and Mary Ainsworth made great strides in applying ethological concepts from Charles Darwin, Konrad Lorenz, and Niko Tinbergen to human mother-infant attachment relationships (Ainsworth, 1967; Bowlby, 1973; 1982). Bowlby proposed that children evolved to show attachment behaviors, which were behaviors that promoted close physical proximity to caregivers. He emphasized that the need for close attachment relationships was part of human nature (Bowlby, 1973). When infants are young, he claimed, their preferences are still building, but by the time they are 3 to 6 months old, they have clear preferences for certain people over others. When infants begin to crawl and walk, they begin to take active roles in maintaining proximity to the caregiver(s) to whom they have become attached (Bowlby, 1982). Importantly, locomoting infants with healthy attachments learn to use their caregivers as secure bases for exploration, meaning the infants would periodically check back with their caregivers during moments when they ventured far away from their caregivers (Ainsworth, 1967). Bowlby and Ainsworth took great strides in expanding the ideas previously presented by Montessori (1936b) about the nature of mother-infant interactions and their effects on infant exploratory behavior.

In contrast with Bowlby and Ainsworth's more holistic ethological theories emerging at the time, Margaret Mahler focused on details in mother-infant interactions through careful study. She monitored how infants gradually separate from their mothers within the relationship. Mahler explained that in early infancy, infants live in symbiosis with their mothers, which to her, meant that infants believed that they and their mothers were one in the same. She claimed that through mutual gazes, smiles, and sounds that occurred during mother-infant interactions, the boundary between each individual was blurred from the infant's perspective (Mahler, Pine, & Bergman, 1975). With age, she explained that infants begin to separate themselves from the symbiotic relationship with their mothers and become more independent as their own person. During the separation/individuation process, the infant begins expanding his or her interactions to the environment, becomes more distant from the mother, and begins to use and understand his or her perceptual abilities to remember where things are in the environment. When they begin to locomote, infants become enthralled with their abilities to explore and discover the widened number of possibilities in their surroundings. They become almost intoxicated with the splendor of their changed perspective and spend a great deal of time practicing their motor skills, and interacting with objects and other humans in their environments. Despite all of these new opportunities for interactions, Mahler and colleagues (1975) claimed that walking infants remain very interested in their mothers' whereabouts. Similar to Montessori (1936b), Mahler also explained that during this process, mothers' may respond calmly and may be quietly available for the child, whereas others may become anxious about their infant's new independence and may disrupt the child's activities (Mahler et al., 1975). Either way, the child learns meaningful information about their new exploratory abilities in part through their mothers' reactions.

Several prominent developmental theorists and researchers have viewed motor development and mother-infant interactions from contextual and systems approaches during the latter half of the twentieth century. The emergence and popularity of these theories emphasized the importance of how events occurring during locomotor development could have further influences in other aspects of infants' early lives and interactions with their caregivers.

In the mid-1900s, Lev Vygotsky was exposed to the early writings of prominent developmental theorists like Gesell and Piaget, but Vygotsky thought development could only be understood within the social-historical context (Vygotsky, 1930-1934/1978). To address this gap, he proposed a theory that explained how children developed based on the knowledge passed to them through their cultural contexts. Unlike Piaget, Vygotsky saw value in instruction, because to Vygotsky, children's minds would not be very advanced if they were only the product of their own discoveries. Vygotsky seemed to think more in line with his predecessor and fellow contextual systems theorist, Baldwin, who more than three decades earlier had written about the importance of the mutual dynamics between the child and others (Baldwin, 1897). Vygotsky introduced the idea of scaffolding in the zone of proximal development as a way to promote learning in children. In this viewpoint, more experienced mentors lead mentees through learning by providing temporary aids just beyond the level at which the mentee can succeed on their own (Vygotsky, 1930-1934/1978). A scaffolding behavior in learning to walk for example, could be when a parent holds their child's hands to lead them across a room until the child learns to effectively balance herself during locomotion. Therefore, in Vygotsky's theory, more skilled adults sometimes play a very important role in the infant's life by providing assistance. This idea was highly contrasted with claims from Montessori (1936b) around the same time about how children must learn to master new skills on their own. These theorists therefore strongly disagree about the parent's role in interacting with their infants during the development of new locomotor skills.

Unlike their maturationist predecessors who downplayed the role of experience in development in place of explanations based on endogenous biological forces, Daniel Lehrman, Zing-Yang Kuo, and Gilbert Gottlieb emphasized that there is no such thing as a nonexperiential component of development (Gottlieb 1991a,b, 2007; Gottlieb, Wahlsten, Lickliter, 2006; Kuo, 1976; Lehrman, 2001). Gottlieb's explanation of probabilistic epigenesis described that development occurs as a result of time-based, probabilistically changing reciprocal interactions between many levels of genetic, physical, and environmental factors throughout life (Gottlieb 1991a,b, 2007; Gottlieb, Wahlsten, Lickliter, 2006). Gottlieb's notions about probabilistic epigenesis are relevant for research about the developmental consequences following the onset of independent infant locomotion (Anderson et al., 2013). He emphasized that the onset of developmental milestones or variety in new experiences, such as crawling and walking, play meaningful roles in further developmental changes in similar or different domains (Gottlieb, 1983; 1991a,b; Gottlieb et al., 2006).

Perhaps influenced by his predecessors, James Mark Baldwin (1897) and Jakob von Uexküll (1920), Gottlieb also wrote about a myriad of influences on development, including physical, social, and cultural aspects of early life and the bidirectional changes occurring between levels (e.g., Gottlieb, 1992; Gottlieb et al., 2006). Nearly a century before, Baldwin was one of the first theorists to describe psychobiological bidirectionality between the organism and the environment in what he called "circular reactions" (Baldwin, 1897). This notion was further emphasized by von Uexküll (1920). According to von Uexküll (1920), animals possess qualities that allow them to perceive certain elements of the worlds around them. They then respond to those perceived elements of their sensory worlds in unique ways. The set of stimuli perceived and the set of responses animals use to act on their environments together create a functional circle. Similarly, Gottlieb (1992) highlighted the essential role of experience in structural and functional developmental processes. This collection of work therefore stressed that individuals play important roles in their own developmental cascades by creating and interacting within environments that contribute to their own developmental progression. Interestingly, this idea is similar to ideas about niche construction, which is very popular in modern evolutionary biology (Laland & O'Brien, 2011). Lehrman, Kuo, and Gottlieb's line of thinking contributed to the emergence and popularity of developmental psychobiology, a field that began to interest many researchers, and importantly for this dissertation, those who investigated early development in infancy.

Many prominent developmental psychobiologists who were interested in infant development have looked to the interrelationship between mothers and infants to describe and explain developmental changes (Moore, 2007). Rosenblatt was a leading figure in characterizing the complementary dynamics in mother-infant relationships by using the word *synchrony* (Rosenblatt & Lehrman, 1963). He was one of the first to describe the mother-infant relationship as a dynamic interaction loop that synchronizes, abruptly changes, and reorganizes iteratively at various developmental levels as a function of developmental time (Rosenblatt, 1965, 1987).

Towards the end of the twentieth century, many researchers showed great interest in understanding the interactive relationships between infants, their mothers, and their environments.

Stemming from the child-centered focus of Piaget and perceptual research from ecological psychology, Eleanor Gibson introduced an ecological approach to studying perceptual-motor development, which emphasized that through the interactive relationships between perceiving and acting on the environment with their own bodies, infants come to understand their surroundings (Gibson, 1988). Gibson's work contains hints of ideas originally introduced by William James, who, nearly a century before, claimed that learning was a process that occurred over a period of time that required distinctive sensory input. James postulated that the environment and the cognitive system cannot be separated because cognition relies on the perception-action context (James, 1892).

Similar to other prodigious theorists before her, Gibson's work showed that when infants begin crawling, they expand their interactions to the more distal environment (1988), which sets the stage for future explorations once they learn to walk. She claimed that everything infants see in their environments provides an incentive for them to explore (Gibson, 1978), and that they must learn the match between their own action skills and the features of the environment that supported their actions (Gibson, 1988). She emphasized that spontaneous self-initiated locomotion had significant influences on these processes by impacting early perception and cognitive development (Gibson, 1988).

Stemming from foundations built by developmental psychobiological systems theory, Esther Thelen and Linda Smith introduced dynamic systems theory to describe many changes in infant motor and language development (Thelen & Smith, 1994). Their popular approach grew from advancements in understanding complex and nonlinear systems in physics and mathematics, but also was influenced by psychology and biological sciences (Thelen & Smith, 2006). Through the lens of dynamic systems theory, infant development could be characterized as a complex system that constantly organizes and reorganizes over time, until stability is established in behaviors called *attractor states* (Thelen & Smith, 1994). Therefore, change in the variability of a behavior often reflects ongoing reorganizations of the system. However, dynamic systems theory also offers the notion of dynamic stability, which is the idea that even though a behavior such as stepping might appear to be relatively stable over time, it is also dynamically composed in the moment as a function of many processes and contextual factors (Thelen & Smith, 1994). Therefore, there are consistent microscopic changes even in behaviors that appear to be stable at macroscopic levels, and those microscopic changes serve as seeds that aid in the production of macroscopic changes in development. It is important, then, to collect observations before, during and after periods of rapid change in behaviors to better understand developmental changes both within infants and in the microcontexts of mother-child interactions (Fogel, 2011; Thelen & Smith, 1994).

The developmental dynamics specifically of mother-infant interactions have also been of interest in recent years. A delicate balance of many factors influence the outcomes of mother-infant interactions in real situations, such as the infants' postural control, motor skill levels, motivations to interact, and cognitive abilities, or the mothers' mood, sensitivity, or distractibility (Fogel, Nwokah, & Karns, 1993). For instance, a mother and infant may be playing happily with a particular toy, when the mother decides to move the infant's body to a standing posture to better allow them to reach for the toy. This new posture however may be a tipping point for the infants' motor skill level and concentrating on maintaining balance in the new posture may distract them from how they were previously engaging with the mother and toy. But, if the mother maintains the infants' balance, they may be just as able to play with the toy as they were before. Therefore, one change in the system (e.g., the infants' posture, or postural stabilization) may affect the ongoing behaviors in the mother-infant interaction. In lieu of many static and linear models of development that came before, dynamic systems theory provides a strong framework for understanding mother infant-interactions during locomotor development.

Despite the wide scope of centuries of theory about motor development and several decades of thought and observation applied to mother-infant interactions, much work still remained for more recent developmental investigators in order to fully understand the complexities of how mother-infant interactions dynamically change during infant postural locomotor progression. In recent years, many of those researchers have drawn inspiration from prominent theorists such as Piaget, Mahler, and Gibson, and have expanded previous theories with a host of empirical evidence.

Developmental Changes in Infants Following the Onset of Independent Locomotion

Researchers today still find evidence that the acquisition of new motor skills plays an essential role in infant exploratory abilities (e.g., Bornstein et al., 2013). For example, recent studies have reported that the acquisition of reaching abilities contributes in creating changes in the ways infants explore social situations (Chen, Reid, & Striano, 2006), as well as their own bodies and objects in their environments (Lobo & Galloway, 2013). Furthermore, the emergence of self-sitting abilities in infants contributes to fostering visuo-manual explorations of objects, which in turn, affects the way infants can detect and complete features of objects visually (Soska, Adolph, & Johnson, 2010). One of the most significant motor skill acquisitions that will be discussed in depth in this dissertation is that of independent locomotion.

For decades, many prominent theorists have claimed that the onset of locomotion aids infants in learning the dynamics of their relationships to objects and people in their environments. Many recent studies have further shown that when infants gain self-initiated exploratory skills such as crawling and walking, the way they perceive, interact with, and explore their environments significantly changes (Anderson et al., 2013; Bornstein et al., 2013, Campos et al., 2000; Gibson, 1988). Many recent studies have supported Gibson's early claims about the importance of self-initiated locomotion and have shown that an infant's new ability to move throughout their environments on their own significantly alters many aspects of behavior, socio-emotional characteristics, and cognitive abilities (for reviews see Anderson et al., 2013; Campos et al., 2000).

The emergence of hands-and-knees crawling and walking, in particular, have a critical impact on this learning process. Prior to independent locomotion, infants are typically only passively moved from one location to another by their caregivers. During this time, their passive movements do not require their attention or postural control. However, with the onset of independent locomotion, it becomes necessary that infants allocate their attention to monitoring their new actions, explorations, and postures.

Since Gibson's early work and in more recent years, the emergence of these two motor skills have continued to be linked to a host of developmental changes. Pre-locomotor infants tend to spend just as much time looking at walls and floors in rooms as they do looking at their mothers and toys (Bertenthal, Campos, & Barrett, 1984). Gustafson (1984) examined the differences in exploratory behaviors when pre-locomotor infants were placed in a walker versus placed on a stationary position on the floor. Pre-locomotor infants in walkers traveled further distances, looked more and showed more directed behaviors towards people and objects in the room (Gustafson, 1984). This simulated experience of walking in a baby walker gave pre-locomotor infants similar experiences to what most infants encounter once they learn to crawl.

Many studies have shown that when infants learn to crawl on all fours, they begin to understand more properties of the objects and environments around them compared to when they could only wriggle or pivot. For example, compared to pre-crawlers, crawling infants are better able to spatially locate hidden goals (Bai & Bertenthal, 1992; Bertenthal et al., 1984; Clearfield, 2004), and show higher performance on object permanence tasks (Bell & Fox, 1997; Gross, Hayne, Perkins, & McDonald, 2006; Kermoian & Campos, 1998). In free play sessions, crawlers become more independent from their caregivers compared to pre-crawlers and spend more time simply watching adults compared to walking infants (Clearfield, Osborne, & Mullen, 2008). Compared to pre-crawling infants, crawlers' actions are more likely to be goal-directed (Zachry & Mitchell, 2012). Pierce, Munier, and Myers (2009) conducted a naturalistic study in participants' homes, which showed that once infants could crawl, they began to pursue objects in the periphery of rooms for interactions, as opposed to the center of rooms where they had previously spent most of their time when they were immobile. All in all, the transition period from pre-crawling to crawling is characterized by infants beginning to expand their interactions to the more distal environment, which sets the stage for future explorations once they learn to walk.

Despite all of these advancements with the onset of crawling, it is important to note that some research suggests that crawling infants tend to seek out individuals rather than objects (Pierce et al., 2009), and their interactions with the environment still tend to be rather passive compared to walking infants (Clearfield et al., 2008; Clearfield, 2011). Dosso and Boudreau (2014) found that object interactions for crawling infants tended to be based on how close the object was to the child. However, for walking infants, object interactions were based more on whether infants preferred the objects, irrespective of the object distance (Dosso & Boudreau, 2014). Walking infants' interactions appear more deliberate compared to crawlers, as walkers will travel further distances than crawlers to obtain a certain toy or reach a particular destination (Dosso & Boudreau, 2014; Pierce et al., 2009). One explanation put forth by Dosso and Boudreau (2014) to explain this difference in crawlers and walkers was that crawling expends more energy than walking, so more effort is required from the infant to move. This claim is supported by other research showing that walking infants show higher levels of travel distance and faster speed of travel compared to infants who are experienced crawlers (Adolph et al., 2012; Clearfield, 2011; Dosso & Boudreau, 2014; Snapp-Childs & Corbetta, 2009).

When infants begin to walk, they become even more interested in actively exploring their environment (Clearfield et al., 2008; Clearfield, 2011), and their use of environmental space no longer relies on room and object edges (Pierce et al., 2009). They begin to preselect destinations and travel to certain locations in the room for seemingly planned interactions (Pierce et al., 2009). Many studies have reported that the behaviors of walkers dynamically changed, such that they became more interactive with toys, their mothers, and other adults (Campos et al., 2000; Clearfield et al., 2008; Clearfield, 2011; Karasik, Tamis-LeMonda, & Adolph, 2011). Walkers also engage in more visual and haptic exploration of their surroundings, show greater abilities to perceive environmental affordances, and navigate various surfaces with more behavioral flexibility compared to crawlers (Gibson et al., 1987; Kingsnorth & Schmuckler, 2000). In line with these perceptual advancements, walking infants have also been shown to display wariness to heights (Campos, Bertenthal, & Kermoian, 1992; Witherington, Campos, Anderson, Lejeune, & Seah, 2005). In sum, these studies highlight that the progression occurring between periods of nonlocomotion, hands-and-knees crawling, and independent walking is an important one that can significantly affect infants' interactions with the environment.

The acquisition of independent locomotion also influences several aspects associated with social interactions. Consistent with prior work by Bowlby (1973; 1982) and Ainsworth (1967), the onset of crawling marks a time period when infants become more likely to display proximity-seeking behaviors and show greater awareness of where their caregivers are (Campos et al., 2000). Despite the desire to be near their caregivers, mothers of crawling infants have reported that their infants show increased positive and negative reactivity during interactions (Whitney & Green, 2011). These patterns are consistent with earlier claims of Mahler et al. (1975), indicating that when infants learn to locomote, they show great excitement, but also show patterns of willfulness. Certainly, mothers begin to notice these changes in their infants as they impact their dyadic interactions. These infant-caregiver dynamics change further when infants transition to upright locomotion. Precocious walkers tend to have fewer positive interactions with their mothers and tend to also experience an increase in maternal prohibition behaviors compared to later walkers, who showed more communicative stability in their interactions with their mothers across the transition to upright locomotion (Biringen et al., 1995).

In addition to the emotional tones of their interactions, there are also differences in how infants capture their mothers' attention during communications. Some research has shown that after the walking onset, infants produce significantly more bids for their mothers' attention compared to when they could only crawl (Clearfield et al., 2008). And, another study by Karasik and her colleagues (2014) showed that walking infants were more likely to produce bids while moving than crawlers, who tended to be more stationary during object-sharing moments. Importantly, the form of infants' object-sharing bids influenced how mothers responded to their infants. Therefore, a cyclical relationship seems to exist in which infants' locomotor skills affect how they engage with their caregivers, which influences how caregivers respond to their infants, and which then affects infant social behaviors. Other researchers have also shown links between infant locomotor status, caregiver responses, and further effects in the infants. Walle and Campos (2014) recently demonstrated that in comparison to crawling infants, walkers with higher levels of caregiver language input also have higher scores on receptive and productive vocabulary assessments.

As reviewed earlier, many notable theorists have written about the changes occurring after the onset of walking. Montessori described the acquisition of walking as a second birth (1936b), in which children transform from holding passive roles to becoming busy-bodied actors on their environments. Mahler and colleagues (1975) also claimed that gaining the ability to move on their own seems to spark an elated state of interactions in infants. They move almost constantly, and at variable speeds, back and forth between objects of interest, or climbing up and down, over and under obstacles in their environments. In fact, they seem to almost be in love with the sensation of moving. Interestingly, Montessori (1936b) and Mahler et al. (1975) also wrote about how parents' responses to their infants' newly discovered passions for movement are also important. Despite these writings, no one, to our knowledge, has ever investigated infants and mothers' naturalistic movements (e.g., distance traveled, speed of travel) and interaction behaviors during playful exchanges with one another in complex environments containing furniture and toys.

The role of posture in infant play

It is important to note, however, that complexity is not solely inherent to the environment. It can also be linked to the range of behaviors infants produce and learn to develop over time. As stated before, the emergence and progression of new locomotor skills makes new interactions with the environment possible and extends the types of behaviors infants previously were able to produce. Consistent with this idea, Infant Space Theory suggests that a codependent interrelationship exists between infants' expanding repertoire of locomotor skills and their attraction to challenge and novelty (Pierce et al., 2009). Decades ago, Gibson (1988) wrote about intrinsic forces within infants that compelled them to actively seek out novelty in their environments, and recent research has confirmed that individual infants' motivations to move and their motor development trajectories are related (Atun-Einy, Berger, & Scher, 2013). Therefore, due to their active efforts to engage with their environments in novel visual, spatial, and tactile ways, they push the limits of their motor abilities. In turn, each new motor skill provides fresh opportunities to pursue objects and experiences in their surroundings (Pierce et al., 2009). Hence, the child's dynamically changing motor lens provides a new world view and a new window of opportunities for children to spatially explore and interact with their environments. And, when infants learn this association, it may motivate them to push themselves to explore further.

Despite the host of prominent researchers who have studied motor development over the last century, we know very little about how infants use their expanding repertoire of postural skills as they interact with their environments within play sessions. In 1988, Reed described the play system as an exaggerated use of movements and postures, characterized by frequent and abrupt changes in rhythm or frequency. These changes in posture are not only modulated by the infants' levels of acquired motor skills, but can also be influenced by environmental factors that may require or attract infants' attention. Clearly, when only sitting is mastered, postural options are more limited than when walking is mastered. As they learn to use their bodies in new ways, infants may opt to rely on earlier appearing postures in place of newly acquired ones if the earlier appearing postures are mechanically and cognitively easier to perform. This established affinity for a certain behavior an example of an *attractor state* in dynamic systems theory, mentioned earlier (Thelen & Smith, 1994). For example, a classic study by Gibson and colleagues (1987) showed that even when they could walk, infants sometimes would rather crawl if it seemed easier in the situation. Therefore, even when infants acquire the new skills of crawling and walking, they may, during those periods, still opt to remain in a sitting position to better manipulate a toy or adopt a different posture. Or, infants who have mastered walking, a posture that newly frees hands for objects, may opt to continue taking steps while interacting with an object, but they also may choose to stand still in order to focus on a particular task at hand.

With experience in any posture, infants begin to develop an internal working model of their posture, which allows them to better estimate their body systems, execute motor commands and operations, and maintain flexible and stable control (Chen, Metcalfe, Jeka, & Clark, 2007). It is therefore possible that novel occurring postures may disrupt or enhance prior occurring ones. There is evidence, for example, that learning to walk causes a recalibration of the infant's internal posture systems (Corbetta & Bojczyk, 2002), which results in more postural sway during sitting postures right after the acquisition of upright locomotion (Chen et al., 2007). Some other research shows that walking experience can facilitate the tuning of sensory motor integration, the perception of body positioning in space, and the control of postural sway (Metcalfe et al., 2005). It is possible, therefore, that such newly acquired motor integration in walking can in turn generalize to other prior acquired postures, like standing or squatting.

Further, even though infants may know how to perform particular skills, such as hands-and-knees crawling or walking, they may not necessarily display these behaviors in moment-to-moment interactions within a free play session. All in all, complexities in natural play sessions may arise as infants accrue postural options, which we see as crucial for discovering and engaging with the environment. However, we know very little about how infants use their expanding repertoire of postural skills to position themselves and transition through various postures at different stages of their motor skill development while they are interacting with their mothers and toys in the environment.

We know that with crawling and walking experience, infants' actions appear increasingly more goal-directed (Dosso & Boudreau, 2014; Pierce et al., 2009; Zachry & Mitchell, 2012). But, what do infants tend to do once they arrive at their goal? Infants who are locomotor may begin to engage in more complex interactions, but can still participate in more simple forms of object play, such as holding or mouthing a toy. New postures allow infants to begin to carry objects while crawling or walking (Karasik, Adolph, Tamis-LeMonda, & Zuckerman, 2012; Pierce et al., 2009), push and drive wheeled toys independently, climb or jump on furniture, and use musical toys to dance (Pierce et al., 2009). Some have reported that walking infants will sometimes plan ahead by transporting objects from room to room for combined object play (Pierce et al., 2009). Although some of infants' play patterns with toys have been delineated, it remains unclear how infants use their postures to engage in playful fine and gross motor interactions with their environments. Furthermore, there is no research describing how mothers use their postures to engage in object manipulation bouts as they participate in play sessions with their infants.

Mothers' behavior and infant playful and exploratory interactions

Of course, infants' interactions with their worlds are usually embedded in social contexts, where interactions with other people in the environment occur regularly. In fact, many prominent psychobiologists have claimed that the mother and the infant develop as individuals who each make up a major part of the other's environment, but they also develop together (Moore, 2007). Similar to Rosenblatt's early work on mother-infant synchrony, researchers have reported major socioemotional shifts in infants following the onset of self-produced locomotion. These changes within the infant affect their interactions with people and things in their environments, which also results in concomitant changes in their relationships with family members (Campos et al., 2000; Whitney & Green, 2011). Therefore, the transition to independent locomotion is also a significant milestone for parents as well as infants. Many researchers in recent years have found evidence for this interaction loop that exists between mothers and infants, in which mothers engage and respond to their infants' behaviors differently depending on their infants' action skill levels and locomotor status (Clearfield, 2011; Fukuyama et al., 2015; Karasik et al., 2014; Lobo & Galloway, 2012). And even very recently, studies continue to show how these mother-infant dynamics are important for the child's growth and development (Biringen et al., 1995; Clearfield, 2011; Lobo & Galloway, 2012; Fukuyama et al., 2015; Yu & Smith, 2013).

Broadly speaking, mothers have been shown to be important contributors to their child's development in many contexts (e.g., Belsky, Goode, & Most, 1980; Brand, Baldwin, & Ashburn, 2002; Lancy, 2016; Yu & Smith, 2013). Even Gesell, who was a maturationist in motor development, often wrote about infant development in the context of the mother-infant dyad (e.g., Gesell, 1928; Gesell & Ilg, 1943), which possibly set the stage for subsequent systems theorists concerned with mother-infant dynamics. Since Rosenblatt's earlier work on the complementary dynamics of mother-infant relationships (Rosenblatt & Lehrman, 1963), many others have also found evidence to support notions of synchrony. Throughout development, interactions between mothers and infants change depending on the growth and physical capabilities of the infant (Moore, 2007). Importantly, mothers and infants both detect regularities in their interactions with one another, which allows them to become familiar with patterns and build expectations for the other person based on their previous and ongoing interactions (e.g., Fukuyama et al., 2015; Fogel, Nwokah, Hsu, Dedo, & Walker, 1993). If mothers refrain from responding to their infants in interactions as they normally would, infants immediately notice the change and correspondingly alter their responses to the mothers' behavior (Cohn & Tronick, 1983). Bertenthal and colleagues (1984) investigated how pre-locomotor or locomotor infants responded to their caregivers when they were facing them or away from them. They discovered that when their mothers were facing away from them, locomotor infants engaged with toys less and spent significantly more time looking at their mothers, presumably in an attempt to reengage in communication, but pre-locomotor infants showed no differences in behavior (Bertenthal et al., 1984). Clearly, infants show perceptual sensitivity to signals coming from their mothers during interactions.

Mothers also show changes in their behaviors in response to subtle changes in their infants. One longitudinal study (Fogel, Nwokah, Hsu, Dedo, & Walker, 1993) tracked how mothers modified their one- to five-month-old infants' postural positioning during free play sessions. Researchers found that mothers were more likely to change their infants' postural positioning when their infants' facial expressions were either neutral or positive, and when their infants were looking away from them. Some mothers considered their infants' developmental gaze patterns and altered their infants' positioning to face where the infants' gaze was directed, but some mothers altered the infants' positioning to face them. The authors argued that throughout development, mothers' postural positioning of their infants' bodies is therefore jointly established result of their interactions with one another (Fogel et al., 1993).

Because of the characteristics dynamically constituted joint interaction, some have argued that the development of self-produced locomotion in infancy should not only be considered a significant event for the infant but should also be considered a developmental milestone for caregivers (Hendrix & Thompson, 2011; Moore, 2007). Recent research suggests that the most important changes for mothers in the mother-infant relationship center around the mothers' behavior and her perceptions and expectations about having a mobile infant (Hendrix & Thompson, 2011; Mondschein, Adolph, & Tamis-LeMonda, 2000). There are important bidirectional influences that occur as mothers prepare and begin to anticipate their infants' progression to new motor milestones. They may even reconfigure their environments to encourage or facilitate the infants' transitions to new abilities. In any case, when infants do acquire a new locomotor skill, their parents are there to respond alongside the infants to its consequences for the infant, the dyadic relationship, and their larger family context (Hendrix & Thompson, 2011).

Interestingly, there are other ways that parents' perceptions and expectations about motor skills may influence their interactions with their infants. For instance, in a study of mothers' expectations about their infants' crawling abilities (Mondschein et al., 2000), mothers of girls tended to underestimate their daughters' crawling performance and mothers of boys tended to overestimate their sons' crawling performance. In addition to differences in mothers' expectations of their girls and boys, another study by Clearfield and Nelson (2006) showed differences in how mothers interacted with their female and male infants during free play sessions, in terms of both the content of their speech and their play behaviors. Although infants in neither study showed gender differences in motor abilities or behaviors (Clearfield & Nelson, 2006; Mondschein et al., 2000), there are still subtle ways that their mothers' behaviors or expectations of them could affect infants' motor abilities later on. These findings were consistent with prior work showing that there are minimal differences between girls' and boys' motor abilities in infancy (Bayley, 1965), but many more become apparent as children age (Eaton & Enns, 1986). In those studies, despite the lack of gender differences in their infants' motor skills and behaviors, mothers still expressed different expectations and treated their infants differently based on their infants' gender. The fact that mothers do this even though their infants' skill levels are the same indicates that the differences in the mothers' behaviors stem from the mothers themselves, and not their infants.

In most cases, parents monitor their infants' behaviors and respond according to their infants' skills. The mother, therefore, scaffolds her interactions to match the infants' skill as well as she is able to (e.g., the mother may demonstrate the functions of a toy). In many cases, infants can recognize these attempts for scaffolding, and are able to use them for their own future actions on a toy. In this scenario, mothers and infants both continuously monitor each others' behaviors and modify their own behaviors during ongoing interactions. Therefore, development can be characterized as a continually shifting dynamic in joint interactions between infants and caregivers that reorganizes over time (Fogel, Nwokah, & Karns, 1993). Some have argued that this conceptualization of development in joint interactions is quite different from the simple process of knowledge transfer between two completely separate individuals that occurs in Vygotsky's (1978) notions about scaffolding in the zone of proximal development (Fogel et al., 1993).

Furthermore, a large body of research has delineated ways that cultural differences impact motor interactions and outcomes in parents and children. Some cultural groups show accelerated or decelerated infant motor development (e.g., Karasik, Tamis-LeMonda, Adolph, &

Bornstein, 2015), and several studies have outlined cultural practices that contribute to those differences. For instance, through varied forms of infant body stimulation and postural manipulations, Bambara mothers enhance sensorimotor outcomes in their infants' development in Mali (Bril & Sabatier, 1986). Experimental enhancement of postural stimulation in Western infants also shows similar acceleration of motor skill development (Lobo & Galloway, 2012).

Furthermore, restricting movements or opportunities to practice motor skills can delay the onset of primary motor skills like sitting, standing, or walking. The "back to sleep" campaign encouraging Western parents to lay their infants on their backs for sleeping to reduce the incidence of sudden infant death syndrome resulted in slight delays in motor skills acquisition (Davis, Moon, Sachs, Ottolini, 1998). Controversial studies conducted by Wayne Dennis and his wife (Dennis, 1935; 1941) also demonstrate how impoverished early environments can delay infant motor development outcomes. These studies highlight how the cultural context and parenting practices can impact the trajectory of motor development, although there are other ways that motor development can be affected beyond timing (see Cintas, 1989; 1995; Karasik, Adolph, Tamis-LeMonda, & Bornstein, 2010 for reviews). These early cultural differences in motor development can also persist in the long term (e.g., Karasik et al., 2010).

More generally, there are also cross-cultural differences in how parents participate in play sessions with their infants because of cultural differences pertaining to the role of infancy in development (Lancy, 2016), or differences in parents' ideas about what is important for infant play (e.g., Keller, 2008). For instance, a study by Roopnarine, Hooper, Ahmeduzzaman, and Pollack (1993) compared Indian parents to American parents, and showed that Indian parents typically played with their children for pleasure, whereas American parents tended to emphasize cognitive benefits. Similarly, Coughlan and Lynch (2011) showed that Irish parents in a qualitative study on mothers' involvement in infant play typically were guided by intrinsic beliefs and expectations of play when choosing play objects that emphasized learning. In this way, parents' motivations and goals of play become apparent in the ways parents interact with their children differs between cultures.

In relation to infants' ability to explore their environment, we can safely assume that before infants are ambulatory, parents play a greater role in bringing objects to them, or in carrying and moving them around, but when infants begin to locomote and gain more independence, parents' role may change. Some research suggests that mothers change their home routines to accommodate their infant's developing sense of independence and explorations in their homes. Mothers of single infants typically tailored their infants' play spaces to their infants' developmental levels and interests, whereas mothers of multiple children were less able to do so (Pierce, 2000).

Despite the host of research showing the importance of mothers in early development, we know very little about mothers' roles in the development of postural progression in infants. This gap has been pointed out previously in the literature (Whitney & Green, 2011; Mondschein et al., 2000), but remains unclear as most studies have instead focused on interviewing mothers about their expectations of their infants' locomotor behaviors (Mondschein et al., 2000), or have detected changes in mothers' vocal productions as a function of their infants' locomotor status, (e.g., Clearfield & Nelson, 2006; Karasik et al., 2014). We know that when infants learn new motor skills, they gain a sense of independence and willfulness, (Biringen et al., 1995; Campos et al., 2000), but little is known about how they still might need assistance from their parents. It is possible that when infants can self-locomote and gain access to new spatial locations, parent involvement still occurs to provide some stabilization to the child, particularly during periods when the infant posture is not fully acquired. One longitudinal study by Pierce (2000) showed that during naturalistic interactions in the home environment, mothers often used their own bodies to guard their infants during moments of potential risk. Overall, we know very little about how mothers physically interact with or assist their infants during free play sessions throughout locomotor skill transitions.

Spatial interaction patterns in mother-infant dyads

One characteristic of the interactions between mothers and infants is that they appear to be linked in space. One longitudinal study by Pierce (2000) tracked motor-infant distance during naturalistic home interactions over time. They found that both mothers and infants seemed aware of where each other were during play, and the distance between them was regulated almost as if a rubber band was between them. When they got further away from one another, the tension increased as the hypothetical rubber band stretched, and then relaxed when they were closer to one another (Pierce, 2000). This is consistent with prior work claiming that when infants become mobile, they still show proximity-seeking behaviors (Campos et al., 2000). Along that same line of thought, Mahler and colleagues (1975) reported that although locomotor infants are especially interested in interacting with their wider environments and venture further distances from their mothers, they still seek emotional support through close physical touches with their caregivers, even though those moments of close proximity may be brief. In cases where infants did not seek close physical connections with their caregivers, they made up for the distance by repeatedly checking in with their caregiver visually (Mahler et al., 1975). This phenomenon has been replicated in animal literature (e.g., Okamoto-Barth, Tanaka, Kawai & Tomonaga, 2007).

There are, however, sociocultural factors that contribute to differences in the distance between infants and mothers and their spatial exploration patterns. In terms of how the space between the mother and her infant is used, research shows that Japanese mothers tend to use their bodies to loom in and out from their infants in phases, whereas mothers from the United States tended to remain in one position, but were closer to their infants than Japanese mothers (Fogel, Toda, & Kawai, 1988). Similarly, mothers who were interviewed as part of a qualitative study in Ireland claimed that they often sought out close, affectionate touch with their infants in order to promote bonding and comfort (O'Brien & Lynch, 2011).

The child's gender could also influence how mothers interact with their infants spatially. In one free play study with 9 and 14-month-old locomoting infants (Clearfield & Nelson, 2006), there were no gender differences in how much time infants spent near or in contact with their mothers. But at earlier ages, some have found differences in how much time mothers spend in close physical contact with their 6-month-old infants, with girls receiving more (Goldberg & Lewis, 1969). Along those same lines, mothers have been shown to spend more time engaging in activities with their infant daughters, whereas mothers tend to spend more time not interacting with their infant sons (Clearfield & Nelson, 2006). This may be because the mother-son relationship during infancy has been characterized by having more clashing behavior and maternal prohibitions (Biringen et al., 1995). Interestingly, these gender differences are also found in primates. Rhesus monkey mothers tend to keep their daughters closer than their sons, and display higher concern if their daughters venture off. They also wean their sons earlier than daughters, and show more displays of anger towards their sons (LaFreniere, 2013).

Beyond sociocultural and gender differences, there are also characteristics of individual families that contribute to differences in mother-infant exploratory behaviors. In one longitudinal study (Pierce, 2000), mother-infant play interactions and explorations in the home tended to be more child-led in situations where mothers only had one child and did not work outside of the home. Mothers who did not want to follow their children through the homes for play interactions tended to have infants and toddlers that remained stationary during play sessions in the home. Clearly, even the spatial relationship between infants and mothers is an important one that is modulated by both individuals.

Despite the host of research evidencing children's need for proximity to their caregivers and naturalistic studies in home environments, we know far less about mother-infant spatial interactions in controlled laboratory settings. In most studies of motor development and early exploration, mothers' behaviors are not included in data collection procedures. And in some cases, mothers were asked to sit in a fixed location (Walle & Campos, 2014), or to not direct their infant's behavior to anything specifically (Clearfield & Nelson, 2006). It would be interesting to determine whether the trends in previous research differed if both mothers' and infants' spatial locations were measured precisely during their ongoing interactions with one another.

There are important implications of delineating patterns of dyadic spatial exploration during free play sessions. Some studies have suggested that the age at which infants learn to walk could be indicative of the emotional climate between infants and mothers. It is possible, they explain, that precociously walking infants may be more likely to seek independence from clashing interrelationships with their parents (Biringen et al., 1995). A description of typical movement patterns would help researchers and clinicians assess the quality of the interactions and further facilitate the identification of potential problems. Several studies have shown that mothers' mental health conditions affect many spatial movement aspects of dyadic interactions. When mothers have postpartum depression, their interactions with their infants seem to be plagued by atypical patterns in the co-creation of relational space (Væver, Krogh, Smith-Nielsen, Harder, and Køppe, 2013). Additionally, mothers with anxiety tend to raise wary and inhibited children and even show discomfort when their children explore novel environments (Rubin, Coplan, Fox, & Calkins, 1995). Furthermore, mothers with high dependency tend to chase, hover, or loom over their children. Their children tend to respond with dodging movements to escape their mothers, and they also tend to show resistant attachments (Beebe et al., 2010).

Even in nonhuman primates, permissive mothers allow their offspring to explore independently, but restrictive mothers prevent independent infant exploration (Altmann, 1980; Fairbanks, 1996). Initially, protectiveness increases infant contact-breaking and leaving behavior (Maestripieri, 2002, 2004), but in the long run, decreased independence and clinginess to the mother emerge (Hinde, 1974). In any case, extreme exhibitions of maternal style can be maladaptive (Altman, 1980; Fairbanks, 1996).

In humans, it is likely that maladaptive dyadic spatial interaction patterns will lead to developmental problems, such as lower Bayley scores (Klein & Feldman, 2007). These studies with clinical populations highlight reasons why studying spatial movement patterns in normative samples is necessary to potentially provide clinicians information necessary to detect maladaptive behaviors and provide a basis for future interventions.

The current study

The aim of this dissertation is to extend this area of research on motor exploration and infant-mother interactions by examining dyadic patterns of spatial exploration as they both change over time and engage in free play sessions in a room equipped with furniture and toys. We tracked 13 mother-infant dyads in biweekly sessions held during the infants' first two years of life. We focused specifically on three transition periods: when infants begin to crawl on all fours, then become proficient hands-and-knees crawlers, and begin to walk independently. No previous studies have tracked changes in these behaviors over such an extended period of time. As reviewed above, the emergence and progression of both crawling and walking are associated with a host of significant cognitive, socioemotional, and physical changes in infants that are linked to locomotor exploration, reasoning about the environment and interactions within it, and changes in dyadic interactions (e.g., Bai & Bertenthal, 1992; Campos et al., 2000; Clearfield 2011; Clearfield et al., 2008; Gibson et al., 1987). Here, we extend prior work by expanding our behavioral observations to capture those of the mothers. Due to the fact that the majority of prior studies have not focused on mothers' naturalistic behaviors, we know very little about how mothers alter their interactions with their infants during these periods of locomotor transitions.

Thus, in this study, we used spatial location coordinates in the room and behavioral video data taken at regular time samplings to examine mothers' and infants' (1) spatial exploration patterns of travel distance, speed of travel, and dispersion in the room (2) relative distance from one another, (3) frequency, diversity, and type of interactive behaviors with toys, furniture, and each other, and (4) use of various postures, posture changes, and the infants' use of postural stabilization from their mothers or objects in the room (see Table 1). To gain understanding about how the development of locomotor skills affect our measured variables, we asked whether (1) mothers and infants would show developmental changes through the transitions to crawling, experienced crawling, and walking, (2) spatial exploration patterns related to infants' and mothers' interactive behaviors and action priorities, and their use of postures (see Table 1).

In our view, spatial exploration patterns of the dyad within the room, the distance they maintain from each other at any moment in time, their interactive behaviors, and their use of postures can capture many main characteristics of mother-infant interactions as they change both within sessions and over time. First, we used prior cross-sectional research to make an informed prediction that infants' spatial exploration of the room would increase as they learned to move independently and became proficient. However, due to the lack of research on mothers, an expected trajectory of mothers' displacement in the room was not clear. Second, prior research provides contradictory and/or incomplete evidence about developmental changes in the distance between mothers and infants. We aim to provide a clearer and never-before-studied picture of how this distance changes throughout motor transitions spanning from pre-crawling up until independent walking. Third, with the increase in infants' exploration of their spatial surroundings, we predict concomitant increases in their interactive activities with toys, furniture, and their mothers. However, we can only speculate about how trends in mothers' spatial displacement may relate to their interactive behaviors. It is possible that in earlier sessions when infants are immobile that mothers play a greater role in providing toys to their infants, but as infants gain motor skills, mothers may gradually withdraw or change their role to merely monitor their child's actions. We expect that through potential changes in her various roles during the play session the mother will consistently interact with her infant more than her infant interacts with her. Fourth, consistent with Infant Space Theory (Pierce et al., 2009), described earlier, we expect expansions in infants' use of their repertoire of postures within sessions to result in concomitant increases in spatial exploration. In mothers, we do not expect a strong link between postural activities within sessions and spatial displacement because we expect mothers' to be more concerned with their child and less with active discovery within the room. Although we have some predictions about links between posture and spatial exploration, predictions about how mothers and infants may use specific postures during specific activities are unclear (see Table 1). This is due to the fact that there is a significant lack of descriptive research on naturalistic exhibition of postures during free play environments. It is highly possible that during play, participants would be more likely to display postures such as sitting that require less energy. It is also likely that infants would display more complex manipulatory behaviors in well-practiced postures such as sitting. We would like to clarify precisely how postures are used during dyadic interactions.

Part 2. Method

Participants

Thirteen mothers and their healthy first-born infants (6 females) participated in this study. All of the infants were born within three weeks of their due date and none of them had neurological problems known to their mothers. Mother-infant dyads were tracked in biweekly sessions longitudinally from before infants could crawl, when they were about 6 months old (M = 6.0 months at start, SD = 0.3 months), up until they had two months of walking experience (Age M = 14.9 months, SD = 1.2, at study completion). Four infants walked before 12 months of age, so they were followed for more than 2 months after walking onset in order to have data up to 14 months for all dyads. There was no attrition. Our relatively small sample size of thirteen families was geared to the intensive longitudinal data collection and further microgenetic analyses we planned. We collected a total of 247 sessions' worth of behavioral video data across all of our families.

After the birth of their infants, birth records were provided by the state of Tennessee to the Child Development Research Group (CDRG) at the University of Tennessee. The CDRG sent out regular monthly mailings to the families with newborns to invite them to participate in research studies. Families who responded to the mailings were added to a human subject database maintained by the CDRG. Only mothers who were in the CDRG database were contacted again by mail when their infant was approximately five months old to participate in the current study. Families who responded to the invitation for the current study were invited to come to the Infant Perception-Action Laboratory for a noncommittal informational meeting, which allowed them to learn more information and meet the researchers before deciding whether they wanted to be a part of the longitudinal study. Out of 14 families who attended the informational meeting, 13 agreed to participate in the study and signed an informed consent form.

Our sample was relatively homogenous. All infants were free from known neurological problems and all except one infant was breastfed for at least 3.5 months. The infants' parents all identified their race/ethnicity as non-Hispanic White. The infants' parents were similar in age when the infants were born (Mothers: M = 32.2 years, SD = 6.2; Fathers: M = 32.7 years, SD = 4.9). Parents' education ranged from high school diplomas to graduate degrees. The mode annual household income of the participants was $60,000 or more (n = 7). Participants were provided $10 compensation after each session. At the end of the study, families were gifted a photo book comprised of pictures of mother and child from each session with the ages of the child's motor milestones indicated and captions for each picture, a copy of all DVD recordings, and a certificate of completion.

Materials

Playroom environment. Observations of mother-infant free play sessions were completed in a laboratory environment that was located on a university campus. The space was temperature controlled and well lit, with an overall floor space measuring 3.3 m X 3.7 m. The space had three walls that structurally were part of the room and the fourth "wall" was a set of two large noise-cancelling panels that were positioned to create an opening to enter and exit the play space. A small set of infant-sized stairs (54 cm tall at highest point off of the ground) were positioned near the entrance of the room to create a walkway into the room. At the mothers' request, a wooden baby gate could be positioned between the stairs and a metal cabinet to create an enclosure in the space. A couch was positioned on the opposite side of the room below a large window with blinds. A bookshelf was located in between the couch and the metal cabinet (see

Figures 1 & 2A). The majority of the floor was lined with colorful interlocking 1 square foot (0.31 m X 0.31 m) foam tiles. There were also several brightly colored posters of animals holding shapes on the walls.

The rest of the room was equipped with a variety of gender-neutral toys meant to encourage both fine and gross motor exploration. The gross motor toys included: a music mat, a push cart (handle 43 cm tall), a rocking horse, a 28 cm wide large ball, a 48 cm X 185 cm nylon collapsible tunnel, a rolling melody push toy, a 29 cm tall wagon, and a rolling pull-string toy. Toys specifically intended to elicit fine motor skills were: colorful letter-shaped magnets positioned on the metal cabinet, an interactive plush jumbo block with different activities built into each side of the block, a 41 cm X 36 cm high round activity table with interchangeable top pieces, a sit-in circular activity center that could be adjusted to different heights (43 cm X 61 cm), a 52 cm tall caterpillar-themed activity center with legs that could be adjusted to different heights, books, magazines, a bead maze, and several small toys in a small plastic box with a latching lid including a plush rattle, a plastic rattle, two plastic musical character toys with buttons, a rattle with multiple handles, and a set of three small balls. A supportive foam seat with straps was also available. Not all fine and gross motor toys were present at all times. Figure 1A and 1B represent the range of toys used from earlier and later sessions. Two Canon Vixia HFR32 digital video cameras were positioned on raised tripods on opposite corners of the room to recorded behaviors from an overhead view. When combined, the two cameras allowed full visibility of the room.

Assessment of motor behavior. At the end of each biweekly session, an experimenter completed Touwen's (1976) Group III Neurological Assessment Scale to track changes in infants' gross motor skills. This motor assessment allows researchers to indicate the highest level of specific motor skills observed in infants' behavior. It is designed to use from the neonatal period up to the emergence of independent walking and takes around 15 minutes to complete (Heineman & Hadders-Algra, 2008). Although we tracked changes in many motor skills, we focused in this dissertation only on those related to locomotion in prone position and walking.

For locomotion in prone position, a score of 0 meant that infants were unable to create independent changes in spatial position, a score of 1 was given to infants who could produce wriggling or pivoting movements, a score of 2 was used for infants who used abdominal progression using the arms only, a score of 3 was used when infants could engage in abdominal progression using the arms and legs, a score of 4 was used for progression using a combination of both belly-crawling and hands-and-knees crawling, and a score of 5 was used when infants could consistently produce hands-and-knees crawling. For walking, a score of 0 was used to indicate that the infant was unable to walk, a score of 1 meant that the infant could walk if held by both hands, a score of 2 meant the infant could walk if held by one hand, a score of 3 was used when the infant could walk fewer than seven independent paces without falling, and a score of 4 was indicated when infants could walk at least seven independent paces without falling.

Because we were interested in identifying how our measured variables changed with the onsets of crawling and walking, we selected scores from Touwen's to represent those onsets. We used a score of 5 to indicate the cutoff point between pre- and post-crawling. We chose consistent hands-and-knees crawling to indicate the onset because previous research has shown that not all prone progression is the same. In Kermoian & Campos' (1988) study about the effects of moving experience, belly-crawling infants performed no better than nonlocomoting infants. A walking score of 4 was used as the cutoff point between pre- and post-walking because our biweekly sampling did not allow us to capture a score of 3 for infants who learned to walk independently at rapid rates.

Procedure

For each session, mothers and infants came to our laboratory to participate in a play session that took about 30 minutes. At the beginning of each session, mothers and infants were given time to acclimate to the laboratory. When they were both ready, a female experimenter turned on the two cameras and bounced a small colorful rubber ball in the center of the room to provide a visual cue in the recordings that would later be used to synchronize the two cameras together. Then, mothers were asked to play with their infants with different types of objects in three randomized 10-minute conditions. The first type of condition involved playing with a problem-solving toy (e.g., puzzle, fit-the-shape toy, hammer and pegs, stackable cups, or blocks). In the second condition, participants played with a startle toy (e.g., jack-in-the-box, popping button toy, or a pop-up animal toy). The last condition was a free play session, in which mothers were simply asked to play with their infants as they would normally in their homes. This dissertation focuses only on mother-infant behaviors occurring in the free-play condition.

The female experimenter always instructed the mother of the condition order and provided or removed any objects for the condition (only for startle and problem solving sessions), but otherwise remained behind a barrier out of view of both infants and mothers. The experimenter quietly monitored the play session through a television monitor that was connected to one of the digital cameras recording the session and remained available if the mother requested to take a break or pause the recording for any reason. In this event, the experimenter paused the recording and resumed when both participants were ready. Out of all of the 247 sessions, only 14 had these interruptions. Interruptions occurred due to diaper changes (3 times), feedings (5 times), both diaper changes and feedings (2 times), child fussiness (1 time), mothers' need of bathroom break (2 times), and to move her car (1 time).

Although the problem solving and startle toys were added and removed from the free play space by the experimenter during each condition, the whole variety of free play toys remained in the space throughout the whole session. Prior to each appointment, researchers positioned the free play toys in the same spatial locations in the room. For example, the books were always placed under the right side of the couch, the bead maze was always positioned at the top of the stairs, etc. The caterpillar-themed activity center, push cart, bead maze, books, magazines, and the plastic box containing small toys remained in the testing room throughout the entire duration of the study. However, some of the toys used in the free play sessions to elicit fine and gross motor exploration of the room were changed when the majority of infants met certain motor milestones. The example, when most of the infants could sit independently, the sit-in circular activity center was replaced with the nylon tunnel, the interactive plush jumbo block was replaced with the music mat and large ball, and the supportive foam seat was removed. When most of the infants could crawl, the rocking horse was replaced with the rolling pull-string toy and rolling melody push toy, and the round activity table was replaced with the wagon.

Coding and dependent measures

All behavioral coding was completed using a combination of Microsoft Excel and The Observer XT, v 9.0 (Noldus Information Technology, Inc. VA, USA). The two camera views were synchronized together and The Observer XT was used to select regular time samplings taken every 30 seconds. At each of those time samplings, we coded for each participant their spatial location coordinates, interactive activities with toys, furniture, and each other, and postural activities, and postural stabilization (for infants only). Using these 30-second intervals for each 10-minute play session, we obtained roughly 20 data points for each variable for each individual. We used this time sampling to get a rough measure of these variables because many of them have never before been investigated in the literature, and none of them have been investigated for a period spanning as many motor milestones as we have here. Each category of coding is explained in the sections below.

Spatial exploration measures. To extract several aspects of participants' exploration of the room, we used spatial coordinates to identify participants' locations in the free play space. Like others who have used gridded flooring to identify spatial locations in mother-infant dyads in similar work (Okamoto-Barth et al., 2007), we used XY coordinates to map out each location in the room based on the colored floor tiles and furniture in the room (see Figure 2B). The Observer provided us with a "snapshot" of the infants' and mothers' behavior at every 30-s interval. Using the coordinate grid in Figure 2, we identified the spatial location for mothers and infants for each of these interval "snapshots". It is important to note that our measures of spatial location were intended to capture where in the space the participants were for each interval. This means that we only captured where they were, but not how they arrived at that location. Moments where infants moved from one location to another could occur for a number of reasons. For example, infants' coordinates could have reflected the infants' own self-produced movements, but also could have occurred through mothers' interactions or assistance (e.g., pushing infant on cart or carrying a pre-locomotor infant). Spatial locations were selected by using the coordinate that aligned with the majority of the participant's upper torso, shoulders, and head. For example, if a participant was laying down across three coordinates, we coded the coordinate which contained the majority of their upper body. We did not code spatial location coordinates for intervals in which the majority of the participants' upper body was not visible. From these spatial location coordinates, we derived four dependent measures for spatial exploration for each individual at each session (see Figure 2C for an example).

Distance traveled. We used the Pythagorean formula to calculate how far participants traveled across intervals:

$d = \sqrt{(X_{ti+1} - X_{ti})^2 + (Y_{ti+1} - Y_{ti})^2}$ where *ti* corresponds to each coordinate coded from one interval to the next. We summed all the distances computed from each interval to derive the distance infants and mothers traveled during the entire free play session.

Speed of travel. To assess how quickly infants and mothers moved about the space, we used the same formula that we used for distance traveled. However, instead of summing the distances for each interval as we did with distance traveled, we averaged them. This measure therefore indicated how far participants traveled every 30 seconds, on average for each session.

Dispersion of exploration. To capture the dispersion of exploration, or the breadth or spread of travel in the room, we first determined each individual's point of central tendency by averaging all the X and Y coordinates for each session. Then, for each interval, we calculated the distance between the point of central tendency for the session and the spatial location coordinate at each interval during the session using the formula:

$d = \sqrt{(X_{avg} - X_{ti})^2 + \left(Y_{avg} - Y_{ti}\right)^2}$ where X_{avg} and Y_{avg} are the central tendency coordinates.

Although dispersion and distance traveled may be very similar, they provide different types of information about how the participant explored. For instance, in a scenario when an infant repeatedly traveled to and from the same two objects, distance traveled would be quite high but dispersion would be rather narrow. On the contrary, an infant who traveled from one toy to another, to the stairs, back to the toy, and then finally to the mother, all in different locations in the room, would show high levels of both distance traveled and dispersion of exploration within the room.

Distance between infant and mother. To capture how far apart mothers and infants were at each interval, we entered spatial location coordinates for the mothers and infants into the following formula:

$$d = \sqrt{(X_{mother\ ti} - X_{infant\ ti})^2 + \left(Y_{mother\ ti} - Y_{infant\ ti}\right)^2}$$

We then averaged mother-infant distances for all intervals to have one final average per session.

Behavioral coding. For each interval, we also coded whether infants and mothers were engaging in interactive behaviors, and we also classified their postures. Interactive behavior coding and posture coding was completed separately from spatial location coordinate coding. As opposed to the spatial location coordinate coding, coding interactive behaviors and postures required us to view a short amount of video just prior to the "snapshot" taken every 30 seconds. For example, we needed to view video data to see if a ball in the air was in the air because the infant threw it, or if the mother threw it. Similarly, we needed to view video to see if an infant was simply stationary on all fours or if she was in the process of crawling. Therefore, we used 2 seconds before the interval to help us interpret the behaviors occurring during the "snapshots" at each interval. For example, for an interval occurring at 4 minutes, 30 seconds, we coded 4:28.0-4:30.0. Frame intervals where the majority of the participant or the participant's hands were not fully visible were not coded.

Infants' and mothers' interactive behaviors. We coded infants' and mothers' interactive behaviors, which occurred when participants used physical motor actions to directly engage or interact with a toy, piece of furniture, or the other person (the mother or the infant). In most cases, we only coded interactive behaviors if participants made contact with a target during the interval. For example, if the infant was walking across the room to a toy, but did not make contact with the toy during the interval, we did not code any interactive activity. There were exceptions to this "contact" rule, however. For example, in instances when the mother was pushing the infant on a cart across the room, the infant and the cart were both coded as the target of the mothers' interactions, even if she was only making contact with the cart and not the infant on the cart. Furthermore, if the infant was leaning on the couch to play with the bead maze, we only coded the bead maze as the target of the infants actions. This was because even though the infant was making contact with the couch (i.e., leaning on it), the couch was instrumental to the goal, but was not the infants' goal. From this coding, we derived how many intervals interactive behaviors occurred, how many bouts of interactions there were, and how many different targets (toys, furniture, or other person) the participants' interacted with.

Manipulatory behaviors. We coded manipulatory behaviors to see how complex infants' and mothers' interactions with targets were. We coded four categories of manipulatory behaviors: (1) no interactive activity (e.g., looking into the distance), (2) passive holding/minimal involvement in interactive behavior (e.g., hand on or holding toy), (3) general fine motor manipulations (e.g., pressing buttons or spinning parts of a toy), and (4) general gross motor activity (e.g., riding or kicking a toy). Figure 3 contains examples of each of the types of manipulatory behaviors in infants, although these were also coded in mothers.

Infants' and mothers' postural activities. We defined seven different general postural categories adopted by the infants and the mothers (laying down, sitting, on all fours, squatting/kneeling, crawling, standing/bending over, and stepping), with two additional infant categories for cruising postures and postural situations in which mothers manipulated the infants' postures. Postural categories, variants of each postural category and coding definitions are listed in Table 2. From this coding, we derived the number of times infants and mothers changed their postures from one category to another, the number of different postures they displayed, and the proportion of intervals each participant spent in any given posture for each free-play session.

Infant postural stabilization. Postural stabilization was coded when infants used assistance or support for their current posture or postural activity (e.g., holding or leaning on to an object or the mother). We defined three types of infant postural stabilization: instances when infants stabilized themselves with an object/furniture, when infants stabilized themselves using the mother, or instances when mothers actively stabilized their infants' postures (see Figure 4 for examples). If the mother was sitting with her hands in her lap and the infant was leaning on some part of her body, this was coded as infant self-stabilization because although the mother was being used to stabilize the infants' posture, she did not play an active role in this process.

Inter-rater reliability

One research assistant independently coded 25% of the data for spatial location coordinates inter-rater reliability assessment. The mean proportion agreement was .86 (*SD* = .09). Another research assistant independently coded 20% of the data for all of the other behavioral dependent variables. The mean proportion agreement for mother and infant interaction targets was .96 (*SD* = .05) and .96 (*SD* = .04), .86 (*SD* = .06) and .90 (*SD* = .07) for mother and infant manipulatory behaviors, and .93 (*SD* = .08) and .90 (*SD* = .10) for mother and infant postural activities. The mean proportion agreement for infant postural stabilization was .95 (*SD* = .06). Inter-rater disagreements were resolved with discussion.

Use of terminology

In the sections below, we will use the words *play, interaction, exploration, and displacement* to describe different components of the dyadic behaviors observed. We will use *play* and *interaction* to describe mother and infant behaviors directed at objects, furniture, and the other person in the room. *Exploration* and *displacement* will be used to describe spatial movement patterns of mothers and infants as they navigate from one location in the room to another.

Analyses

Out of all the data we collected, we were most interested in detecting developmental changes around locomotor onsets in each infant. Therefore, for the current analyses, we focused on two 6-session transition periods centered around when each infant learned to crawl and walk. We analyzed those 12 sessions of data by comparing: (1) the three sessions before and the three sessions after the onset of hands-and-knees crawling, (2) the three sessions after hands-and-knees crawling onset (novice hands-and-knees crawling) and the three sessions before walking onset (experienced hands-and-knees crawling), and (3) the three sessions before and the three sessions after walking onset (see Figure 5). By dividing our data this way, we used each infants' locomotor skill level as an independent variable. This allowed us to detect changes between 3 transition periods over 4 blocks of time made up of 3 sessions each.

With this blocking structure, no infants' data overlapped. However, some infants learned to walk more slowly than others, so the two 6-sessions blocks centered around crawling and walking onsets were not successive for all infants. Five infants learned these skills successively and the 3 sessions of novice hands-and-knees crawling were immediately followed by the 3 sessions of pre-walking. The remaining infants (n = 8), gained more crawling experience before learning to walk. Therefore, their novice hands-and-knees crawling sessions and pre-walking sessions were separated by 1 to 3 sessions (1 session: n = 3; 2 sessions: n = 3; 3 sessions: n = 2). Figure 6 shows how the data were selected for each infant.

Nearly all of our variables were normally distributed, so we used repeated measures ANOVAs with Greenhouse-Geisser corrections to detect longitudinal changes in our variables for mothers and infants. In cases where normal distributions were not met, we used a combination of nonparametric Friedman tests (2-tailed) to detect within-subject changes in our variables over time and Mann-Whitney U tests (2-tailed) to analyze potential differences between the mother and infants. We used Friedman tests in those cases because they are similar to one-way ANOVAs on Ranks and can account for repeated measures. One infant (08) did not have pre-crawling sessions because he was already able to crawl at the first session. Therefore, for the ANOVA tests, we averaged pre-crawling data from the other 12 infants and filled infant 08's data in with the group average. In some cases, our data were more sparse, so ANOVA and Friedman tests were not possible. In those situations, we averaged each dyads' data across the 3 sessions in each time block in order to assess developmental changes using two-tailed nonparametric Wilcoxon signed-rank tests.

We first analyzed all 12 sessions centered around crawling and walking onsets to detect developmental changes over the whole time period. If these tests were significant, we performed additional analyses directed at the 6-session transition periods between crawling onset, crawling experience, and walking onset.

Part 3. Results

> "Walking seems to have great symbolic meaning for both mother and toddler: it is as if the walking toddler has proved by his attainment of independent upright locomotion that he has already graduated into the world of independent human beings."
>
> – Margaret Mahler, Fred Pine, & Anni Bergman (1975, pg. 74)

Progression through motor milestones

At their first laboratory session, four infants could sit on their own for at least 30 seconds (infants 07, 11, 12, & 13 on Figures 6 and 7), and one infant could hands-and-knees crawl (infant 08). All infants sat on their own at 6.6 months of age on average (*SD* = 0.6 months), began to hands-and-knees crawl at 8.8 months of age (*SD* = 1.4 months), stood independently at 11.2 months of age (*SD* = 1.2 months), and could walk at least seven independent paces when they were 12.4 months old (*SD* = 1.6 months; see Figures 6 and 7).

Gender comparisons

Before investigating developmental changes, we wanted to identify whether there were any gender differences in our data. To assess this, we averaged all sessions for each dyad and tested for differences in each variable. Across the majority of our variables, there were no differences between girls and boys or mothers of girls and boys.

Mann-Whitney tests on spatial exploration variables showed that girls and boys did not differ in how far they traveled (U = 11.000, Z = -1.429, p = .181), how quickly they traveled (U = 10.000, Z = -1.571, p = .116), or their dispersion of travel (U = 12.000, Z = -1.286, p = .199). There were also no differences in these variables for mothers of girls and boys (distance traveled:

U = 18.000, Z = -.429, p = .668, speed of travel: U = 16.000, Z = -.714, p = .475, travel dispersion: U = 11.000, Z = -1.429, p = .181). Furthermore, the distance between mothers and their daughters and sons was not different (U = 9.000, Z = -1.714, p = .086).

Levels of total interactive activities were also similar across girls and boys (U = 10.000, Z = -1.506, p = .132), and mothers of girls and boys (U = 18.000, Z = -.429, p = .668). Girls and boys also did not differ in the proportion of interactions with toys (U = 11.000, Z = -1.429, p = .153), or furniture (U = 18.000, Z = -.429, p = .668), but girls interacted with their mothers significantly more than did boys (U = 7.000, Z = -2.000, $p < .046$). Mothers of girls compared to mothers of boys, however, interacted with toys (U = 9.000, Z = -1.714, p = .086), furniture (U = 15.000, Z = -.857, p = .391, and their daughters and sons (U = 14.000, Z = -1.000, p = .366) at the same levels.

Girls and boys also used their postures similarly. The proportion of time spent in various postures did not differ between girls and boys (laying down: U = 20.000, Z = -.145, p = .885; sitting: U = 10.000, Z = -1.571, p = .166; on all fours: U = 11.000, Z = -1.429, p = .153; crawling: U = 19.000, Z = -.286, p = .775; standing: U = 14.000, Z = -1.000, p = .317; cruising: U = 15.000, Z = -1.047, p = .295; or stepping: U = 19.000, Z = -.286, p = .775). The only exception was that boys spent more time in squatting and/or kneeling postures than girls did (U = 7.000, Z = -2.000, $p < .046$). Similar to their children, mothers of girls and boys did not differ in the amount of time spent in any posture (laying down: U = 20.500, Z = -.075, p = .940; sitting: U = 12.000, Z = -1.286, p = .199; on all fours: U = 7.500, Z = -1.934, p = .053; squatting/kneeling: U = 17.000, Z = -.571, p = .568; crawling: U = 18.000, Z = -.431, p = .667; standing: U = 20.000, Z = -.143, p = .886; or stepping: U = 18.500, Z = -.360, p = .719). Girls and boys transitioned between postures at similar rates (U = 12.000, Z = -1.287, p = .198), as did their mothers (U = 12.000, Z = -1.286, p = .199). There were also no differences in how often infants stabilized their own postures across girls and boys (U = 21.000, Z = -0.000, p = 1.000). Mothers of girls and boys also did not differ in how regularly their stabilized their child's posture (U = 18.000, Z = -.429, p = .668). Due to the very few differences between girls and boys and their respective mothers, we merged all infants and all mothers together for the remaining analyses.

Measures of spatial exploration

One of our first goals of this study was to identify how the onset of crawling and walking affected both infants' and mothers' spatial exploration of the room. We specifically analyzed changes in their traveled distance, speed of travel, travel dispersion, and distance from each other as they interacted in our free play environment.

Traveled distance. We aimed to determine whether the acquisition of self-produced locomotion affected how far infants and mothers traveled in our testing room, and specifically where any changes may have occurred around crawling onset, crawling experience, and walking onset. We ran a Group (2: infants vs mothers) X Session (12) repeated measures ANOVA on the distance traveled on all 12 sessions. This revealed a main effect of Group ($F(1, 24) = 6.672$, $p < .016$, $\eta^2 = .218$), Session ($F(6.050, 145.193) = 26.739$, $p < .0001$, $\eta^2 = .527$), and a main Group x Session interaction ($F(6.050, 145.193) = 3.570$, $p < .002$, $\eta^2 = .129$). This indicated that dyads increased traveled distance during the duration of the study, but infants covered more ground than their mothers (see Figure 8A).

Next, we ran targeted repeated measures ANOVA tests on the three 6-session transition periods in order to identify whether this increase in traveled distance occurred as a result of crawling acquisition, crawling experience, or walking onset. We found significant main effects of Session from pre- to post- hands-and-knees crawling ($F(3.828, 91.860) = 12.746$, $p < .0001$,

$\eta^2 = .347$) and from early to experienced crawling ($F(3.565, 85.569) = 15.946$, $p < .0001$, $\eta^2 = .399$), but not from experienced crawling to walking, $F(3.743, 89.820) = 1.885$, $p = .128$, $\eta^2 = .073$; Figure 8A). There were no main Group effects for the two early transition periods ($F(1, 24) = .196$, $p = .662$, $\eta^2 = .008$ and $F(1, 24) = 3.891$, $p = .060$, $\eta^2 = .139$, respectively), but Group was significant across the pre-walking to walking transition period ($F(1, 24) = 14.924$, $p < .001$, $\eta^2 = .383$). There were no Group X Session interactions in any of the three transition periods ($F(3.828, 91.860) = 2.259$, $p = .071$, $\eta^2 = .086$; $F(3.565, 85.569) = .519$, $p = .701$, $\eta^2 = .021$; $F(3.743, 89.820) = 1.197$, $p = .318$, $\eta^2 = .047$). Therefore, these subsequent analyses directed at detecting changes as a result of specific locomotor transitions showed that the increase in distance traveled by the dyad occurred mostly during pre-crawling to experienced crawling, and leveled out during the transition to walking. Mothers and infants did not differ in the distance they traveled in those earlier time periods, but this changed as infants traveled significantly further than their mothers when they gained upright locomotion.

Speed of travel. With the increases in traveled distance during the 10-minute free play sessions, we would expect infants' and mothers' speed of travel to also increase. To test this, we ran a Group (2: infants vs mothers) X Session (12) repeated measures ANOVA on the speed of travel, which revealed a main effect of Group ($F(1, 24) = 6.932$, $p < .015$, $\eta^2 = .224$), Session ($F(5.265, 126.353) = 25.524$, $p < .0001$, $\eta^2 = .515$), and a main Group x Session interaction ($F(5.265, 126.353) = 3.757$, $p < .003$, $\eta^2 = .135$). Therefore, dyads increased their speed of travel across the 12 sessions, but infants' speed of travel significantly surpassed that of their mothers'.

In order to determine if the increase in travel speed was tied to the acquisition of locomotor skills specifically, we ran similar repeated measures ANOVAs across the 3 main transition periods. We found significant main effects of Session with the transition to crawling and experienced crawling ($F(3.187,76.493) = 14.725$, $p < .0001$, $\eta^2 = .380$; $F(3.418, 82.034) = 15.328$, $p < .0001$, $\eta^2 = .390$), but not from experienced crawling to walking, $F(3.363, 80.709) = 1.726$, $p = .162$, $\eta^2 = .067$; Figure 8A). There were no main Group effects for the two early block periods ($F(1,24) = .180$, $p = .676$, $\eta^2 = .007$ and $F(1,24) = 3.625$, $p = .069$, $\eta^2 = .131$, respectively), but Group was significant across the experienced crawling to walking block period ($F(1,24) = 16.718$, $p < .0001$, $\eta^2 = .411$). None of those 6-session block analyses revealed a Group X Session interaction ($F(3.187,76.493) = 1.601$, $p = .194$, $\eta^2 = .063$; $F(3.418, 82.034) = .578$, $p = .653$, $\eta^2 = .024$; $F(3.363, 80.709) = 1.328$, $p = .270$, $\eta^2 = .052$). Similar to our measures of distance traveled, these post hoc analyses therefore indicate that increases in speed of travel occurred predominately after the acquisition of crawling and through the transition to experienced crawling, but not to walking. Initially, the speed of travel did not differ between mothers and infants, but during the time period when infants could walk, mothers moved around the room at slower rates compared to their infants.

Travel dispersion. As infants and mothers began to travel further distances and at faster speeds in our free play environment, how did their distribution of travel change? Was their spread of exploration wide or narrow within the room? And did this change with acquisition of specific locomotor milestones? We ran a Group (2: infants vs mothers) X Session (12) repeated measures ANOVA on dispersion of travel within the room to answer these questions. Results revealed a main effect of Group ($F(1, 24) = 9.967$, $p < .004$, $\eta^2 = .293$), Session ($F(5.769, 138.452) = 26.037$, $p < .0001$, $\eta^2 = .520$), and a main Group x Session interaction ($F(5.769, 138.452) = 2.751$, $p < .016$, $\eta^2 = .103$). This meant that with the progression of locomotor skills, dyadic travel became more disperse within the room as they visited more locations during each session. This effect was more pronounced in infants than in their mothers (see Figure 8B).

We ran similar repeated measures ANOVAs over the three 6-session transition periods. These revealed significant main effects of Session with the acquisition of crawling ($F(4.185, 100.446) = 10.574$, $p < .0001$, $\eta^2 = .306$), as infants gained crawling experience ($F(3.209, 77.014) = 16.789$, $p < .0001$), $\eta^2 = .412$), and from experienced crawling to walking, $F(3.294, 79.067) = 3.228$, $p < .023$, $\eta^2 = .119$; Figure 8B). There were no main Group effects for the earliest transition period ($F(1, 24) = .141$, $p = .710$, $\eta^2 = .006$), but Group was significant across the transition from novice to experienced crawling ($F(1, 24) = 8.745$, $p < .007$, $\eta^2 = .267$), and the experienced crawling to walking transition ($F(1, 24) = 26.868$, $p < .0001$, $\eta^2 = .528$). None of those 6-session transitions demonstrated Group X Session interactions (F4.185, 100.446) = 1.489, $p = .209$, $\eta^2 = .058$; $F(3.209, 77.014) = .585$, $p = .638$, $\eta^2 = .024$; $F(3.294, 79.067) = 1.077$, $p = .367$, $\eta^2 = .043$). Therefore, over time, not only did dyads cover more ground at faster speeds, they also traveled to increasingly diverse locations in the room. The increases in travel dispersion took place in all three transition periods, and also were more pronounced in infants than in mothers as infants gained crawling and walking experience. As predicted, the progression of locomotion was associated with many concomitant changes in infants' exploratory abilities.

Mother-infant distance

A second goal of this study was to identify specific trends in the distance between mothers and infants as infants acquire new locomotor skills. With increasing mobility, infants traveled further distances, increased their speed of travel, and their spread of travel in the room became more dispersed than their mothers'. With these changes in infants' spatial exploration, we also therefore expected the distance between infants and mothers to increase over time. To test this, we ran a one-way repeated measures ANOVA on the distance between mothers and infants across the full period studied. Results revealed that the distance between mothers and infants increased significantly across the 12 sessions (F(3.893, 46.720) = 6.970, $p < .0001$, η^2 = .367, see Figure 8C). However, our targeted post hoc repeated measures ANOVAs over the 6-session transitions indicated that this increase was not significant around any of the three transition periods (F(2.684, 32.204) = 2.228, $p = .110$, η^2 = .157; F(2.837, 34.042) = 2.530, p = .076, η^2 = .174; F(2.610, 31.322) = 2.227, $p = .112$, η^2 = .157). Therefore, the increase in mother-infant distance appeared to occur gradually over time and was not tied to specific locomotor milestones (see Table 3 for a summary of results of spatial exploration measures).

Mother and infant interactive behaviors

As infants and mothers increasingly traveled further, faster, and to more locations, how did their interactions during free play change? A third goal of this study was to track how spatial exploration of the room affected infants' and mothers' interactive behaviors. We analyzed changes in infants' and mothers' bouts of interactions, the diversity of interactions, and the specific types of interaction with toys, furniture, and each other. To capture general differences in mothers' and infants' interactive behaviors, we averaged each individual infants' and mothers' data across all 12 sessions. We discovered that overall, infants spent 83.9% (*SD* = 4.1) of intervals engaging in interactive behaviors, whereas mothers spent 58.9% (*SD* = 8.7) of intervals engaging in interactive behaviors. This difference between infant and mother was significant (Mann-Whitney U = .000, Z = -4.333, $p < .0001$). Therefore, mothers spent more than half of the intervals during sessions interacting, but infants were much more involved in consistently interacting with their surroundings.

Bouts of interaction. We predicted that with the progression of locomotor milestones, infants and mothers would not only increase their spatial exploration of the room, but they may also show increasingly more interactions with various things in the free play environment. To test this, we ran a Group (2: infants vs mothers) X Session (12) repeated measures ANOVA on the number of interaction bouts within each session. Results revealed a main effect of Session ($F(7.432, 178.372) = 7.747$, $p < .0001$, $\eta^2 = .244$) and a main Group x Session interaction ($F(7.432, 178.372) = 3.273$, $p < .002$, $\eta^2 = .120$). However, we did not find a main effect of Group ($F(1, 24) = 3.797$, $p = .063$, $\eta^2 = .137$). Therefore, dyads increased their interactive behaviors. The Group x Session interaction revealed that infants' interactions were initially somewhat lower than that of their mothers' before they could crawl, but the number of infants' interaction bouts met those of their mothers' with time (see Figure 8D).

To assess whether these changes occurred as a result of specific locomotor milestones, we followed up again with 6-session transition repeated measures ANOVAs. These analyses again revealed significant main effects of Session from pre- to post-crawling ($F(4.068, 97.629) = 4.320$, $p < .003$, $\eta^2 = .153$) and from novice to experienced crawling ($F(4.369, 104.853) = 7.040$, $p < .0001$, $\eta^2 = .227$), but not from experienced crawling to walking, $F(4.268, 102.421) = 1.049$, $p = .388$, $\eta^2 = .042$; Figure 8D). There were no Group X Session interactions in the pre- to post-crawling transition ($F(4.068, 97.629) = 1.352$, $p = .256$, $\eta^2 = .053$), or the pre- to post-walking transition ($F(4.268, 102.421) = 1.124$, $p = .351$, $\eta^2 = .045$), but there was a significant interaction during the novice to experienced crawling transition ($F(4.369, 104.853) = 3.155$, $p < .014$, $\eta^2 = .116$). Therefore, as we predicted, we found that it was after the onset of crawling and once infants gained crawling experience when their rate of bouts of interactive behaviors met that of their mothers'.

Variety of interactions. Although we knew that with locomotor skill development, there were significant increases in infants' and mothers' interactive behaviors and travel dispersion, we were not certain if these trends were due to visiting similar toys or pieces of furniture. We wanted to know, did locomotor autonomy change the likelihood that infants and mothers would play with a wider variety of things? To address this question, we ran a Group (2 – infants vs mothers) X Session (12) repeated measures ANOVA on the variety of interactions with unique targets. Results revealed a main effect of Session ($F(6.381, 153.140) = 9.292$, $p < .0001$), and a main Group x Session interaction ($F(6.381, 153.140) = 2.158$, $p < .046$), but no main effect of Group ($F(1, 24) = 1.718$, $p = .202$). This indicated that dyads increased the variety of interactive activities over the 12 sessions, and the variety of infants' interactions met the level of their mothers', as there were no significant differences. We also ran similar repeated ANOVAs over transition periods of 6 sessions to determine how the variety of interactions increased in relation to the onset of crawling, crawling experience, and onset of walking. We found significant main effects of Session from pre- to post- hands-and-knees crawling ($F(4.187, 100.482) = 3.707$, $p < .007$) and from novice to experienced crawling ($F(3.937, 94.485) = 6.440$, $p < .0001$), but not from experienced crawling to walking, $F(3.924, 94.180) = 1.049$, $p = .386$). We did not detect a Group X Session interaction in any of the three 6-session blocks ($F(4.187, 100.482) = .905$, $p = .468$; $F(3.937, 94.485) = 1.352$, $p = .257$; $F(3.924, 94.180) = .840$, $p = .501$). These posthoc analyses indicated that increases in the variety of interactions occurred mainly during the pre-crawling to experienced crawling periods, but did not change significantly after walking onset.

Interactions with toys, furniture, and each other. Our free play environment offered many possible activities for infants and mothers to perform. We wanted to know how often infants and mothers interacted with toys, furniture, or the other person (mother or infant) in the room, and whether infants and mothers differed in their types of interactions. To capture general patterns and to simplify trends, we averaged each individual infants' and mothers' data across all 12 sessions. We discovered that both infants and mothers spent significantly more intervals interacting with toys (Infants: 78.8% (*SD* = 7.8); Mothers: 62.0% (*SD* = 6.4)), than furniture (Infants: 10.5% (*SD* = 3.3); Mothers: 4.0% (*SD* = 2.5)) or the other person (Infants: 10.0% (*SD* = 5.9); Mothers 31.0% (*SD* = 6.8); see Figure 9). For both individuals, there were significant differences across the three types of interaction targets (Infant Friedman χ^2 (2) = 19.846, $p <$ .0001; Mother Friedman χ^2 (2) = 26.000, $p < .0001$). When we directly compared infants and mothers, we found that infants interacted with toys and furniture significantly more than their mothers did (Mann-Whitney U = 9.0, $p < .0001$ and U =10.0, $p < .0001$, respectively), while mothers interacted significantly more with their infants than their infants did with them (Mann-Whitney U =3.0, $p < .0001$; see Figure 9). Therefore, even though they both interacted with toys more than with furniture or each other, infant and mothers still differed in how they targeted their interactions.

These comparisons between all sessions showed that both infants and mothers spent more time interacting with toys than they did with furniture or each other. We wanted to know how this trend may have evolved over developmental time. So, we ran a Group (2 – infants vs mothers) X Session (12) repeated measures ANOVA on the number of interactions for which toys were the target. Results revealed a main effect of Session (F(6.768, 162.441) = 3.220, $p <$ .004), and a main Group x Session interaction (F(6.768, 162.441) = 2.993, $p < .006$). However, we did not find a main effect of Group (F(1, 24) = 2.310, $p = .142$). This indicated that dyads increased interactive behaviors with toys across the 12 sessions, and infants' toy interactions met the level of their mothers', and there were no significant differences. We also ran similar repeated ANOVAs over blocks of 6 sessions to determine how interactive activities with toys increased in relation to the emergence of crawling, crawling experience, and emergence of walking. We did not find main effects of Session in any of the three 6-week blocks (F(4.076, 97.816) = 2.152, p = .079; F(3.603, 86.465) = 1.369, p = .254; F(4.054, 97.290) = 1.513, p = .204), or Group X Session interactions in any period (F(4.076, 97.816) = 1.951, p = .107; F(3.603, 86.465) = 2.145, p = .089; F(4.054, 97.290) = .884, p = .478). These posthoc analyses indicated that toy interactions showed gradual increases over time and were not intrinsically tied to any one of the three locomotor experiences.

Did mothers or infants change how often they interacted with each other as the infant gained motor skills? Although we knew interactions with the other person were not as common as toy interactions, we were still interested in determining how actions directed to the other person changed over developmental time. We first ran a one-way repeated measures ANOVA on the number of mothers' infant-directed interactions across Sessions (12). We did not find a main effect of Session (F(5.363, 64.360) = 1.631, p = .160), indicating that across the 12 sessions, the mothers did not significantly change the number of interactions with their infants. Infant's mother-directed actions were not normally distributed, so next, we ran Friedman tests on the number of infants' mother-directed interactions across the 12 sessions, and did not detect significant changes over time (n = 13, χ^2 = 11.081, p = .436). These analyses revealed that infant and mother interactions with one another did not significantly change during the 12 sessions we studied.

Our earlier tests comparing mothers' and infants' actions directed to one another across all dyads and sessions revealed that mothers were significantly more likely to engage in infant-directed activities than were infants in mother-directed activities, but we wanted to know how this may have differed in each time block. Posthoc Mann-Whitney tests comparing averages for mothers and infants at each 3-session block showed that mothers' actions directed to their infants always exceeded those of their infants' actions directed toward them (n = 12, U = 2.000, Z = -

4.085, $p < .0001$; n = 13, U = 12.500, Z = -3.720, $p < .0001$; n = 13, U = 12.500, Z = -3.722, $p < .0001$; n = 13, U = 18.000, Z = -3.431, $p < .001$).

The last type of interactive activity that we were interested in was furniture-directed interactions. Similar to other-person interactions, infants and mothers spent very little time engaging in furniture interactions. We first ran a one-way repeated measures ANOVA on the number of mothers' furniture-directed interactions across Sessions (12). We found a main effect of Session ($F(3.173, 38.079) = 3.130$, $p < .034$), indicating that across the 12 sessions, the mothers significantly increased furniture-directed interactions. We also ran similar repeated ANOVAs over blocks of 6 sessions to determine how mothers' furniture interactions increased as a function of their child's locomotor skill development. We did not find main effects of Session in any of the three 6-week blocks ($F(2.164, 25.967) = 2.549$, $p = .094$; $F(2.16, 25.923) = 1.818$, $p = .180$; $F(2.566, 30.796) = 1.157$, $p = .337$). These posthoc analyses indicated that mothers' increases in furniture directed actions were not intrinsically tied to infants' locomotor skill progression. Next, we ran Friedman tests on the number of infants' furniture-directed interactions across the 12 sessions, and found significant increases (n = 13, $\chi^2 = 47.328$, $p < .0001$). We ran similar Friedman tests over blocks of 6 sessions to determine how infants' furniture interactions increased in relation to crawling onset, crawling experience, and walking onset. We did not find significant changes across the first and last 6-week blocks (n = 13, $\chi^2 = 6.792$, $p = .237$; n = 13, $\chi^2 = 4.255$, $p = .513$), but did find significant increases in furniture-directed actions during the transition to experienced crawling (n = 13, $\chi^2 = 19.008$, $p < .002$). These posthoc tests revealed that the increase in infants' furniture directed interactions was tied to crawling experience.

Our earlier tests comparing mothers' and infants' furniture-directed actions across all dyads and sessions revealed that infants were significantly more likely to engage in furniture-directed interactions than were mothers. Posthoc Mann-Whitney tests conducted on 3-session block averages showed that during the pre-crawling and novice crawling periods, mothers and infants did not differ in their amount of interactions with furniture (n = 12, U = 64.000, Z = -0.577, p = .564; n = 13, U = 54.000, Z = -1.725, p = .084), however in the following two transition periods, infants performed significantly more interactions with furniture than did their mothers (n = 13, U = 20.000, Z = -3.351, $p < .001$ and n = 13, U = 34.000, Z = -2.615, $p < .009$, respectively). Posthoc tests indicated that infants and mothers initially showed low levels of furniture interactions, but when infants gained crawling experience, their interactive activities with the furniture surpassed those of their mothers' (see Table 4 for a summary of results of interaction measures).

Interactions on the stairs. Interestingly, Friedman tests showed that infants' interactions with furniture seemed to be related to the proportion of intervals infants spent on the stairs, which increased across the 12 sessions studied (n = 13, χ^2 = 55.430, $p < .0001$). Posthoc tests across the locomotor transitions reveals that the normalized frequency of intervals that infants spent on the stairs significantly increased during each 6-session block (n = 13, χ^2 = 11.105, p = .049; n = 13, χ^2 = 24.150, $p < .0001$; n = 13, χ^2 = 12.289, $p < .031$; see Figure 10A). These analyses indicated that the time infants spent on the stairs was tied to their locomotor experience. Furthermore, when the infants could walk, two-tailed Wilcoxon tests showed that mothers were significantly closer to their infants when they were on the stairs compared to when they were not (n = 12, Z = -2.667, $p < .008$). Prior to infants' walking onset, the distance between mothers and infants when infants were or not on the stairs did not differ (pre-crawling: n = 2, Z = -0.447, p =

.655; crawling: n = 3, Z = -0.535, p = .593; pre-walking: n = 11, Z = -1.334, p = .182; see Figure 10B). Therefore, the distance between the mother and infant was shorter when walking infants were on the stairs compared to when they were not.

Correlations between spatial exploration and interaction bouts

Thus far, the results to this point suggest that with increases in spatial exploration of the room, infants' interactions with things in their environments, namely with toys and furniture, are also progressively affected. But, to this point, all of our analyses have been conducted on group averages as they change over time. To test these trends more rigorously, we also measured these changes within individual infants and mothers. To address whether trends in spatial exploration and interactive behaviors were related, we used Spearman correlations to assess those variables for each individual dyad, keeping the infant and mother separate.

We first wanted to assess within individual infants and mothers whether their number of interactive behaviors (combining all interactions with toys, furniture, and the other person) was significantly positively correlated to the distance they traveled in the room for each session. This relationship was significant for 10 out of the 13 individual infant correlations (range r = .579, p < .049 to r = .929, p < .0001, see Figure 11A). However, the relationship between the number of interaction bouts and distance traveled was not significantly related in the majority of mothers' data, as only two showed a significant positive relationship (r = .701, p < .002 and r = .798, p < .011). Next, we continued with similar Spearman correlations between the number of interaction bouts and travel dispersion. There were significant positive correlations between these variables in 8 out of 13 infants (range r = . 641, p < .025 to r = .871, p < .0001, see Figure 11B), but similar to comparisons with distance traveled, only one mother showed a significant positive correlation between interaction bouts and travel dispersion (r = .830, p < .001). These analyses therefore show that although both infants and mothers showed increases over time in traveled distance, dispersion, and interactive activities, the relationship between these variables was only significant in infants.

Infants' and mothers' postural activities

Moving about the room, visiting new locations, carrying toys, climbing stairs, bouncing balls, and other exploratory interactive behaviors may involve using and transitioning between a wide range of various postures. Our fourth novel goal aimed to quantify how mothers and infants differed in the range of postures they utilized as they interacted with toys, furniture, and each other during free play sessions and with locomotor development.

Postural distributions over locomotor development. We first wanted to know how mothers and infants changed their adoption of specific postures over the transitions to independent locomotion. When we averaged infant posture data across all sessions, we found that infants spent an average of 3.9% of intervals laying down (*SD* = 4.3), 42.6% sitting (*SD* = 12.3), 9.8% on all fours (*SD* = 3.5), 9.5% squatting or kneeling (*SD* = 2.6), 6% creeping (*SD* = 5.4), 20% standing (*SD* = 10.8), 0.3% cruising (*SD* = .6), and 4.6% stepping (*SD* = 2.8). A Friedman test showed that this distribution was significant (n = 13, $\chi^2 = 83.627$, $p < .0001$; see Figure 12A). Sitting and standing postures were therefore the most commonly displayed postures for infants.

Similar to infants, when we averaged mothers' posture data across all sessions, we found that mothers spent an average of 1.9% of intervals laying down (*SD* = 3.8), 77.4% sitting (*SD* = 9.9), 3.0% on all fours (*SD* = 3.3), 7.8% squatting or kneeling (*SD* = 5.7), 1.5% creeping (*SD* = 1.3), 6.9% standing (*SD* = 5.2), and 1.4% stepping (*SD* = .9). A Friedman test showed that this distribution was also significant (n = 13, $\chi^2 = 50.019$, $p < .0001$; see Figure 12A). Similar to their children, sitting and standing postures were most frequently adopted in mothers.

We also compared how mothers and infants differed in the proportion of intervals spent in each posture. Mann-Whitney tests on averaged data for each dyad showed that mothers sat significantly more than infants (U = 1.000, Z = -4.282, $p < .0001$). Infants spent more intervals than mothers on all fours, squatting/kneeling, standing, and stepping (U = 13.000, Z = -3.668, $p < .0001$; U = 0.000, Z = -4.336, $p < .0001$; U = 14.000, Z = -3.615, $p < .0001$; and U = 23.500, Z = -3.131, $p < .002$). Mothers and infants spent equal amounts of intervals in creeping postures overall (U = 69.000, Z = -.795, $p = .427$; see Figure 12A). These comparisons therefore meant that mothers were more likely than infants to spend intervals in sedentary postures.

Infant postures over time. We also wanted to know how infants' postures changed over time, but due to the lack of representation, we excluded data for cruising. We conducted Friedman tests on the proportion of intervals that infants spent in each postural category by session (see Figure 12B). Analyses revealed that many postures followed classically predicted progressions across the motor skill transitions.

After the onset of hands-and-knees crawling, there was a significant decrease in the proportion of intervals infants spent laying down (n = 12, $\chi^2 = 11.643$, $p < .040$) and sitting (n = 12, $\chi^2 = 12.275$, $p < .031$), and there was a significant increase in the proportion of intervals spent on all fours (n = 12, $\chi^2 = 26.845$, $p < .0001$), and kneeling (n = 12, $\chi^2 = 16.367$, $p < .006$). Crawling, standing, and stepping postures were not exhibited enough during the transition from pre- to post-crawling and were not included in the analyses for this time period. The shift from laying down and sitting postures to postures on all fours was expected during this transition to crawling.

During the transition from novice crawling to experienced crawling, these trends continued. The proportion of intervals spent sitting further decreased significantly (n = 13, χ^2 = 11.782, p < .038) while the proportion of intervals spent kneeling, crawling, and now standing increased significantly (respectively: n = 13, χ^2 = 15.264, p < .009; n = 13, χ^2 = 12.723, p < .026; n = 13, χ^2 = 14.209, p < .014). The proportion of intervals spent on all fours did not significantly change during this time (n = 13, χ^2 = 6.430, p = .267). Laying down and stepping postures were not demonstrated enough throughout the entire pre-to-post crawling time period to conduct statistical tests and were not included in analyses for this time period. Therefore, as infants gained crawling experience, they used sitting postures even less and spent more intervals in stationary kneeling and standing postures, but also in movement, in crawling postures.

Finally, in the transition to walking, the proportion of intervals infants spent on all fours decreased (n = 13, χ^2 = 24.691, p < .0001) and the proportion of intervals spent stepping increased (n = 13, χ^2 = 13.532, p < .019). The proportion of intervals spent sitting, kneeling, crawling, and standing remained low and did not change significantly during the transition to walking (respectively: n = 13, χ^2 = 2.114, p = .833; n = 13, χ^2 = 4.506, p = .479; n = 13, χ^2 = 7.265, p = .202; n = 13, χ^2 = 4.777, p = .444; see Figure 12B). Laying down postures were not demonstrated enough during the pre-walking to walking time period to conduct statistical tests and were not included in analyses for this time period. This meant that walking infants' behavior in play also showed reductions in quadrupedal positions and increases in bipedal locomotion as they began to use their new motor skills.

Mother postures over time. We also conducted Friedman tests on the proportion of intervals that mothers spent in each postural category by session to further understand how mothers' postures changed over time in conjunction with infant locomotor skill development (see

Figure 12C). Due to lack of representation in the data, mothers' laying down, on all fours, crawling, and stepping postures, however, were demonstrated very infrequently and were therefore excluded from all subsequent analyses. Analyses revealed that mothers spent most of their time in sedentary postures throughout the duration of the study.

During the transition from infant pre-crawling to crawling, there was a significant decrease in the proportion of intervals mothers spent sitting (n = 12, $\chi^2 = 14.104$, $p < .015$). The proportion of intervals mothers spent kneeling and standing did not significantly change during this time (n = 12, $\chi^2 = 8.320$, $p = .139$ and n = 12, $\chi^2 = 9.704$, $p = .084$, respectively). Therefore, when their infants learned to crawl, mothers reduced the amount of time spent in sitting positions.

With crawling experience in their infants, the proportion of intervals mothers spent sitting further decreased significantly (n = 13, $\chi^2 = 19.860$, $p < .001$) while the proportion of intervals spent now kneeling and standing increased significantly (respectively: n = 13, $\chi^2 = 11.265$, $p < .046$; n = 13, $\chi^2 = 22.308$, $p < .0001$). This meant that mothers were being attentive to their infants' movements around the room and spent more intervals in kneeling postures, presumably making themselves more available than they would have been in sitting postures.

When infants gained independent walking, the proportion of intervals mothers spent in any posture remained unchanged (sitting: n = 13, $\chi^2 = 6.438$, $p = .266$; kneeling: n = 13, $\chi^2 = 9.373$, $p = .095$; standing: n = 13, $\chi^2 = 4.282$, $p = .510$; see Figure 12C). Therefore, when their infants gained upright locomotion, mothers' postural activities remained the same as when their infants were experienced crawlers.

Manipulation behaviors in postures. As infants and mothers moved about the room and pushed carts, climbed stairs, rolled balls, and pushed buttons, how did they use their postures to engage in particular manipulation activities? Because sitting and standing were the most commonly displayed postures for both participants, we investigated how mothers' and infants' manipulation behaviors differed in both postures within sessions and across time.

When we averaged across all sessions for each infant, we found that the proportion of sitting intervals in which infants engaged in no interactive activity was 24.2% (*SD* = 9.9), was 20.6% (*SD* = 8.0) for passive holding/minimal involvement, was 36.5% (*SD* = 10.2) for general fine motor manipulations, and was 17.5% (*SD* = 11.8) for general gross motor manipulations. A Friedman test showed that this distribution was significant (n = 13, $\chi^2 = 15.923$, $p < .001$; see Figure 13). This indicated that while they were sitting, infants were more likely to engage in general fine motor activity than they were to engage in other types of manipulatory behaviors.

We averaged across sessions to observe differences in manipulatory behaviors for standing as well. However, to calculate percentages for standing postures, we only averaged the six sessions for pre-walking and walking sessions. This was because prior to those sessions, infants rarely stood. Our calculations showed that when infants were standing, they spent 20% (*SD* = 10.6) of the intervals engaging in no interactive activity, 47.8% (*SD* = 10.8) engaged in passive holding/minimal involvement, 25.1% (*SD* = 10.6) taking part in general fine motor manipulations, and 6.4% (*SD* = 6.8) of intervals engaging in general gross motor manipulations (see Figure 13). A Friedman test showed that this distribution was also significant (n = 13, $\chi^2 = 24.508$, $p < .0001$). Therefore, when infants stood, they were more likely to passively interact with objects.

We completed these same analyses to assess how mothers' activities differed depending on whether they were sitting or standing. When we considered sitting, the proportion of intervals mothers spent engaging in no interactive activity was 45.4% (*SD* = 9.9), was 25.5% (*SD* = 5.6) for passive holding/minimal involvement, was 17.2% (*SD* = 4.0) for general fine motor manipulations, and was 12.1% (*SD* = 6.2) for general gross motor manipulations (see Figure 13). According to a Friedman test, this distribution was significant (n = 13, χ^2 = 31.615, p < .0001). This meant that mothers were more likely to not engage in any activities when they were sitting.

When standing, our calculations showed that mothers spent 19.4% (*SD* = 17.1) of the intervals engaging in no interactive activity, 41.3% (*SD* = 26.8) engaging in passive holding/minimal involvement, 18.1% (*SD* = 27.3) taking part in general fine motor manipulations, and 15.9% (*SD* = 15.1) engaging in general gross motor manipulations of objects (see Figure 13). A Friedman test revealed that this distribution was significant (n = 13, χ^2 = 9.991, p < .019;). Therefore, when mothers were standing, they were more likely to also be engaging passively with objects as opposed to no activity or active fine or gross motor manipulations.

To better understand how these trends for manipulations in postures differed among mothers and infants, we ran Mann-Whitney tests on the averages of all sessions for each dyad. Mann-Whitney tests showed that when they were seated, mothers spent more time than infants engaging in no interactive activity (U = 12.000, Z = -3.718, p < .0001), and infants spent more time than mothers engaging in general fine motor manipulations of objects (U = 7.000, Z = -3.974, p < .0001). Infants and mothers spent equal amounts of time engaging in passive holding/minimal involvement with objects (U = 54.000, Z = -1.564, p = .118) and general gross motor manipulations (U = 64.000, Z = -1.051, p = .311) of objects when seated. This meant that infants were more likely to use sitting postures to engage in detailed fine motor manipulations such as pressing buttons, shaking parts of a toy, turning flaps on toys, among other actions. Mothers were more likely to remain inactive while they were sitting. When in standing postures, mothers and infants did not differ in their levels of no interactive activity (U = 77.500, Z = -.359, p = .719), passive holding/minimal involvement with objects (U = 67.000, Z = -.898, p = .369), general fine motor manipulations (U = 46.5, Z = -1.951, p = .051), and general gross motor manipulations (U = 64.500, Z = -1.041, p = .298). This indicated that when mothers stood, they engaged with the play environment similarly to their children.

We also wanted to know how progression through motor milestones might impact the ways in which mothers and infants used sitting and standing postures to act on their environments. Earlier, we showed that when infants were sitting, they were more likely to show general fine motor manipulations than other postures. According to a Friedman test across the 12 session studied, general fine motor manipulations initially were very common, but declined in frequency over time (n = 7, χ^2 = 33.330, p < .0001; see Figure 13A). An additional Friedman test on the levels of no interactive activity, passive holding/minimal involvement, and general gross motor manipulations showed that they remained stable and less common throughout the periods studied (n = 7, χ^2 = 16.297, p = .130; n = 7, χ^2 = 9.935, p = .536; n = 7, χ^2 = 7.657, p = .744, respectively). We also wanted to know whether the decline in fine motor manipulations while seated declined as a result of locomotor skill acquisition. Further analyses indicated that this was the case. During sessions in the transition to crawling, when infants were seated, there was a significant reduction in general fine motor manipulations (n = 10, χ^2 = 13.134, p < .022). After this initial reduction, there were no further significant changes in the latter two transitions (n = 13, χ^2 = 8.544, p = .129; n = 10, χ^2 = 8.773, p = .118; see Figure 14A). This meant that once infants learned to crawl, they used sitting postures less frequently for detailed fine motor manipulations and began to use the posture more broadly for other interactive behaviors. Sitting therefore became less specialized for one type of manipulatory activity over time.

Our earlier analyses showed that when infants were standing, they were more likely to passively hold toys or show minimal involvement with toys. A Friedman test on the various types of manipulation activities over the transition from pre-walking to walking revealed that there were no significant changes in any of the manipulation types (no interactive activity: n = 9, $\chi^2 = 6.109$, $p = .296$; passive holding/minimal involvement: n = 9, $\chi^2 = 7.789$, $p = .168$; general fine motor manipulations: n = 9, $\chi^2 = 6.517$, $p = .259$; general gross motor manipulations: n = 9, $\chi^2 = 4.914$, $p = .426$; see Figure 14B). Therefore, in the 6-session period when infants could stand, they did not show changes in how they used their standing postures to interact with objects.

The analyses on mothers' sitting postures above showed that mothers predominately did not engage in interactive activities when sitting. Friedman tests revealed that their levels of no interactive activities remained frequent and constant throughout the 12-session period studied (n = 12, $\chi^2 = 8.948$, $p = .627$; see Figure 14C). Mothers' levels of passive holding/minimal involvement, and general fine and gross motor manipulations also remained unchanged throughout the study (n = 12, $\chi^2 = 6.295$, $p = .853$; n = 12, $\chi^2 = 11.973$, $p = .366$; n = 12, $\chi^2 = 13.154$, $p = .283$). Mothers were therefore consistent with how they used sitting postures for no active involvement with objects throughout the duration of the study. Only two mothers consistently stood throughout all pre-walking to walking sessions, so we were therefore unable to run Friedman tests on those data, but they are graphed in Figure 14D.

Earlier when using averaged data, we showed that seated infants spent more intervals engaging in general fine motor manipulations than mothers. Mann-Whitney tests on 3-session averages for each of the 4 time blocks showed that was only significant in pre-crawling, crawling, and pre-walking sessions (U = 12.000, Z = -3.466, $p < .001$; crawling: U = 28.000, Z =

-2.897, $p < .004$; pre-walking: U = 33.000, Z = -2.641, $p < .008$), but when infants were capable of walking, they used sitting postures similarly as their mothers did (U = 54.500, Z = -1.539, $p =$ .124). Furthermore, we showed that mothers spent more sitting intervals than infants engaging in no activity. Mann-Whitney tests on 3-session averages for each of the 4 time blocks showed that this remained true for each block (pre-crawling: U = 16.000, Z = -3.234, $p < .001$; crawling: U = 45.000, Z = -2.026, $p < .044$; pre-walking: U = 19.000, Z = -3.360, $p < .0001$; walking: U = 21.000, Z = -3.257, $p < .001$). This shows that infants used their sitting posture differently than mothers.

Distance between mother and infant and infant posture. We were curious if the distance between the mother and infant depended on the range of postures displayed by infants within sessions. To assess this question, we investigated how far apart mothers and infants were from each other when the infants were laying down, sitting, on all fours, squatting/kneeling, crawling, standing/bending over, cruising, or stepping. Because some of those postures were not well represented in each session, we averaged the 3-sessions in each of the four time blocks for pre-crawling, novice crawling, experienced crawling/pre-walking, and walking. We used these data to assess whether the distance between the mother and infant changed depending on the infants' postures within the play sessions and also their level of postural progression over time.

Even using averages, many postures were not well represented across all four blocks for all infants, so we were unable to use Friedman tests across the 4 blocks to assess changes in those postures. Sitting, on all fours, and standing postures were shown in at least 7 infants throughout all 4 time periods, so Friedman tests on those postures showed that over the course of the 12 sessions studied, the distance between the mothers and infants significantly increased during intervals when then infants were sitting (n = 12, $\chi^2 = 16.500$, $p < .001$) and standing (n =

9, $\chi^2 = 20.467$, $p < .0001$), but remained the same across the 12 sessions during intervals when infants were on all fours (n = 7, $\chi^2 = 2.486$, $p = .478$). For sitting and standing postures, we followed up with more analyses to determine whether the increases in the distance between the infants and mothers occurred at specific motor milestones. We also examined mother-infant distance in other postures that were not as well represented across the whole 12-session period studied, but were demonstrated during enough during particular transitions for more targeted analyses.

A set of Wilcoxon signed-rank tests revealed that during the 6- session transition from pre- to post-crawling, mother-infant distance did not significantly change during intervals when the infants were laying down, sitting, or kneeling (respectively: n = 5, Z = -0.674, $p = .500$; n = 12, Z = -1.883, $p = .060$; n = 4, Z = -0.365, $p = .715$). However, during the transition from novice crawling to experienced crawling, mother-infant distance significantly increased during intervals when infants were sitting and crawling (n = 13, Z = -1.992, $p < .046$ and n = 11, Z = -2.045, $p < .041$), but showed no changes when infants were kneeling, and standing (respectively: n = 12, Z = -1.334, $p = .182$; n = 11, Z = -1.511, $p = .131$). Finally, when infants transitioned from pre-walking to walking, the distance between mother and infant increased when infants were kneeling (n = 13, Z = -2.411, $p < .016$), and marginally increased when infants were standing and stepping (n = 13, Z = -1.922, $p < .055$ and n = 10, Z = -1.955, $p < .051$, respectively). However, during this transition period, the distance between the mother and infant did not significantly change when infants were sitting or crawling (respectively: n = 13, Z = -0.874, $p = .382$; n = 11, Z = -1.067, $p = .286$). Thus, during locomotor skill development, infants gradually gained more experience using some early-appearing postures. The distance between the mother and the infant increased over time during intervals when infants adopted those well-practiced postures.

Infant posture stabilization. Finding support or seeking help to stabilize a posture can be a common occurrence during the developmental periods studied. We classified three overall types of stabilization: instances when infants stabilized themselves either with an object or furniture, instance when infants stabilized themselves using the mother, or instances when mothers actively stabilized their infants. We wanted to investigate developmental changes in mothers providing postural stabilization to their infants or infants using postural stabilization from their environment. To assess this, we ran a Group (2: infants vs mothers) X Session (12) repeated measures ANOVA on the proportion of intervals that infants or mothers spent stabilizing the infant's posture. Results revealed a main effect of Session ($F(5.670, 136.073) = 2.891$, $p < .013$, $\eta^2 = .107$) and Group ($F(1,24) = 39.715$, $p < .0001$, $\eta^2 = .623$), and a Group by Session interaction ($F(5.670, 136.073) = 2.950$, $p < .011$, $\eta^2 = .109$; see Figure 15A). This meant that across the 12 sessions, there was a significant increase in the proportion of intervals infants' posture was stabilized, but infants stabilized themselves more than they were stabilized by their mothers.

To determine whether these trends changed as a function of infants' locomotor skills development, we ran similar repeated ANOVAs over blocks of 6 sessions. There were main effects of Group in all three transition periods ($F(1,24) = 7.972$, $p < .009$, $\eta^2 = .249$; $F(1,24) = 31.877$, $p < .0001$, $\eta^2 = .570$; $F(1,24) = 62.959$, $p < .0001$, $\eta^2 = .724$). However, no transition periods showed main effects of Session ($F(3.984, 95.626) = 2.040$, $p = .095$, $\eta^2 = .078$; $F(4.202, 100.836) = 1.987$, $p = .099$, $\eta^2 = .076$; $F(3.468, 83.223) = 1.831$, $p = .139$, $\eta^2 = .071$), or Group x Session interactions ($F(3.984, 95.626) = 2.197$, $p = .075$, $\eta^2 = .084$; $F(4.202, 100.836) = 1.786$, p

= .134, η^2 = .069; F(3.468, 83.223) = .567, p = .663, η^2 = .023; see Figure 15A). These posthoc analyses meant that throughout all time periods, infants stabilized themselves more than they were stabilized by their mothers, but the increases in postural stabilization were not linked in time to specific transitions in infants' locomotor abilities.

We were also curious about whether certain postures were more likely to be stabilized than others. Infants' most common postures were sitting and standing postures, but we were also interested in locomotor postures like crawling and stepping. Therefore, we investigated how infant sitting, crawling, standing, and stepping were stabilized during the play sessions. When we averaged data from each dyad across all sessions, Friedman tests comparing the proportion of intervals in which sitting, crawling, standing, and stepping postures were stabilized showed that infants stabilized themselves with objects and their mothers in standing postures more than the other three postures (objects: M = 12.0%, SD = 8.7, χ^2 = 33.805, p < .0001; mothers: M = 1.1%, SD = 1.1, χ^2 = 14.134, p < .003; see Figure 15B). Similarly, mothers stabilized their infants in standing postures more than they stabilized their infants' sitting, creeping, or stepping postures (M = 3.7%, SD = 3.9%, χ^2 = 24.656, p < .0001). Therefore, standing postures were the most common postures to be stabilized out of the ones measured here.

Number of different postures. As infants gained locomotor skills and moved about the room more, mothers and infants spent fewer intervals in sitting postures. We wanted to measure whether the number of postures mothers and infants displayed during each session increased over time. A Group (2: infants vs mothers) X Session (12) repeated measures ANOVA on the number of postures revealed a main effect of Session (F(7.269, 174.461) = 17.561, p < .0001, η^2 = .423), Group (F(1,24) = 32.782, p < .0001, η^2 = .577), and a Group by Session interaction (F(7.269, 174.461) = 2.796, p < .008, η^2 = .104). Therefore, as expected, dyads showed increases in the number of postures they displayed per session, but the increase was greater in infants than in their mothers.

We ran similar repeated measures ANOVAs specifically on the three transition periods to identify if increases in the number of postures shown were related to transitive motor stages. During the transition to crawling, there were main effects of Session ($F(3.503, 84.069) = 13.274$, $p < .0001$, $\eta^2 = .356$) and Group ($F(1,24) = 7.774$, $p < .010$, $\eta^2 = .245$), as well as a significant Group x Session interaction ($F(3.503, 84.069) = 4.374$, $p < .004$, $\eta^2 = .154$). During the transition to experienced crawling there was an effect of Group ($F(1,24) = 39.507$, $p < .0001$, $\eta^2 = .622$) and Session ($F(4.419,106.067) = 11.125$, $p < .0001$, $\eta^2 = .317$), but no significant interaction ($F(4.419,106.067) = .158$, $p = .968$, $\eta^2 = .007$). During the period when infants transitioned from experienced crawling to walking, there were a main effect of Group ($F(1,24) = 51.474$, $p < .0001$, $\eta^2 = .682$), but no effect of Session $F(4.384, 105.226) = 1.135$, $p = .575$, $\eta^2 = .030$) and no interaction ($F(4.384, 105.226) = .526$, $p = .733$, $\eta^2 = .021$). Our subsequent analyses therefore showed that the onset of crawling and crawling experience was associated with increases in the number of postures dyads showed, but this increase was not tied to walking onset. Furthermore, infants produced more postures in each play session than their mothers did at all stages.

Number of postural changes. As infants and mothers increasingly moved about the room and interacted with the objects within it, we showed that they tended to use some postures more than others during play. However, we still wanted to know how postures may have changed from one interval to the next. To address this, we examined how often infants and mothers transitioned from one posture to another during play and across locomotor development. When we averaged all sessions together for each infant, we found that infants changed posture 8.8 ($SD = 1.7$) times per session, and mothers changed posture 4.3 ($SD = 1.8$) times in each session. A Group (2: infants vs mothers) X Session (12) repeated measures ANOVA on the number of postural changes revealed a main effect of Session ($F(6.483, 155.580) = 22.971$, $p < .0001$, $\eta^2 = .489$) and Group ($F(1,24) = 44.583$, $p < .0001$, $\eta^2 = .650$), and a Group by Session interaction ($F(6.483, 155.580) = 4.128$, $p < .0001$, $\eta^2 = .147$). Thus, across the 12 sessions, dyads increased how frequently transitioned between postures within sessions, but infants did so more than their mothers (see Figure 16).

As we did before, we ran similar repeated measures ANOVAs over the 6-session transitions to identify whether changes occurred as a result of specific locomotor transitions. During the transition from pre-crawling to crawling, there were main effects of Session ($F(3.298, 79.143) = 11.622$, $p < .0001$, $\eta^2 = .326$) and Group ($F(1,24) = 12.646$, $p < .002$, $\eta^2 = .345$), as well as a significant Group x Session interaction ($F(3.298, 79.143) = 5.386$, $p < .001$, $\eta^2 = .183$). From novice to experienced crawling there was an effect of Group ($F(1,24) = 54.025$, $p < .0001$, $\eta^2 = .692$) and Session ($F(4.204, 100.897) = 14.205$, $p < .0001$, $\eta^2 = .372$), but no significant interaction ($F(4.204, 100.897) = .170$, $p = .958$, $\eta^2 = .007$). Finally, for the experienced crawling to walking transition period, there were a main effect of Group ($F(1,24) = 56.958$, $p < .0001$, $\eta^2 = .704$), but no effect of Session $F(4.452, 106.846) = 1.235$, $p = .299$, $\eta^2 = .049$) and no interaction ($F(4.452, 106.846) = .173$, $p = .962$, $\eta^2 = .007$). These follow-up analyses therefore indicated that the increase in the frequency of changes in posture was related specifically to the onset of crawling and crawling experience, but not to walking onset. Also, infants displayed more postural transitions than their mothers throughout all transition periods (see Table 5 for a summary of results of posture measures).

Correlations between spatial exploration and posture changes

One of our goals was to understand whether or not the frequency of changes in posture were linked to traveled distance and dispersion in the room. To assess this, we ran Spearman correlations on all sessions for each infant and mother individually between those two measures of spatial exploration and postural changes. For 10 out of 13 infants, the number changes in posture per session was significantly positively correlated with how far they traveled (range $r = .613$, $p < .034$ to $r = .877$, $p < .0001$; see Figure 11C), and for 8 out of 13 infants, postural changes were significantly positively correlated with travel dispersion (range $r = .582$, $p < .047$ to $r = .898$; $p < .0001$; see Figure 11D). Thus, as infants gained independent locomotion, they showed concomitant changes in how far they traveled, how many locations they traveled to, and how frequently they transitioned between postures.

Similar to their infants, mothers also displayed significant correlations between these measures. There were significant positive correlations between the number of postural changes and distance traveled in 10 out of 13 mothers (range $r = .578$, $p < .049$ to $r = .936$, $p < .0001$), and there were significant positive correlations between the number of postural changes and travel dispersion in 7 out of 13 mothers (range $r = .586$, $p < .045$ to $r = .956$, $p < .0001$). For both mothers and their infants, there was an increase in transitions between postures as they increasingly explored the room.

Part 4. Discussion

> "We shall walk together on this path of life, for all things are a part of the universe, and are connected with each other to form one whole unity. This idea helps the mind of the child to become fixed, to stop wandering in an aimless quest for knowledge. He is satisfied, having found the universal centre of himself with all things."
>
> – Maria Montessori (1989, pg. 6)

We investigated how mother-infant interactions changed over the course of locomotor development. Our study had four novel goals. We wanted to understand how mothers' and infants' spatial exploration patterns of traveled distance, speed of travel, and dispersion in the room changed over time. Second, we observed changes in mother-child distance. Third, we tracked differences in the frequency, diversity, and types of interactions that infants and mothers displayed. And fourth, we monitored changes in mothers' and infants' use of various postures, changes between postures, and infants' postural stabilization both within and across sessions (see Table 1). We discovered that the infants' locomotor development was tied to concomitant changes in infants' and mothers' spatial exploration patterns in the room, their interactive behaviors, and their use of postures within sessions.

Our data showed that during the transitions to crawling and experienced crawling, infants showed increases in how far they traveled, how quickly they moved, and the dispersion of travel in the room. The dispersion of travel continued to significantly increase as infants learned to walk. These results in infants were expected, but we are the first to show that mothers' spatial displacement in the room increases with infant locomotor development, although not as much as in their infants (see Table 3). We further showed that the patterns we observed in infants' spatial exploration were strongly related to their interactive behaviors and postural changes displayed within each session. Mothers' increases in spatial displacement in the room was only related to the increasing number of postural changes performed and not to their interactive activities, which became more likely over time. As infants explored the room and the toys and furniture within it, they ventured further away from their mothers. However, this mother-infant distance was modulated by the specific postures infants adopted within in the session, whether they were on the stairs, and also across postural-locomotor development. Additionally, we found that mothers and infants spent the majority of intervals sitting, but the activities performed during sitting postures changed significantly for infants as they gradually used prior-occurring postures in novel ways. Mothers spent less time stabilizing infants' postures than infants spent stabilizing themselves (see Table 5). Many of the changes we observed in infants' and mothers' behaviors occurred in conjunction with the transition to crawling and crawling experience, and tended to level out unchanging with the acquisition of walking.

Gender comparisons

We did not find gender differences in neither mothers nor infants in almost any of the variables our study. Although our sample size was small, this finding agrees with prior work showing that girls and boys do not differ in rates of progression in crawling and walking and at given ages, girls and boys have similar motor skills (Bayley, 1965; Mondschein et al., 2000). Previous work explains that girls and boys move at similar speeds of travel, with similar step lengths, and with similar trajectories (Mondschein et al., 2000). Our work adds to existing knowledge about gender comparisons in infancy because we were the first to examine whether patterns of interactive activities and uses of posture varied between boys and girls within sessions. Boys and girls are therefore far more similar during infancy than most adults may expect. Prior research shows that mothers' have different expectations for their locomotor infants based on their infants' gender (Mondschein et al., 2000), so we did expect some differences in mothers' behaviors. These differing expectations in mothers can sometimes lead to differences in mothers' behaviors with their daughters and sons. Clearfield & Nelson (2006) used free-play sessions and found differences between mothers of girls and mothers of boys in both the content of mothers' infant-directed speech and mothers' levels of engagement with their children. Specifically, they discovered that mothers spent more time engaged in activities with their daughters, whereas mothers of boys spent more time simply watching their sons' activity in the room (Clearfield & Nelson, 2006). Here, we did not find any differences in mothers' behaviors with their daughters or sons. This may be because we investigated slightly different variables than previous studies. Whereas previous work investigated speech content and levels of engagement, we simply coded the presence or absence of mothers' motor activities.

Changes in spatial exploration

Our study is the first to investigate spatial displacement patterns in not only infant behaviors, but also mothers' while they interact with their children. Consistent with many prior claims, we showed mothers' behaviors change with their infants' developmental progression in locomotor skill. This provides even more concrete evidence that even though most acknowledge the significant developmental changes following the onset of locomotion in infancy, it is also important to consider concomitant changes in mothers (Hendrix & Thompson, 2011; Moore, 2007). In our data, mothers showed similar trends to their infants in terms of how they increasingly moved about the room during interactions with their children. No prior studies have ever studied those changes in mothers' spatial interaction patterns with their infants prior to, during, and after the onset of independent locomotion.

In addition to delineating novel patterns in mothers' spatial displacement in the room, we found that as infants gained crawling experience, they traveled further distances and at faster speeds in our free play environment. Similarly, with crawling and walking experiences, infants showed greater travel dispersion in the room as they visited more locations. The ability to explore independently is an important activity for infants. If infants are not allowed the capability to move freely and spatially explore their homes, they may show delays in locomotor milestones (Crouchman, 1986), and their early cognitive-intellectual development is detrimentally affected (Wachs, 1979).

Our current findings about infants' spatial exploration in the room were expected based on previous research showing that the onset of locomotion, and especially the onset of crawling, serves as a setting event that increases the probability for many advancements in infants' exploratory skills (Anderson et al., 2013; Bertenthal et al., 1984; Campos et al., 2000). Our findings support previous studies showing gradual increases in distance traveled and travel dispersion in the room with the progression of locomotor skills. For example, Nishio, Aoyama, & Sasaki (2015) tracked infants' likelihood to visit certain locations in the home and discovered that infants increasingly explored different spaces in their homes as a result of locomotor development.

Our findings partially agree with previous work showing that the distance covered and speed of infants' travel increased with crawling experience, showing no drop with the onset of walking. Other studies (Adolph et al., 2012; Snapp-Childs & Corbetta, 2009) have followed infants well into several weeks of walking and showed that the distance traveled and speed of travel both increase further with walking experience. Although our data did not extend this far in to walking progression, we confirm their claims that new walkers gain all the benefits of upright locomotion without any cost to travel efficiency (Adolph et al., 2012). It is possible that the 6 weeks we followed infants after the onset of walking was not long enough to capture additional improvements in walking proficiency. As in our study, Clearfield (2011) used a similar longitudinal design to investigate changes in infants' distance traveled across the transition from experienced crawling to walking. Similar to our own findings, Clearfield (2011) found no differences in the distance infants covered in their last crawling session to their first two sessions of walking. Therefore, we think differences between studies concerning spatial exploration proficiency in walkers relates mostly to how much walking experience infants have.

We think it may be possible that differences in our room layouts may have contributed to differences observed between our findings about distance traveled and speed of travel and those from Adolph et al. (2012). The free play environment in our study was 3.3 m x 3.7 m, but was a much larger 8.7 m x 6.1 m room in Adolph et al.'s (2012) cross-sectional study. Having a much larger environment could have contributed to Adolph et al.'s (2012) findings that walking infants' explored further and at faster speeds than experienced crawlers. Clearfield's (2011) longitudinal study used a free play environment measuring 3 m x 3 m, and interestingly, her findings were similar to ours, showing that there was no difference between how far infants traveled when they were experienced crawlers and when they became walkers. In addition to room size, other elements of the space could have contributed to our findings. For instance, because walking infants in our study spent nearly 20 percent of the time on the stairs, it may be possible that they may not have traveled as far and as fast as they would have if they were on the ground. Certainly, a newly walking infant on stairs may slow down in order to focus on maintaining balance to navigate the unlevel, raised surface.

Distance between mothers and infants

As infants and mothers increasingly moved about the room, we found that the distance between them increased over time. Interestingly, the distance between the mothers and infants differed in certain intervals depending on the infants' postures and whether or not they were on the stairs. It is therefore possible that mothers may have stayed closer to their pre-locomotor infants to monitor their children's behaviors, but gradually may have withdrawn as infants became more autonomous. The relatively small 1- to 2-tile increase we found in infant-mother distance over time likely shows that although mothers may have recognized their infants developing more motor independence, they still remained close enough to their infants to reach out and help them if necessary.

This first attempt to delineate patterns in mother-infant distance was novel, but was appropriate for our typical sample. Previous research with clinical populations has shown that when mothers remain too close and loom over their infants' activities, their behaviors usually occur as a result of atypical interaction patterns (e.g., Beebe et al., 2010).

It is possible that mothers' movement in the room and distance from the infant may be related to other aspects of development that were not measured here. For instance, Biringen, Emde, Campos, and Appelbaum (2008) conducted a study on the development of physical autonomy in walking infants. They showed that during the transition to walking, both precocious and late walkers showed increases in separateness from their mothers, but the effect was more pronounced in precocious walkers. Our sample size was too small to begin to investigate questions about locomotor timing (e.g., early versus late), but it would likely prove fruitful to study further.

Beyond locomotor timing, there are also potential effects of language ability on locomotor exploration. For example, in their study on language development, Walle and Campos (2014) found that parents who moved less tended to have infants with larger vocabularies. They suggest that it is possible that the child's language abilities play a role in the development of specific communication styles, which affects the need for parents to become physically involved in the interaction (Walle & Campos, 2014).

Play behaviors with toys and each other

Mothers' interactive behaviors. Writings from Montessori (1936b) and Mahler (1975) both explained that the mothers' behaviors and reactions during their infants' acquisition of locomotor skills can significantly impact infants' cognitions about their own abilities. Despite these claims, no studies to our knowledge, have investigated how mothers' interactive activities may change during their infants' locomotor development. Therefore, one important contribution of our study was the investigation of mothers' interactive physical behaviors with her infant. We show that mothers were not as active as their infants, but they still participated in the free play session. Importantly, mothers directed more interactive behaviors to their infants than their infants did to them. Furthermore, the frequency of infants' interactive activities initially was somewhat lower than that of their mothers', but eventually became similar to those of their mothers' once infants gained crawling experience. These findings suggest that during pre-locomotor periods, mothers played a greater role in moving their infants to promote infants' interactions with toys and furniture. However, as infants became more mobile and proficient navigators guided by their own interests, mothers may have shifted from directive to more supportive types of actions intending to maintain their infants' attention to particular toys. Therefore, even in later periods, mothers would still interact with their infants in the free play environment, but the motivation driving their activities may have changed. This is consistent with prior work showing that mothers' responsivity to their infants in their home environments is relatively stable over time (Masur & Turner, 2001).

Pierce (2000) examined mothers' maintenance of infants' play spaces in the home and showed that some mothers typically positioned their infants' favorite toys in easily accessible places for the infants to come cross during self-initiated play. Clearly, activities like this show that mothers are attuned to infants' interactive activities, but assume more supportive roles in play. Mothers' early interactive behaviors with their young children has been shown to relate to children's later outcomes in cognitive and social independence (Landry, Smith, Swank, & Miller-Loncar, 2000). Our future research will identify how different types of mothers' interactive behaviors differ as a function of their infants' mobility levels. It may be possible that mothers' play strategies with their developing infants change over time, but our current analyses did not capture those details.

We found that mothers' furniture directed interactions increased steadily during the 12 sessions studied, and we think this is related to the fact that infants were increasingly more likely to venture onto the stairs during each transition period we tracked. In previous studies, parents have reported on their efforts to teach their infants about stair safety, which included moving their infants' body to show them the motions for getting down stairs, physically modeling how to descend stairs themselves, and providing verbal instructions or encouragement (Berger, Theuring, & Adolph, 2007). Although we did not measure mothers' verbal behaviors, we did find that when their infants could walk, mothers were significantly closer to their infants when they were on the stairs compared to when they were off the stairs. When their children were on the stairs, mothers often stood by and watched, guarded their infants' potential falls, or stabilized their infants' posture. Clearly, mothers in our study were invested in safe-guarding their children, but recognized situations when their infants were more autonomous (e.g., when infants were on the floor).

Most studies investigating differences in mothers' roles during infants' locomotor development has usually focused on mothers' expectations (Mondschein et al., 2000) or changes in the content of their vocal productions (Clearfield & Nelson, 2006; Karasik et al., 2014; Walle & Campos, 2014). Some have reported that mothers seem to take passive roles when it comes to physically interacting with their children in free play sessions. We think this could be because in some of those studies, experimenters asked mothers to not direct their child's attention to anything specifically (Clearfield & Nelson, 2006), or to remain in one location during the session to complete a lengthy questionnaire (Walle & Campos, 2014). Our findings therefore cannot be directly compared to previous research because we encouraged mothers to play with their infants as they normally would in their homes, without imposing restrictions.

Infants' interactive behaviors. Whereas mothers spent more time not engaging in interactive behaviors, infants were much more likely to show interactions with their surroundings. This became particularly true as infants gained crawling experience. This finding has important implications for development because as infants matured, they transitioned from being passive to becoming more active participants in their environments, which is consistent with prior work (Campos et al., 2000; Mahler et al., 1975; Montessori, 1936b). In fact, prior to the ability to express themselves verbally, infants' early behaviors such as object interactions, and explorations are direct expressions of their curiosities, interests, and choices.

We found that with each locomotor transition we studied, the variety of interactions that infants produced became more varied. This is advantageous for exploratory development because in a previous study by Caruso (1993), infants who explored toys more broadly were better able to interact with objects in different ways. This provides evidence for benefits of greater breadth rather than depth in free play (Caruso, 1993). Furthermore, toy-directed behaviors were the most common type of interactive behavior for both mothers and infants. It is possible that mothers' consistent interactive behaviors across time facilitated infants' toy-directed actions. In their study about object play in 4-month-olds, Van Egeren, Barratt, and Roach, 2001 found that mothers were more influential about object-directed behavior and infants were more influential about expressive behavior in mother-infant interactions. Furthermore, previous work investigating mother-infant joint play showed that with age, infants spent more time engaging in coordinated joint play (Bakeman & Adamson, 1984), and infants show more complex forms of play when interacting with their mothers compared to when they were playing alone (Bigelow, MacLean, & Proctor, 2004; Fiese, 1990). Future research could identify how developmental changes in joint play may affect spatial exploration variables studied here and concomitant increases in posture complexity.

Infants showed increases in stair interactions at each of the three transition periods we studied. This is consistent with prior work showing that climbing play made up a significant proportion of play types that occurred in home environments (Pierce et al., 2009). Although, some research shows that when infants have stairs in their homes, they are more likely to crawl and walk up stairs earlier in development compared to infants who do not have stairs in their homes (Berger et al., 2007). Although learning to ascend stairs came earlier, only about half of infants in that study had descended a flight of stairs, even at 13 months of age (Berger et al., 2007). Some of the infants who walked earlier in our study were only followed until 14 months of age. It is possible that if we had followed our sample longer, that those infants would have spent progressively even more time on the stairs in our free play environment as they mastered postural control.

Importantly, our data showed developmental changes in how infants moved about spatially and interacted with objects in their play spaces. Specifically, the number of bouts of interactive behaviors also related to the distance infants traveled in the room and the dispersion of their activity in the room. Initially, pre-locomotor infants spend more time sedentary and engage in play with their own bodies or objects directly in front of them. The acquisition of crawling then allows them to move around slightly more and encounter more objects. Finally, gaining additional locomotor experiences in crawling and walking further facilitates discovery of objects, but also allows for the introduction of space and place play, in which infants engage in playful interactions that may combine object and space play (e.g., carrying a ball while repeatedly climbing stairs; Lynch, 2011). Our data therefore highlight an important interrelationship between infants' interactions and their use of space. This is consistent with prior work that measured similar behaviors. Previous research has shown that 10-month-olds engaged with a wider environment by departing from their mother, and that the properties of the wider environment, such as the availability and number of toys, altered infant's contact with their mother (Rheingold & Eckerman, 1969). In that study, researchers found a relationship with the number of toys in a room and the amount of time infants spent engaged with toys and the distance they traveled. In that study, one group of infants was provided one toy to play with and another group was provided three toys. The group of infants provided with three toys increased the time spent away from the mother, increased the time spent playing with the toys, and increased the distance they traveled in the area (Rheingold & Eckerman, 1969).

Engaging with toys while moving about a space during exploration allows infants to experience their own changing position as they move, but also the changing locations of objects while interacting (Thelen & Smith, 1994). This type of play is reflected in the link we discovered between spatial exploration measures and interactive activities. Our finding is related to other research showing that the shift to self-produced locomotion is associated with a shift from a predominately egocentric to allocentric view of the world, which creates opportunities for infants to learn about their environments from differing perspectives. This results in advancements in spatial cognition and search tasks (Campos et al., 2000; Clearfield, 2004).

Several prominent researchers have claimed that the onset of crawling importantly marks the beginning of a whole host of developmental changes in infants (Anderson et al., 2013; Campos et al., 2000). Our data support this claim such that the acquisition of crawling showed significant changes in not only infants' spatial exploration of the room and interactive activities, but also carried over into mothers' behaviors. Even though we did not find significant increases in infant interactive activities during the transition from experienced crawling to walking, walking infants still showed similar levels of interactive activities compared to their mothers. This finding supports previous research indicating that walking infants show intentionality in object-directed actions, and children with more extensive walking experience show preferences for interacting with certain objects over others, even if their preferred objects were much further away (Dosso & Boudreau, 2014). Indeed, our data show that the number of infants' interactive activities and postural changes were significantly associated with our measures of spatial exploration, revealing that they were actively exploring the room.

We interpret our data to show that infants' behaviors became increasingly more mobile, centered on discovery, and based on interactions with their environments. This is not consistent with prior work showing that 13- and 19-month old infants' bouts of stepping usually do not appear to be goal-directed (Cole, Robinson, & Adolph, 2016). However, our findings may differ because of our data collection and coding methods. In comparison to their cross-sectional walking sample, our data were with a smaller sample of mother-infant dyads tracked longitudinally over the progression from pre-crawling to walking. We were interested in considering how interactive behaviors changed with various types of locomotor experience, where they instead focused specifically on bouts of walking in infants producing upright locomotion. Additionally, the free play environments were set up differently, with room size, furniture, elevations, and the number of toys differing between studies.

It is possible that mother-infant distance and interactions with toys were related. We found that when infants showed less frequent toy interactions during the transition from crawling to pre-walking, the distance between the mother and infant increased. Although we did not analyze patterns in playing with certain types of toys, we noticed that the toys infants seemed to enjoy the most played music. Mualem & Klein (2013) found that musical free play sessions with mother-infant dyads, compared to nonmusical free play sessions, were associated with higher levels of physical contact, more eye contact and more positive affect, and longer communication events between mother and child. Future analyses will examine more in depth those moments were mother and infant interact jointly.

We found that mothers were very rarely considered targets of infants' motor interactions. These findings are somewhat inconsistent with prior work that has investigated how infants begin to orient to and interact with their social environments during locomotor development. Prior work has shown that walking infants produce more social looking behaviors, display more directed gestures, and interact more with their mothers compared to crawling infants (Clearfield et al., 2008; Clearfield, 2011). Whereas Clearfield (2011) defined infants' mother-directed interactions as either vocal or physical types of behaviors, our coding only considered infants' physical motor behaviors. There are a few aspects of our study that may have contributed to the difference in findings. First, our behaviors of interest were distinct from prior work, our time sampling may not have been frequent enough to capture detailed changes in infant-mother communicative interactions, and our inclusion of the infant-sized stairs into the free-play environment may have created a shift in infant's interactions that may have otherwise been directed towards the mother or to toys in the room. Other longitudinal work by Bakeman and Adamson (1984) has shown that infants spent less than 10% of the time engaging in joint play with their mothers up until they were 15 months old. Bakeman and Adamson claimed that it may have been possible that infants their study were not followed long enough to observe developmental trends in interactions with their mothers, and this may have also been true in our own.

However, although infants' interactions with their mothers were rare in our study, we did find that female infants were more likely to interact with their mothers than were male infants. Previous research by Goldberg and Lewis (1969) shows that when infants were 6 months old, mothers of girls spent more time interacting with their daughters than did mothers of boys of the same age. When those infants were 13 months old, girls were more likely to interact with their mothers than were boys. It seems as though infants may learn these behaviors from their mothers, because in that same study, mothers who engaged in more close physical contact with their sons at 6 months had sons who were more likely to continue those behaviors with their mothers when they were 13 months old (Goldberg, & Lewis, 1969). It is therefore possible that mothers socialize their infants to engage in behaviors that are more acceptable within their society. Previous work concerning mother-infant play found support for the notions that sons are socialized to show instrumental characteristics, associated with independence and acting on the world, whereas daughters are socialized to value interpersonal relatedness (Robinson, Little, & Biringen, 1993). Another study by Clearfield and Nelson (2006) showed support for these claims and discovered that mothers of girls are more likely to engage in close interactions with their daughters, but are more likely to simply watch their sons play independently.

Postural activities

Another novel contribution of this study is that we have tracked how infants and mothers use various postures during play and across infants' locomotor development. Not surprisingly, we discovered that both infants and mothers spent the majority of their time sitting during the sessions, but both began to show more varied postures and transitions between postures as they increasingly moved about the room to interact with toys. This pattern was particularly pronounced in infants. Infants' acquisition of unpracticed locomotor skills like walking for example, did not affect their ability to transition through postures, explore the room, and discover objects for interactions.

Whereas mothers only transitioned between postures once every few minutes, infants transitioned between postures an average of about once per minute. The frequency of times infants changed their body positioning during play reveals how active they are while interacting and discovering the environment around them. Indeed, the number of times infants transitioned between postures was strongly related to their patterns of distance traveled and dispersion in the room. In mothers, this was not the case. This meant that infants' use of postures and transitions between them were linked to their movements about the room and encounters with toys, whereas for mothers, the use of postures was related to monitoring their infants' play and not making new discoveries in the room. These results are consistent with prior research characterizing the use of postures in play (Reed, 1988), and the interrelationship between infants' expanding repertoire of postures and new discoveries (Pierce et al., 2009). In future research, we think it would be useful to measure the behaviors preceding and following mothers and infants' postural changes to delineate specific motivations for changing postures to move about the room.

We also discovered that from the onset of crawling to the onset of walking, infants spent much more time stabilizing their own postures than mothers spent stabilizing their infants. Infants were more likely to self-stabilize their standing postures than they were to stabilize other postures, which may be indicative that infants were beginning to learn about the limitations of their own motor abilities. This is consistent with prior work showing that by the time infants learn to cruise, they begin to understand how properties of their environments may support their efforts to stabilize their postures for play or locomotion (Berger, Chan, & Adolph, 2014). Trends in infants' postural stabilization occurred even though mother-provided stabilization of the infant was omnipresent but infrequent throughout the study, but similar to infants' self-stabilization, was more common when infants displayed standing postures.

Mother-provided infant postural stabilizations are very important for facilitating infant motor performance. For example, studies have shown that stabilizing infants' postures (even using other means that the mother) helps infants produce more mature reaching movements in both pre-reaching and reaching infants (Hopkins & Rönnqvist, 2002; von Hofsten, 1982). Although mother-provided postural stabilization did not change in our study over time, Fogel, Nwokah, and Karnes (1993) have previously written about the dynamic changes occurring in mother-provided scaffolds during interactions as a result of the infants' postural progression. Specifically, mothers' behavior becomes altered by the infants' behavior concomitantly with developmental changes occurring in the infant, and therefore may in part be formed and emerge through interactions with their infants (Fogel, Nwokah, & Karnes, 1993). Here, mothers did not provide much postural stabilization overall, but they stabilized unsteady standing postures more than others, they remained fairly close to their infants throughout the duration of the study, and they were closer to their infants during moments when infants used unpracticed postures. These behaviors might reflect mothers' sensitivity to their infants' intuitions about self-stabilization. As their infants became more mobile, mothers carefully observed and understood their infants' actions, and allowed them to experiment with their balance by themselves but were still available to provide support if needed. Maternal adaptations such as these that correspondingly change with infants' skills seem to relate to accelerated infant development in other contexts (Landry, Smith, Miller-Loncar, & Swank, 1998).

It is important that we point out differences in necessary versus supplementary postural stabilization (Berger et al., 2014). Before an infant can walk independently, it is necessary for them to seek stabilization to cruise down the length of a couch, or to hold their mother's hand. However, when the infant can walk on their own, there may still be periods where infants seek stabilization from their surroundings (e.g., stair handrails), or from their mothers. Thus, there is a difference in the motivations for seeking postural support. In the earlier scenario, the external stabilization makes the postural activity possible, but in the latter, it makes the postural activity easier. The current study did not capture those differences.

With each new motor skill that infants develop, they must learn new ways of responding appropriately to the demands their surroundings (Adolph, 1997). For example, infants' understandings of perception-action relationships improve when they learn to walk, as they use surfaces to not only stabilize themselves, but also begin to understand more about postural coordination, which facilitates sensory-motor tuning (Metcalfe & Clark, 2000). As Adolph (2008) explained, each posture is constrained by a specific problem space. New postures sometimes require that infants utilize limbs differently and therefore sometimes free or limit their use of their hands. New postures provide infants new perspectives from which they can view their surroundings (Adolph, 2008), or different levels of their homes for which they can reach or interact (Pierce et al., 2009). Different postures may require the use of certain groups of muscles for balance (Adolph, 2008), which could affect the likelihood of certain types of object interactions. For instance, prior work shows that walking infants were more likely to carry objects than were crawling infants (Karasik et al., 2012). These posture-specific problem spaces not only change depending on infants' postures from moment to moment, but also over the course of motor development in the first few years. In our study, we tracked the use of sitting and standing postures for interactive behaviors within sessions and across the progression of locomotor development. We found that early in development, infants tended to use sitting postures more to engage in detailed fine motor manipulations with objects, but as they progressed through motor milestones, sitting postures were no longer dedicated for those specialized activities. Similarly, infants were more likely to stabilize themselves and engage in passive interactions with objects when they were in standing postures. This is likely because when they were standing, their attention was now directed to maintaining balance, which may have detrimentally affected their ability to focus on detailed object manipulation interactions.

Implications

Infants' first experiences with locomotor exploration and object play are often with their parents. These early playful interactions are important for many aspects of social, motor, and brain development. For instance, when infants and caregivers engage in joint attention by engaging in the same activity as their infant, the child's play became more advanced compared to when they played alone (Bigelow et al., 2004). Modeling behaviors, encouragement, and scaffolding are all behaviors that mothers may produce to facilitate their infants' object play during moments of joint attention. Some research suggests that typical variations in the quality of mother-infant interactions are even enough to influence the trajectories of normative brain development (Bernier et al., 2016).

Importantly, early patterns we detected in mother-infant interactions may lay the foundation for behaviors appearing in later childhood. Some have claimed that infants' playful manipulations of objects contribute to their subsequent object control skills in later years (Bourgeois, Akhawar, Neal, & Lockman, 2005), and early motor competence contributes to subsequent outcomes in many childhood cognitive skills (Bornstein et al., 2013). As Bornstein and colleagues have previously explained (2013), infants' ability to learn new things about their worlds is strongly related to their ability to explore. Infants' efficient exploration provides them more opportunities to interact with various things in their environments. This in turn can impact the types of interactions with their caregivers, who facilitate infant learning through joint attention events and the use of referential communication.

Research on parenting shows that naturalistic communication and behavioral patterns established early on tend to be relatively stable throughout future interactions as children age (e.g., Belsky, Gilstrap, & Rovine, 1984; Bornstein & Tamis-LeMonda, 1990; Gunderson et al., 2013). Furthermore, early patterns in infants' active play and exploration can potentially form habits that persist later in life. For instance, more sedentary behaviors in early childhood will persist into inactivity in adulthood (Reilly et al., 2004).

The play environment we used in our study was indoors and relatively small, and therefore did not promote many physical activity behaviors. However, early interactions that children have with their caregivers may have health consequences when discussed in the context of physical activity and exploration during childhood. Although many parents claim that their children do not seem to stop moving, some research suggests that preschoolers spend most of their outdoor playground time engaging in sedentary behaviors (Brown et al., 2009). It is therefore important for parents to get involved in their children's active physical play early in infancy by modeling and encouraging behaviors that require movement and physical activity. One study by Watamura, Donzella, Alwin, and Gunnar (2003) suggests that children who engaged in more active social play while in childcare had significantly lower levels of cortisol, a stress hormone, at the end of the day. There are therefore many social, motor, and physical benefits for caregivers engaging their children in active physical play, and basic motor behaviors such as jumping are best learned and practiced in contexts in which caring adults use active structured strategies such as demonstrations or modeling to encourage children's activities (e.g., Labiadh & Golomer, 2010; Landry, Garner, Swank, & Baldwin, 1996). Of course, these active physical behaviors were not possible or contextually appropriate in our small indoor free play environment, but our findings about mother-infant spatial displacement and interactive behaviors could be relevant for studies that investigate similar measures outdoors, in yards, playgrounds, or parks.

In addition to physical activity levels and health related outcomes, our current findings with our typical sample of mother-infant dyads may also have implications for clinical populations. Some have suggested that infants who walk at earlier ages do so out of desires for independence from inharmonious relationships with caregivers (Biringen et al., 1995). Research in clinical settings suggests atypical patterns in mothers' use of inter-personal space with their infants (Beebe et al., 2010; Væver et al., 2013). Through continued study of advantageous and maladaptive patterns in spatial interaction patterns, we may be able to produce improvements in intervention outcomes for clinical populations.

There are other intervention applications for this type of research in populations of children with motor impairments. Throughout this dissertation, we have explained many ways that self-produced locomotion provides children with opportunities to interact with and learn from their environments in critical ways (e.g., Gibson, 1988; Thelen & Smith, 1994). In support of this claim, Campos and colleagues (1992) showed that compared to pre-locomotor infants, only locomoting infants showed sensitivity to heights. They provided more evidence about the importance of locomotor experience by describing a case study about an infant who was placed in a full a body cast due to dislocated hips. This case study showed that the infant did not show wariness to heights until after his body cast was removed and he gained crawling experience (Campos et al., 1992). The effects of locomotor experience extend to other visual-spatial skills as well. Another study by Foreman, Foreman, Cummings, and Owens (1990) found that children showed better performance during spatial search tasks when they actively locomote to the target themselves or provide instructions to an experimenter pushing them in a wheelchair, as opposed to being guided by an experimenter or pushed in a wheelchair without providing directions. Many have since argued that *active* participation in spatial search tasks facilitates performance (for review, see Yan, Thomas, & Downing, 1998).

Although active locomotion seems to be extremely important for spatial skills, wariness of heights, and potentially many other important developmental milestones, infants and toddlers with motor impairments usually do not have a great deal of experience with self-produced locomotion and are more commonly passively moved from one location to another by their caregivers. This can have detrimental consequences for development. Even for typically developing infants, having restricted or limited movement capabilities can be disadvantageous for cognitive functioning (Beckwith, 1971; Wachs, 1979). Therefore, many have attempted to find solutions to this problem that children with mobility impairments must face.

In one study, Butler (1986) tailor-made power chairs for six children aged 23 to 38 months who suffered from mobility impairments. Compared to baseline measurements, the introduction and use of powered chairs resulted in significant changes in all of the children's toy and caregiver interactions and spatial exploration of their environment. Most importantly, the whole group of children showed increases in relative changes in location during the sessions. One child increased self-initiated interactions with their caregiver and spatial exploration of their environment but decreased toy interactions, and another two children showed increases in spatial exploration only. A recent case report from Huang and colleagues (2014) has shown similar advancements in peer socialization, cognitive measures, and exploration in a child with cerebral palsy who received a ride-on toy car to increase mobility. While these studies were preliminary and with a limited number of children, certainly having access to a wheeled device allowed these children similar perceptual experiences and a sense of independence that most typically-developing infants gain with the acquisition of crawling and walking. After all, one study by Uchiyama and colleagues (2008) showed that typically developing pre-locomoting infants provided with locomotor experience in a powered-mobility-device showed similar responses to infants with locomotor experience when confronted with peripheral optic flow. Similarly, Gustafson (1984) placed pre-locomotor infants in a baby walker, which allowed them to cover more ground, look more at people and toys, and show more directed and social behaviors to adults. Although these studies suggest links between mobility status, interventions that provide locomotor experience, and changes in perceptual, behavioral, and cognitive outcomes, there is still much work that needs to be done to better understand interventions with children who have mobility disorders (Anderson et al., 2013).

Many of our findings about the contributions of locomotor experience to changes in infant behaviors could also be applied in occupational therapy. Occupational therapists are concerned with providing services to at-risk infants and toddlers by implementing interventions in children's early environments. These interventions aim to facilitate the use of objects and physical spaces to promote developmental trajectories. However, many approaches in occupational science rely heavily on theory and are largely removed from real-life situations (Pierce et al., 2009). Studies like our current one can provide descriptive trends in mother-infant play patterns, which could be useful for therapists when designing naturalistic family-based interventions. By using the motor lens of infants at varying developmental stages, therapists can alter the opportunities available to infants to promote spatial awareness, engagement with objects and furniture, active discovery, and environmental exploration (Pierce et al., 2009).

Along that same line of thought, research on the variables we have tracked here could be useful for applications to ecological or environmental psychology, which are fields concerned with understanding how people interact with their environments. Factors that influence those interactions are the characteristics of the environment, psychological processes mediating person-environment interactions, and developmental changes in person-environment interactions over the life span (Gärling & Evans, 1991). Most of the research conducted on human spatial behavior has been conducted by geographers about adult populations (Gärling & Evans, 1991). Recently however, environmental psychologists have emphasized understanding person-environment interactions for special populations such as children (Barnes, 1994). Data from our normative sample could potentially be useful for applications. For instance, infants and toddlers with disabilities are at risk for delayed motor development, and motor play behaviors such as locomotion or manipulating objects are often used to identify developmental difficulties (de Campos, Savelsbergh, & Rocha, 2012).

Our findings about developmental increases in mother-infant spatial displacement patterns may also be relevant for specific applications to environmental cognition, which is one element of environmental psychology that is concerned with using real-world spatial or temporal settings to observe dynamic changes in an individual's interactions with a particular space (Gärling & Evans, 1991). Our findings suggest many effects of locomotor experience on spatial displacement patterns in both infants and their mothers. Developmental effects of action on spatial skills originated with Piaget's early theories (1936), and continues to grow with current empirical research delineating a shift from predominately egocentric to allocentric views of the world, and the role of locomotor experience in spatial search skills (e.g., Bai & Bertenthal, 1992; Campos et al., 2000; Clearfield, 2004). These findings are also consistent with Gibson's (1988) ecological approach, which explained that our sensory experiences of our surroundings, in addition to our physical interactions within them, allow us to gain better understanding about our environments.

Infant-mother interactive behaviors and spatial displacement patterns such as the ones we have studied here are relevant for anthropological research on material aspects of culture (Pierce et al., 2009). In contrast with other animals, humans have evolved highly material aspects of culture and behaviors. For instance, the everyday life of human infants involves interactions with many material objects and spaces, such as toys, books, cabinets, rooms of their homes, food, technological devices, among others. Infants' interactions with these objects and spaces are an important part of play, as children gain competence about material aspects of their culture through play (Bruner, 1972). For instance, motor activities such as climbing or object manipulations are often thought of as practice for fundamental motor skills such as jumping or throwing. These are frequently encouraged by caregivers due to culturally relevant applications to athletic sports (Burghardt, 2006).

Finally, the body and the actions it produces both reflect and enhance many ongoing experiences in the mind (Corbetta, 2009). Several decades ago, Bruner (1972) argued that the first uses of language are closely linked to action. There is a growing body of research supporting this notion, which shows that the acquisition of crawling and walking contributes to changes in language abilities (He, Walle, & Campos, 2015; Oudgenoeg-Paz, Volman, & Leseman, 2012; Walle & Campos 2014; Walle, 2016). Some research on embodied cognition has shown that when infants walk around their environments and explore, they learn about spatial concepts. This learning facilitates later advancements in the use of spatial language (Oudgenoeg-Paz, Volman, & Leseman, 2016). Other embodied accounts have explained that prior to age three, children learn verbs in the context of their own actions and body parts (Maouene, Hidaka, & Smith, 2008). These early trends play meaningful roles in later development. For instance, early exploratory competence in infancy may relate to long-term childhood outcomes in language and academic achievement (Bornstein et al., 2013).

Cautionary notes

We want to point out a few cautionary notes to keep in mind. First, because of the small sample used in the current microgenetic study, and our structured observation research design, we were unable to detect causal relationships between our measures. For example, we are unable to determine if infants' spatial exploration provides more opportunities for interactions with toys, or if their curiosity for discovery in play drives their spatial exploration of the room. As mentioned before, the dimensions of our free play space may have affected our findings. Prior work in occupational science has shown that the size of the environmental space available and the arrangements within the room can influence the quality of children's participation in children with physical disabilities (Rigby & Gaik, 2007). Using a larger room may have elicited even more broad exploration in our sample of typically developing infants, which may have also altered mothers' behavior, as they may want to remain closer to their infants to monitor their behavior in a larger room. Furthermore, there is also evidence that ecological resources in children's environments affect the type of play exhibited by young children (Morgante, 2013). For instance, highly structured objects elicited more advanced cognitive play in preschoolers, whereas minimally structured objects elicited more social play (Morgante, 2013). It is unclear how infants' behaviors may be affected by the size of the room, or the number and types of toys available for play. These questions could be answered in experimental designs that manipulate those aspects of the environment.

Another potentially interesting causal relationship that we were not able to address here is the relationship between mothers' supporting or guiding behaviors and infants' subsequent exploratory behavior. Specifically, there is a great deal of evidence that mothers' behaviors, even so subtle as small sharp gasps that communicate warnings, or otherwise negative affect, have the potential influence infants' exploratory behaviors with objects (Hertenstein & Campos, 2001; Hornik, Risenhoover, & Gunnar, 1987). Belsky and colleagues (1980) showed that the ways mothers physically and verbally stimulate their infants and focus their infant's attention to certain objects leads their infants to demonstrate more competent play than control infants. The effects of mothers' stimulation of infants' exploratory play even go beyond interaction with toys.

Landry and colleagues (2000) investigated mother's maintaining their child's interests during play sessions. They discovered that children show better outcomes in later cognitive skills and social independence when their mothers show higher levels of maintaining their child's interests from two to three years of age. In addition to these stimulating behaviors, mothers may serve as models for demonstrating the utility of objects in object-related behaviors. This has been well documented in both human and animal literature (Abravanel, Levan-Goldschmidt, & Stevenson, 1976; McCabe, & Uzgiris, 1983; Nahallage & Huffman, 2007). In fact, in her naturalistic dyadic interaction study in the home, Masur (1987) showed that mothers were more likely to imitate infants' vocal productions and infants were more likely to imitate mothers' actions on objects. Beyond the influence of mothers' stimulating and modeling behaviors, research from nonhuman primates further shows that mothers' movements and foraging behaviors can also influence infants' gross motor development and exploratory behaviors (Andrews & Rosenblum, 1993; Dettmer, Ruggiero, Novak, Meyer & Suomi, 2008). Future research therefore could address the causal relationship between mothers' behaviors and subsequent outcomes in infants' exploratory behaviors.

Second, our participants' ethnic and cultural identifications were relatively homogenous. These factors have been shown to greatly affect the prevalence and characteristics of early infant-caregiver interactions (Bazyk, Stalnaker, Llerena, Ekelman, & Bazyk., 2003; Bril & Sabatier, 1986; Fouts, Roopnarine, Lamb, & Evans, 2012; Lancy, 2016; Little, Carver, & Legare, 2016), which may potentially stem from rearing goals adopted by their culture of origin. For example, Taiwanese parents are more likely to teach their children how to act on the world by emphasizing object relations and actions, whereas parents from the United States are more likely to describe the world, providing labels and information about object features (Chan, Brandone, &

Tardif, 2009). Cultural transmission of these emphases is reflected in US and Taiwanese infants' gestural communication (Wang & Vallotton, 2016). Additionally, cultural factors have been related to differences observed in mother-infant interactions with objects (Bakeman, Adamson, Konner, & Barr, 1990; Bornstein, Cote, Haynes, Suwalsky, & Bakeman, 2012), and a higher propensity for parents of certain ethnic groups to be classified as "protective" (Rodríguez, Donovick, & Crowley, 2009). Because of the homogeneity of our sample, we were not able to address ethnic or cultural factors. However, even with the small sample, we did have some inter-individual variability in the mothers' behaviors and infants' progression through motor skills.

Third, mothers in our study reported a variety of education levels and socioeconomic statuses (SES). We know that infants' homes in low SES families are less safe, are smaller in size, more crowded with people and objects, with fewer play objects and less access to outdoor space (Pierce, 2000; Poresky & Henderson, 1982). Children from low SES families have fewer opportunities to play with their caregivers and when infants from lower SES are given opportunities to interact with objects, they show reduced levels of manual exploration compared to infants from high SES (Clearfield, Bailey, Jenne, Stagner, & Tacke, 2014; Collard, 1971; Poresky & Henderson, 1982). Children from low-income homes show sensitivity to the characteristics of their homes and families associated with impoverished environments, which negatively affects their fine motor development more than gross motor development (Raikes, 2005). Middle class infants therefore seem to show more ability in fine motor skills and social interaction than lower class children (de Campos et al., 2012). These trends are important because previous work suggests a relationship between availability of objects in the home, opportunities for exploration at 7 months of age, and cognitive performance at 24 months of age (de Campos et al., 2012; Power & Chapieski, 1986). Clearly, these factors could have affected how certain infants interacted with the environment we provided, which may have contributed to individual differences. Furthermore, other studies have shown that mothers who have limited resources lack the ability to adapt to their children's changing needs over time (Smith, Landry, Miller-Loncar, & Swank, 1997). Thus, research shows that both mothers' and infants' behaviors could be affected because of socioeconomic conditions.

Fourth, we did not collect anthropomorphic data. The physical body characteristics of infants in our sample could have affected their exploration in the play area, as well as their progression through motor skills. For example, infant overweight is associated with delayed motor development (Slining, Adair, Goldman, Borja, & Bentley, 2010). Additionally, Snapp-Childs and Corbetta (2009) previously highlighted ways that infants' body characteristics, such as chubbiness, could potentially impact how infants learn to walk.

Fifth, and finally, we chose to only focus on mother-infant interactions. In part, we did so in order to control for parent effects because of our small sample. A recent study by Chiang, Lin, Lee, and Lee (2015) showed that mothers' parenting behaviors had a larger effect on infants' motor development, but this effect may be explained by how much time mothers spend engaging in caregiving tasks compared to fathers. Previous research has shown that mothers and fathers supervise and interact with their young children in different ways (e.g., Belsky et al., 1984). Fathers tend to engage in more proprioceptive stimulatory tactile play with their infants, utilizing more objects and speaking more, whereas mothers tend to engage in more soothing play and calmer visual games (Brachfeld-Child, 1986; Lamb, 1997; 2010; Parke & Sawin, 1976; Yogman, 1982a,b).

Research has highlighted that these behavioral patterns of parent-child interaction not only differ between mothers and fathers, but that there are different neuroendocrine reward pathways for each (Feldman, Gordon, Schneiderman, Weisman, & Zagoory-Sharon, 2010; Gordon, Zagoory-Sharon, Leckman, & Feldman, 2010). Some have argued that mothers' affectionate interactions with their infants are influenced strongly by hormonal factors, but it is possible that fathers' interactions with their offspring could be constructed by more active forms of behavior that shape specific neuroendocrine pathways involved in fathering (Feldman et al., 2010). The pattern in late infancy that infants prefer fathers for play and mothers for comfort persists until middle childhood (Russell & Russell, 1987). Fathers' play with their infants is based more on tactile stimulation (Lamb, 1997; 2010; Yogman, 1982a; 1982b), and body stimulation and positioning seem to advance infant motor development (Lobo & Galloway, 2008; 2012). Therefore, it is possible that our results could have varied if we had observed fathers interacting with their infants. This interesting idea could be addressed in future studies.

Conclusion

By studying infants' and mothers' spatial displacement patterns, interactive activities, and use of postures through the transition from pre-crawling to independent walking, we have captured changes in both mothers' and infants' behavior. We showed that mothers initially spent more time supporting their infants' behaviors, but gradually shifted to simply monitoring their children. They were therefore sensitive to their infants' changing skills and allowed their infants the freedom to explore, but remained involved and available to their infants during potentially unsafe or unpracticed contexts.

Further, we showed that infants change their own micro-environments and extend their opportunities for interaction by actively using their range of postures for moving around more and engaging more with objects in the room. Some infants chose to repeatedly climb the stairs, whereas others instead opted to engage in fine motor exploration with small toys in the floor. In studying these types of object interaction behaviors, we have shed light on how infants themselves begin to take on an active role in shaping the types of experiences their environments offer to them. Furthermore, we can improve our understanding of how the infants' expanding motor lens opens new windows of opportunity for visual, tactile, and spatial exploration of surroundings that interactively drive discovery (Pierce et al., 2009).

The onset of locomotion has historically been described as the "psychological birth" of the infant and as Mahler, Pine, and Bergman pointed out in 1975, seems to spark a "love affair with the world." Our findings support previous research indicating that after the onset of self-produced locomotion, infants break symbiosis with their mothers, gain a personal sense of autonomy, and begin exploring their environments on their own (Campos et al., 2000). These dynamic and constantly reorganizing interactions that evolve both within sessions and over time show developmentally and contextually appropriate responses from mothers, which further foster infant autonomy and environmental exploration.

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Appendix

Table 1

List of four measures used with prediction of change over locomotor development and predicted relationship between measures

	Prediction of change over locomotor development	
Measure	**Infants**	**Mothers**
1. Spatial exploration	Increase	Unclear
2. Infant-Mother Distance	Unclear	
3. Interactive Behaviors	Increase	Unclear; possibly more involved initially, then shift to simply monitoring
4. Use of Postures/Transitions	Increase	Unclear
Relationships between spatial exploration, interactiveness, and use of posture	Together, may suggest active discovery and exploration	Links not expected

Table 2

Codes for infants' and mothers' postural categories

Postural Category	Postural Activity	Description
Laying down	Laying down - supine	participant is laying flat on their back
	Laying down - prone	participant is laying flat on their stomach
	Laying down - on side	participant is laying on the side of their torso
	Wriggling/pivoting	participant is laying down in prone, but is moving around in a very small area in the floor, but is not systematically moving forward or backward
	Rolling on to stomach	participant is moving into a position where they are laying down on their stomach
	Rolling on to back	participant is moving into a position where they are laying on their back
Sitting	Sitting	participant is on their bottom, but upright with their legs in front of them or folded under their torso and is not leaning on another object
	Sitting/laying over	participant is on their bottom, but is not completely upright and is laying over on to one side using their arm and their legs are outstretched in front of or beside them
	Leaning over	participant is on their bottom, but is propped on or leaning over on to one side using an object - half of their back (horizontally) is in contact with the other object
	Leaning back	participant is on their bottom, but is propped on or leaning back on an object - a portion of their whole back (horizontally) is in contact with the other object
	Suspended	infant is inside the round sit-in activity center toy
On all fours	Rolling on to all fours	participant is moving into a position where they are on all fours and their stomach is lifted up off of the ground
	Stationary on all fours	participant is on hands and knees with their stomach lifted off of the ground, but is not moving

Table 2. Continued.

Postural Category	Postural Activity	Description
On all fours	Tripod activity	participant is on two knees and one hand with their stomach lifted off of the ground, and is using the other hand in another way, usually to act on an object
Squatting/kneeling	Squatting	participant's body is upright with feet on the floor, but legs are bent and they are crouched down
	Kneeling	participant's body is upright with knees on the floor, and their bottom is raised up off of the ground
	Pulling-to-kneel	participant is using an object or piece of furniture to pull him or herself up to a kneeling position
	Knee-walking	participant is in the kneeling position, but is moving across the room by moving legs and balancing on knees
Crawling	Scooting	participant is moving across the floor in a sitting position
	Belly crawling	participant is moving using abdominal progression with their stomach touching the ground
	Crawling on hands-and-knees	participant is moving on all fours with their stomach lifted off of the ground
	Climbing	participant is in the process of trying to ascend or get on an object or piece of furniture but is not clearly walking or crawling up
	Descending	participant is in the process of trying to get down or off of an object or piece of furniture but is not clearly walking or crawling down
Standing/bending over	Pulling-to-stand	participant is using an object or piece of furniture to pull him or herself up to a standing position
	Standing	participant's body is upright in a vertical position with their legs straight and feet on the floor

Table 2. Continued.

Postural Category	Postural Activity	Description
Standing/bending over	Bending over	participant's body is upright in a vertical position with their legs straight and feet on the floor, but they are bent forward and their torso is not in line with their legs
Cruising (only apply to infants)	Cruising	participant is walking down the length of an object, but uses the object for balance by holding on with their hands
Stepping	Stepping	participant's body is upright in a vertical position with their legs straight and feet on the floor and they are moving with a succession of steps
Others (only apply to infants)	Being picked up	infant is not completely controlling his or her postural activity because the mother is partially holding the infant and gaining control over the infant’s body
	Being put down	infant is not completely controlling his or her postural activity because the mother is partially holding the infant and ending control over the infant’s body
	Being held	infant is not in control of his or her postural activity because the mother is holding the infant in her arms or lap but is not moving the infant in space or location
	Being moved	infant is not completely controlling his or her postural activity because the mother is holding the infant (sometimes partially) and is moving the infant's whole body or the infant’s limbs in space or location (e.g., when the mother moves the infant so that the infant is closer in proximity to a goal object or is placed onto or inside a goal object; when the mother moves the infant’s body through the motions of an object or activity)
	Being carried	infant is not in control of his or her postural activity because the mother is holding the infant completely off of the ground, in her arms or lap, and is moving both her own body and the infant in space or location

Table 2. Continued.

Note. Postures were sorted into categories based on complexity (listed above in order of complexity). If the participant performed two postural activities in the same 2-sec coding period for an interval, only the most complex activity was counted. Any postures in which the participant was also dancing was still considered the same posture.

Table 3

Summary of results for spatial exploration measures

	Longitudinal Changes in the Dyad			
		6-session transition period		
Measure	**Full 12-session period**	**Pre-crawling to crawling**	**Novice crawling to experienced crawling**	**Experienced crawling to walking**
Distance Traveled	increase	increase	increase	unchanged
Speed of Travel	increase	increase	increase	unchanged
Dispersion	increase	increase	increase	increase
Mother-Infant Distance	increase	unchanged	unchanged	unchanged
	Comparison between Infant and Mother			
		6-session transition period		
Measure	**Full 12-session period**	**Pre-crawling to crawling**	**Novice crawling to experienced crawling**	**Experienced crawling to walking**
Distance Traveled	infants > mothers	infants = mothers	infants = mothers	infants > mothers
Speed of Travel	infants > mothers	infants = mothers	infants = mothers	infants > mothers
Dispersion	infants > mothers	infants = mothers	infants > mothers	infants > mothers
Mother-Infant Distance	not applicable			

Table 4

Summary of results for interaction measures

	Longitudinal Changes in the Dyad/Infant/Mother			
		6-session transition period		
Variable	**Full 12-session period**	**Pre-crawling to crawling**	**Novice crawling to experienced crawling**	**Experienced crawling to walking**
Bouts of Interactions	increase	increase	increase	unchanged
Variety of Interactions	increase	increase	increase	unchanged
Interaction Types				
Toys	increase	unchanged	unchanged	unchanged
Other Person	unchanged	n/a	n/a	n/a
Furniture	increase	unchanged	I: increase, M: unchanged	unchanged
Stairs (Infant On)	increase	increase	increase	increase
	Comparison between Infant and Mother			
		6-session transition period		
Variable	**Full 12-session period**	**Pre-crawling to crawling**	**Novice crawling to experienced crawling**	**Experienced crawling to walking**
Bouts of Interactions	infants = mothers	n/a	n/a	n/a
Variety of Interactions	infants = mothers	n/a	n/a	n/a
Interaction Types				
Toys	infants = mothers	n/a	n/a	n/a
Other Person	infants < mothers	infants < mothers	infants < mothers	infants < mothers
Furniture	infants > mothers	infants = mothers	infants > mothers	infants > mothers
Stairs (Infant On)	not applicable			

Table 5

Summary of results for posture measures

	Longitudinal Changes in the Dyad/Infant/Mother			
		6-session transition period		
Variable	**Full 12-session period**	**Pre-crawling to crawling**	**Novice crawling to experienced crawling**	**Experienced crawling to walking**
Posture and Locomotion				
Laying down	unable to assess because of lack of representation of postures across all 12 sessions	I: decrease, M: n/a	I & M: n/a	I & M: n/a
Sitting		I & M: decrease	I & M: decrease	I & M: unchanged
On all fours		I: increase, M: n/a	I: unchanged, M: n/a	I: decrease, M: n/a
Squatting/kneeling		I: increase, M: unchanged	I & M: increase	I & M: unchanged
Crawling		I & M: n/a	I: increase, M: n/a	I: unchanged, M: n/a
Standing		I: n/a, M: unchanged	I & M: increase	I & M: unchanged
Cruising		I & M: n/a	I & M: n/a	I & M: n/a
Stepping		I & M: n/a	I & M: n/a	I: increase, M: n/a
Manipulations in postures				
Sitting				
No interactive activity	I & M: unchanged	n/a	n/a	n/a
Passive/minimal involvement	I & M: unchanged	n/a	n/a	n/a
General fine motor	I: decrease, M: unchanged	I: decrease, M: n/a	I: unchanged, M: n/a	I: unchanged, M: n/a
General gross motor	I & M: unchanged	n/a	n/a	n/a

Table 5. Continued.

Variable	Full 12-session period	Pre-crawling to crawling	Novice crawling to experienced crawling	Experienced crawling to walking
	Longitudinal Changes in the Dyad/Infant/Mother			
		6-session transition period		
Standing				
No interactive activity	unable to assess because of lack of representation of standing postures across sessions			I & M: unchanged
Passive/minimal involvement				I & M: unchanged
General fine motor				I & M: unchanged
General gross motor				I & M: unchanged
Mother-Infant Distance in Postures				
Laying down	not enough data	unchanged	n/a	n/a
Sitting	increase	unchanged	decrease	unchanged
On all fours	unchanged	n/a	n/a	n/a
Squatting/kneeling	not enough data	unchanged	unchanged	increase
Crawling	not enough data	n/a	decrease	unchanged
Standing	increase	n/a	unchanged	increase
Cruising	not enough data	n/a	n/a	n/a
Stepping	not enough data	n/a	n/a	increase

Table 5. Continued.

	Longitudinal Changes in the Dyad/Infant/Mother			
		6-session transition period		
Variable	**Full 12-session period**	**Pre-crawling to crawling**	**Novice crawling to experienced crawling**	**Experienced crawling to walking**
Infant Posture Stabilization	increase	unchanged	unchanged	unchanged
Number of different postures	increase	increase	increase	unchanged
Number of posture changes	increase	increase	increase	unchanged
	Comparison between Infant and Mother			
		6-session transition period		
Variable	**Full 12-session period**	**Pre-crawling to crawling**	**Novice crawling to experienced crawling**	**Experienced crawling to walking**
Posture and Locomotion				
Laying down				
Sitting				
On all fours				
Squatting/kneeling	did not assess - general differences seen in 12-session averages for mothers and infants			
Crawling				
Standing				
Cruising				
Stepping				

Table 5. Continued.

	Comparison between Infant and Mother			
		6-session transition period		
Variable	**Full 12-session period**	**Pre-crawling to crawling**	**Novice crawling to experienced crawling**	**Experienced crawling to walking**
Manipulations in postures				
Sitting				
No interactive activity	did not assess - general differences calculated in 12-session averages for mothers and infants	infants < mothers	infants < mothers	infants < mothers
Passive/minimal involvement		n/a	n/a	n/a
General fine motor		infants > mothers	infants > mothers	infants = mothers
General gross motor		n/a	n/a	n/a
Standing				
No interactive activity	unable to assess because of lack of representation of standing postures across sessions			did not assess - no differences seen in 6-session averages for mothers and infants
Passive/minimal involvement				
General fine motor				
General gross motor				

Table 5. Continued.

	Comparison between Infant and Mother			
		6-session transition period		
Variable	**Full 12-session period**	**Pre-crawling to crawling**	**Novice crawling to experienced crawling**	**Experienced crawling to walking**
Mother-Infant Distance in Postures				
Laying down				
Sitting				
On all fours				
Squatting/kneeling	not applicable			
Crawling				
Standing				
Cruising				
Stepping				
Infant Posture Stabilization	infants > mothers	infants > mothers	infants > mothers	infants > mothers
Number of different postures	infants > mothers	infants > mothers	infants > mothers	infants > mothers
Number of posture changes	infants > mothers	infants > mothers	infants > mothers	infants > mothers

Note. I = infants; M = mothers.

A B

Figure 1. Example camera views of laboratory room for free-play sessions from different sessions to illustrate the range of toys used in the (A) earlier time periods. (B) later time periods.

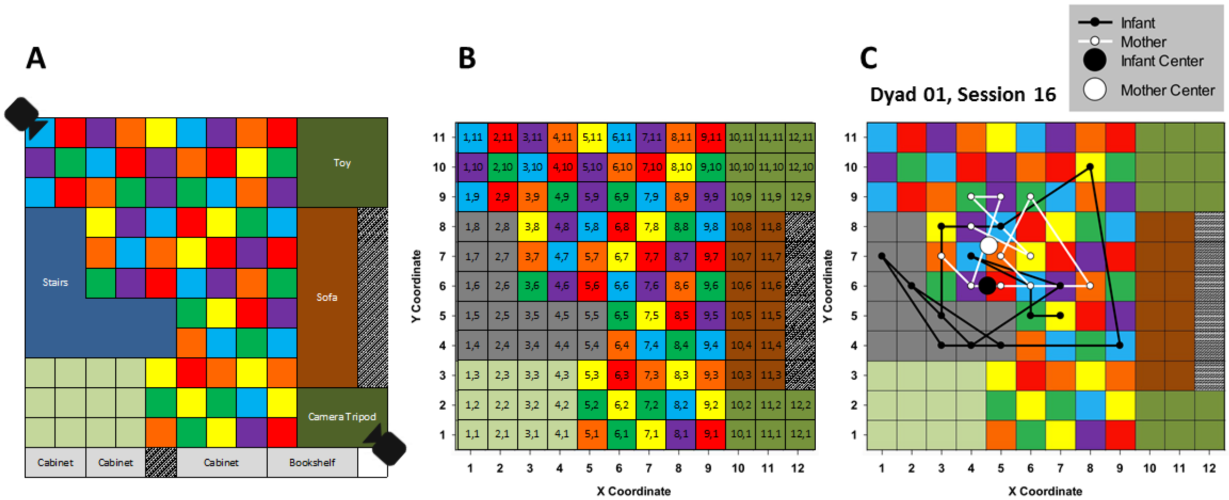

Figure 2. (A) Picture representation of layout and locations of key furniture items in the free-play room. (B) Spatial location coordinates superimposed over all possible locations in the free-play room. (C) Example of one dyad's spatial exploration patterns during a session. During this time, the infant was 13 months of age and was able to walk at least seven or more independent paces without falling. The small black and white circles represent the infant and mother's spatial location coordinates for each of the instantaneous samples during the 10-minute free play session. The larger black and white circles represent the averaged center points for that session for both the infant and the mother.

Figure 3. Examples of manipulatory actions in infants. (A) No interactive activity in sitting posture. (B) Passive holding/minimal involvement in sitting posture. (C) General fine motor manipulations in sitting posture. (D) General gross motor manipulations in stepping posture.

Figure 4. Examples of infant postural stabilization. (A) self-stabilization using object in standing posture (B) self-stabilization using mother in sitting posture (C) mother-provided stabilization in stepping posture.

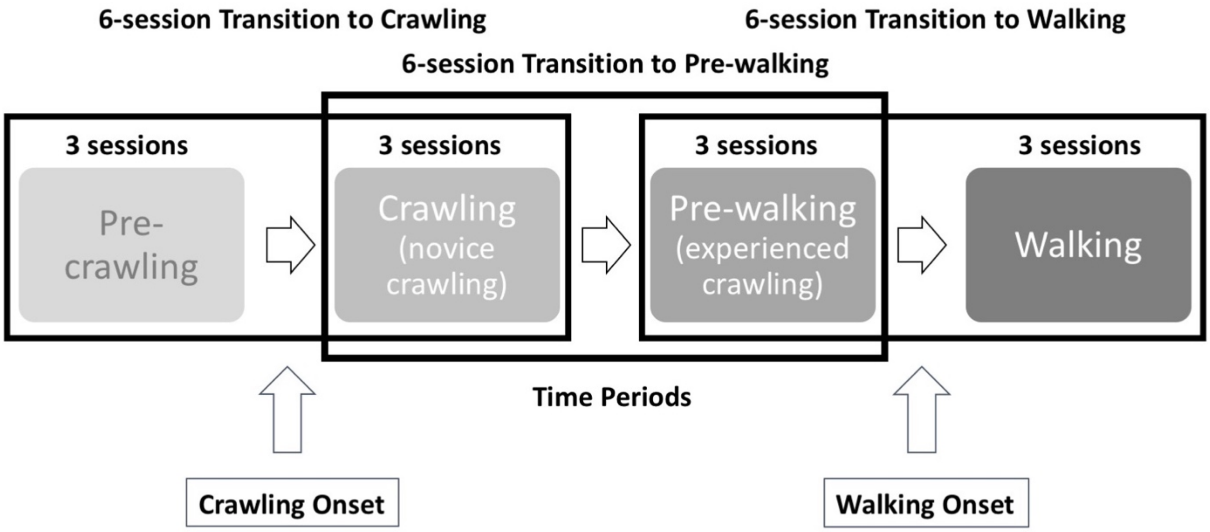

Figure 5. Schematic representing how 12 sessions of data were used across 4 time periods for each infant during transitive motor stages. Bold black boxes represent how the data were grouped for analysis using repeated measures ANOVAs and Friedman tests.

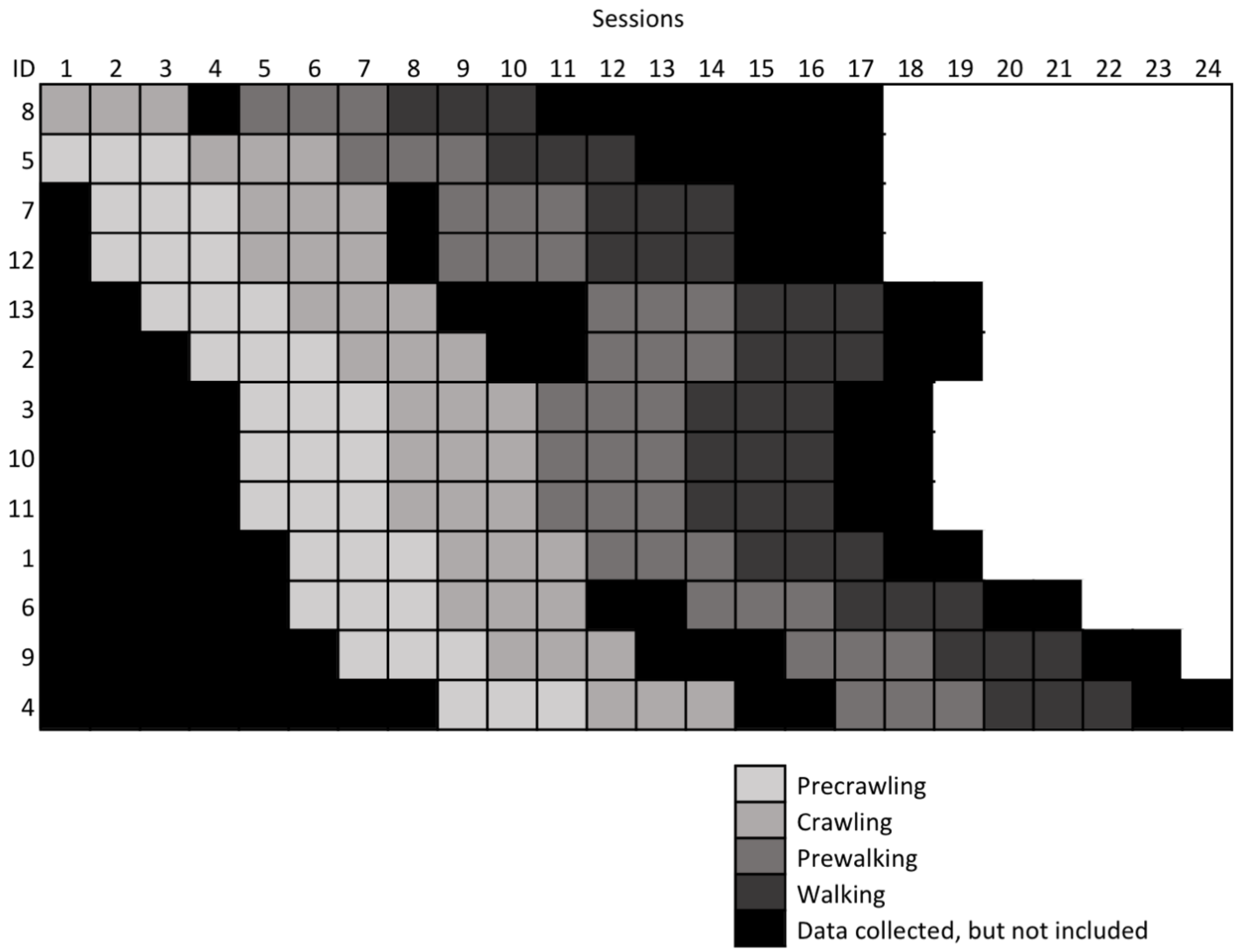

Figure 6. Representation showing how 12 sessions of data were selected from each infants' complete dataset. 12 sessions of data were used across 4 time periods for each infant during transitive motor stages. Very light gray, light gray, gray, and dark gray colors are used to indicate precrawling, crawling, prewalking, and walking sessions, respectively. Black colors show data that were collected but were not analyzed in this dissertation. White space designates when we stopped following each infant because they had either reached 14 months of age or had two months walking experience.

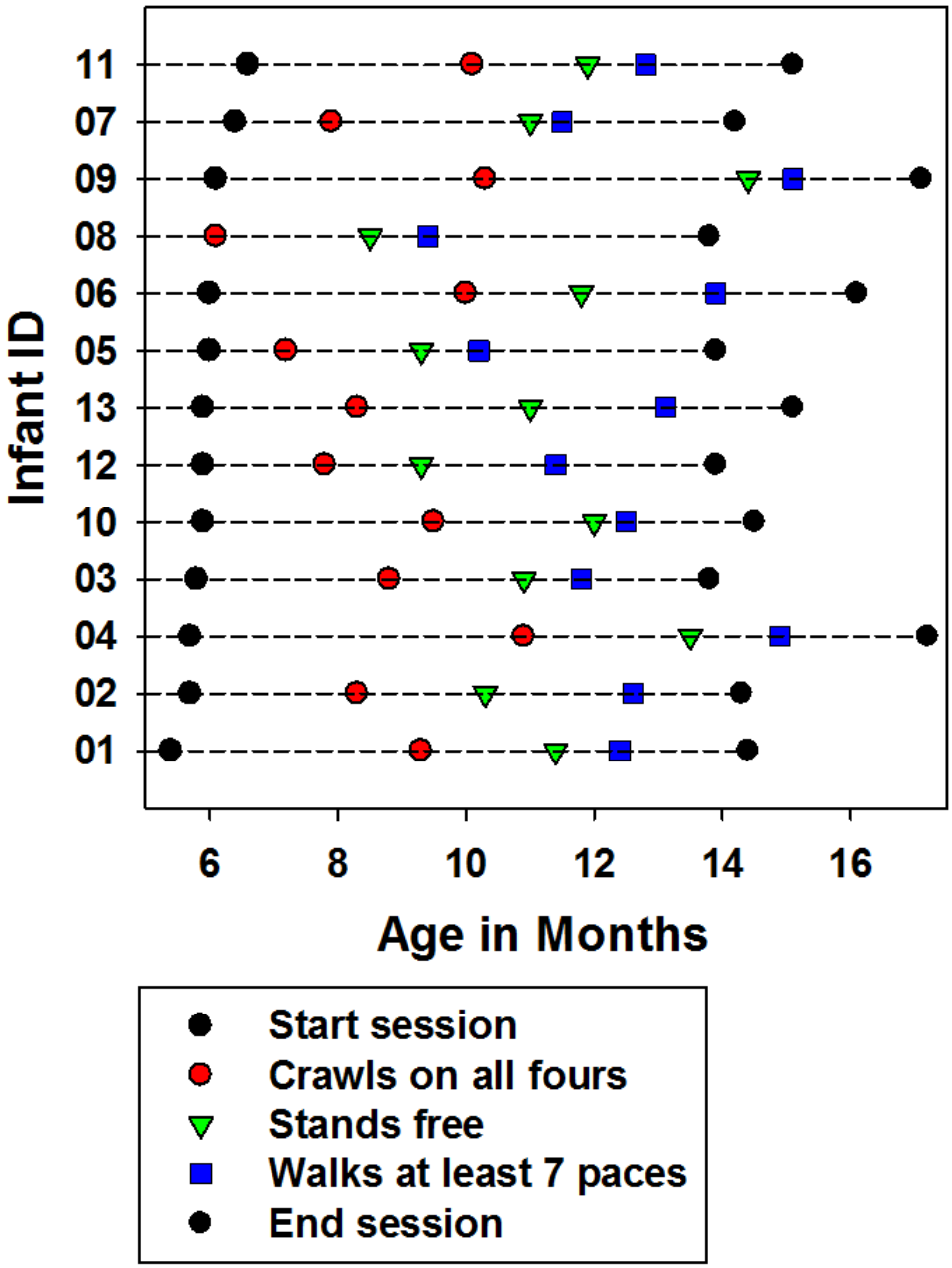

Figure 7. Summary of duration of data collection ages for each infant from start session to end session, with motor milestone onsets.

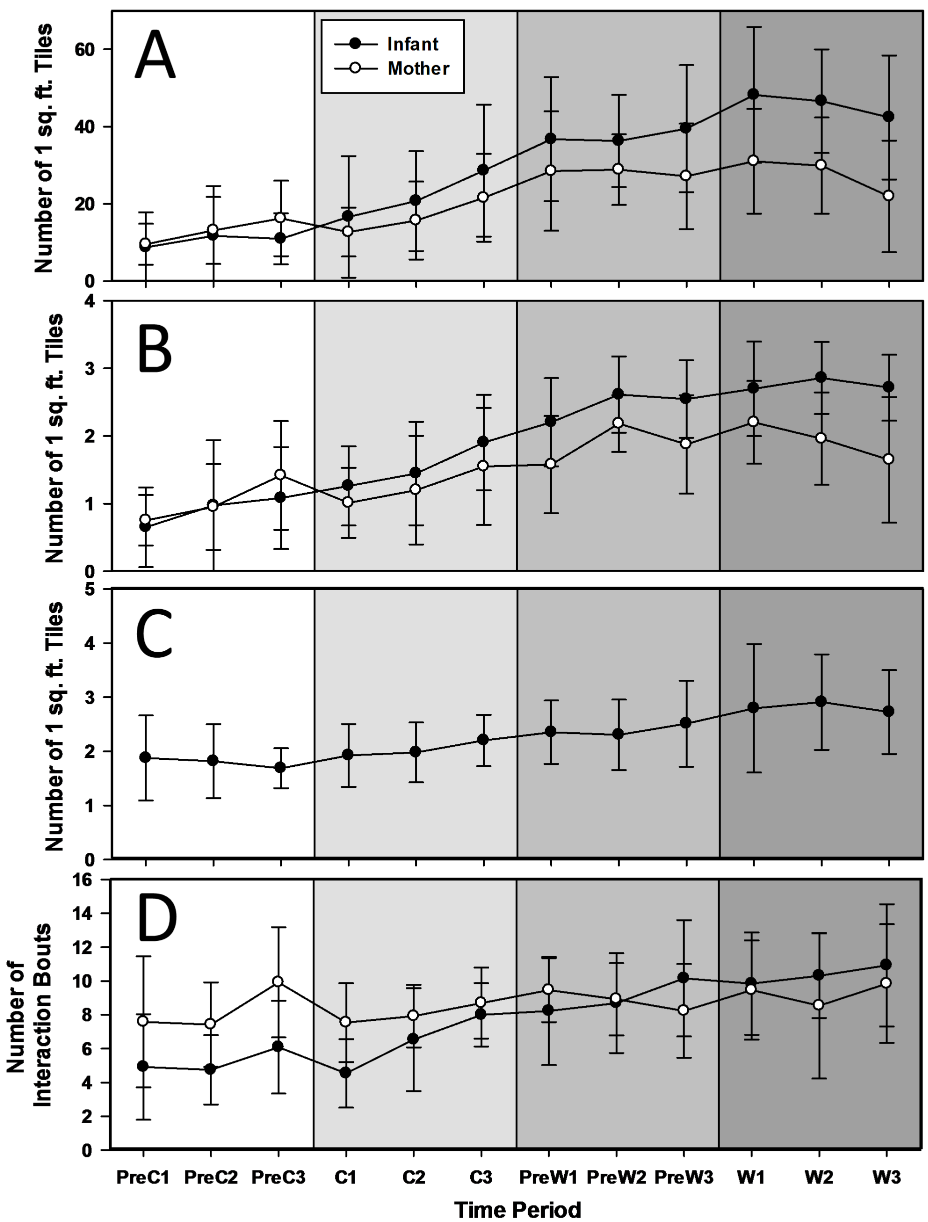

Figure 8. Longitudinal trajectories of (A) distance traveled, (B) dispersion, (C) distance between mother and infant, and (D) bouts of interactive activities across motor milestones. Infants are designated with black symbols and mothers are white symbols. Lines are averages with standard deviations.

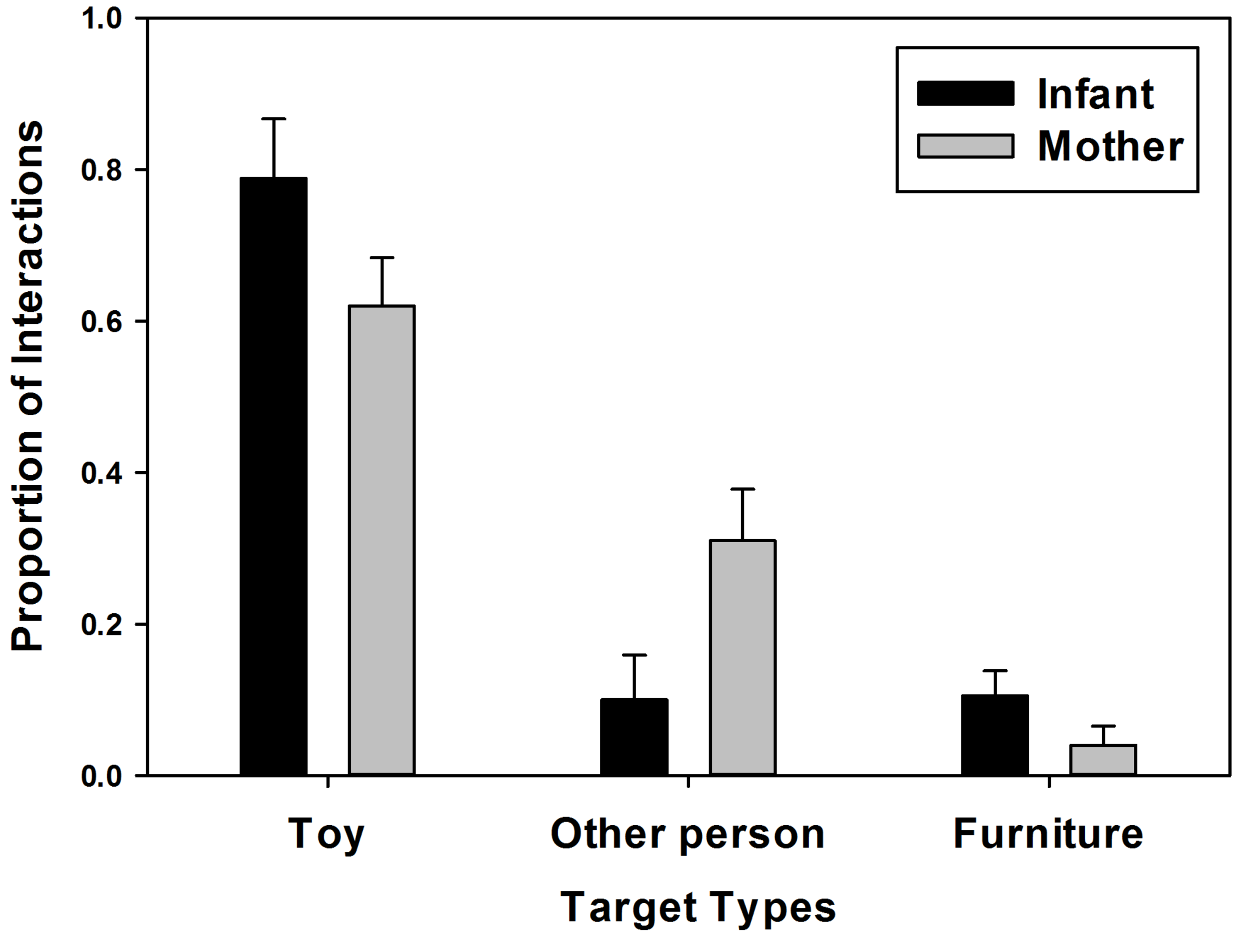

Figure 9. (A) Distribution of the proportion of interactions that were directed to toys, the other person, and furniture during free play sessions. Bars represent averages of each dyad's average across all 12 sessions. Infants are represented with black bars and mothers are gray bars. Error bars represent the standard deviation of the mean.

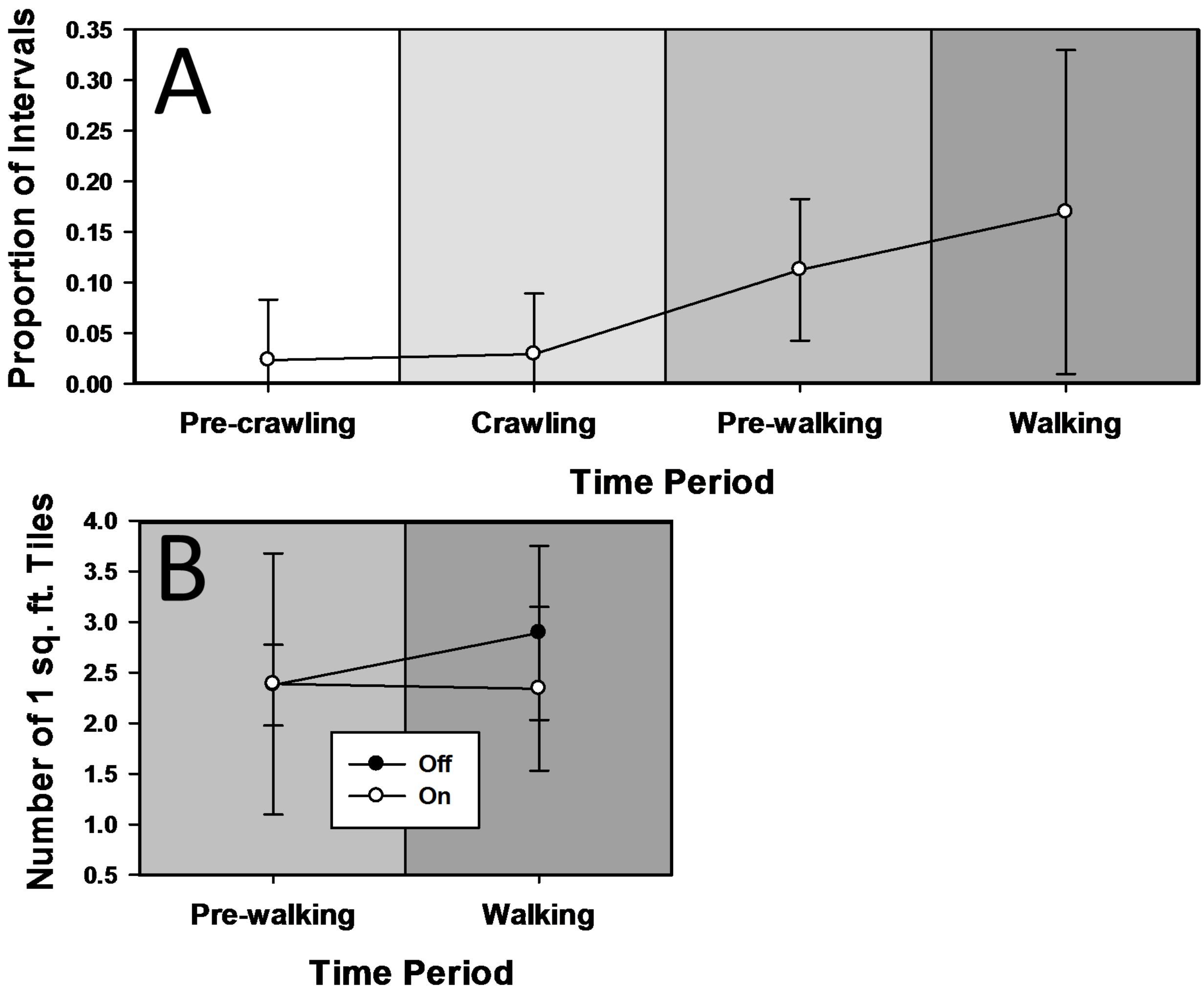

Figure 10. Longitudinal trajectories of (A) the proportion of intervals per session that infants spent on the stairs. Lines are averages with standard deviations of the mean. (B) the average distance between the mothers and the infants when infants were off the stairs (black circles) or on the stairs (white circles). Lines are averages with standard deviations.

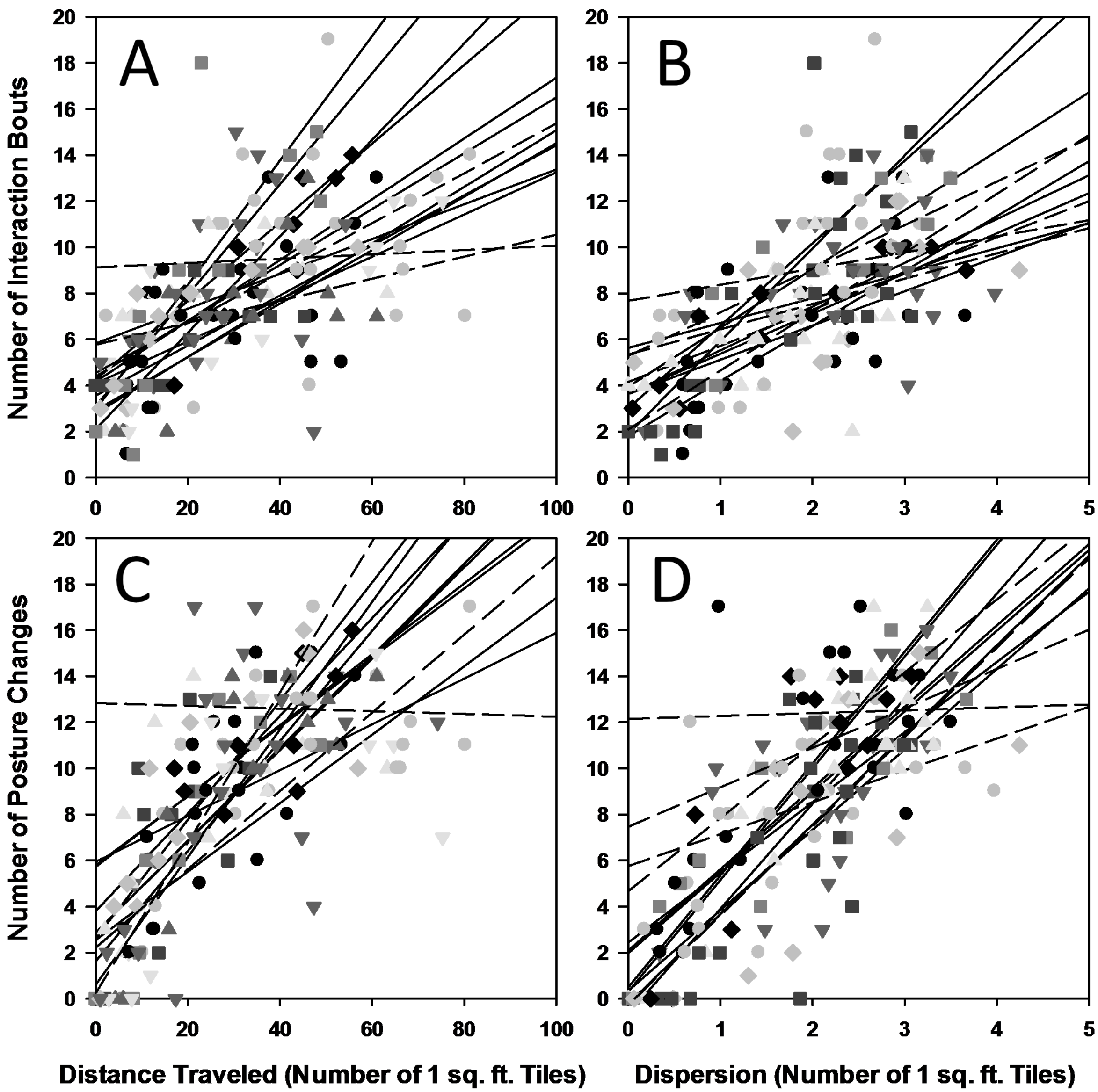

Figure 11. Correlations between infants' (A) distance traveled and bouts of interactive activities, (B) dispersion and bouts of interactive activities, (C) distance traveled and number of postural changes, and (D) dispersion and number of postural changes. Data from each infant are represented with different symbols and shades of gray. Solid trend lines indicate significant correlations and dashed trend lines indicate nonsignificant relationships.

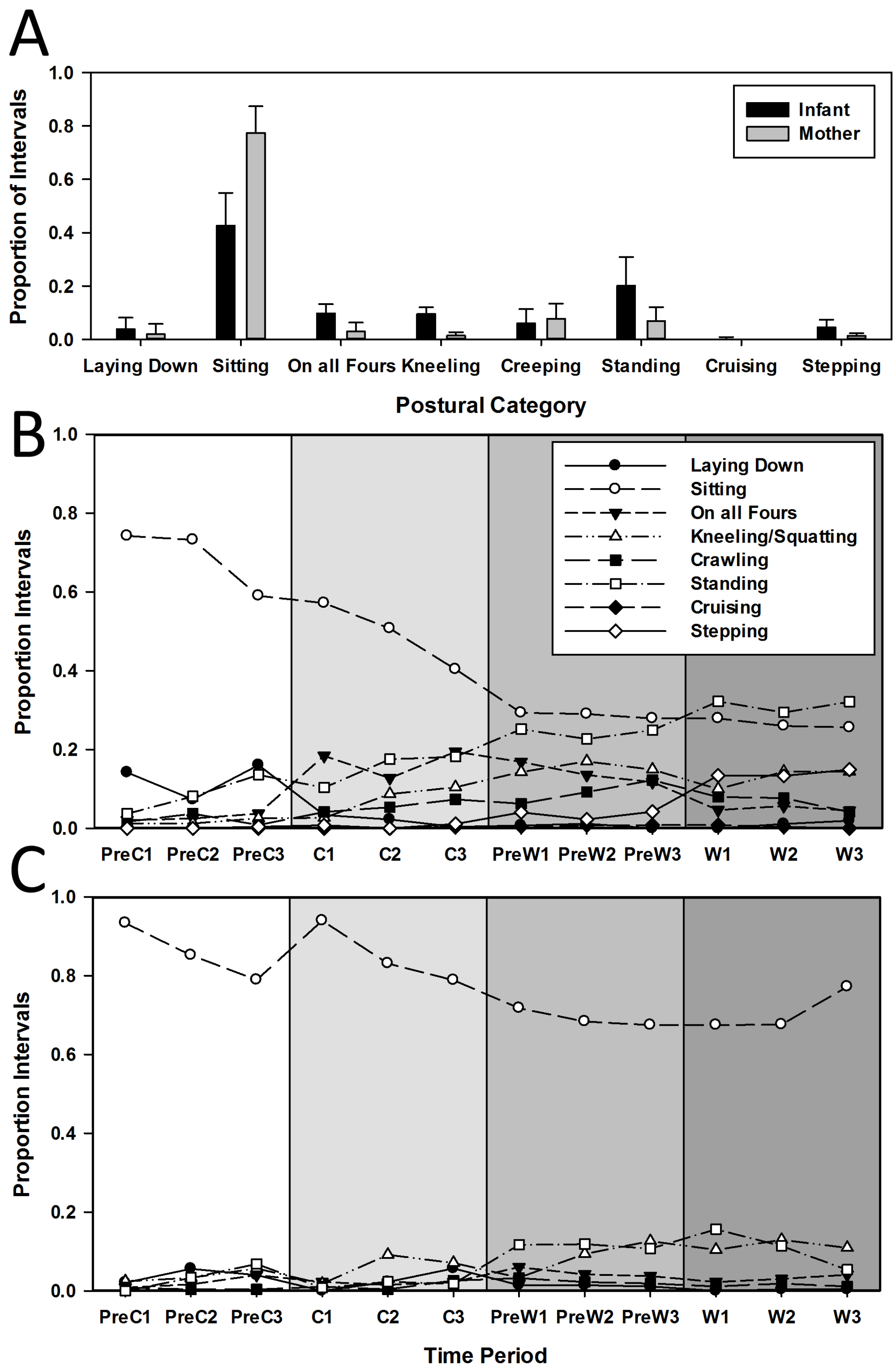

Figure 12. (A) Distribution of proportion of intervals per session that different postures were displayed during free play sessions. Bars represent averages of each dyad's average across all 12 sessions. Infants are represented with black bars and mothers are gray bars. Error bars represent the standard deviation of the mean. (B) Infants' and (C) Mothers' longitudinal trajectories of the proportion of intervals per session that participants spent in each posture across motor

milestones. Dashed lines with black circles, white circles, black triangles, white triangles, black squares, white squares, black diamonds, and white diamonds represent the average proportion intervals spent in laying down, sitting, on all fours, kneeling/squatting, crawling/crawling, standing, cruising, and stepping postures.

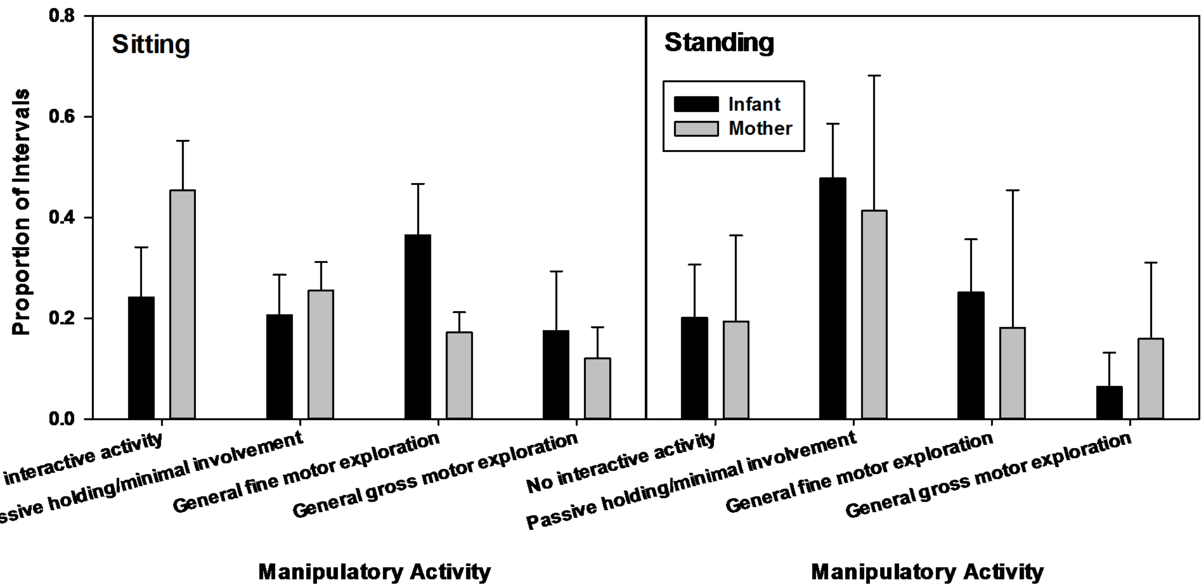

Figure 13. Distribution of proportion of sitting and standing intervals per session that different manipulatory activities were displayed during free play sessions. Sitting averages were calculated across all 12 sessions and standing averages were calculated across the 6 pre-walking and walking sessions. Infants are represented with black bars and mothers are gray bars. Error bars represent the standard deviation of the mean.

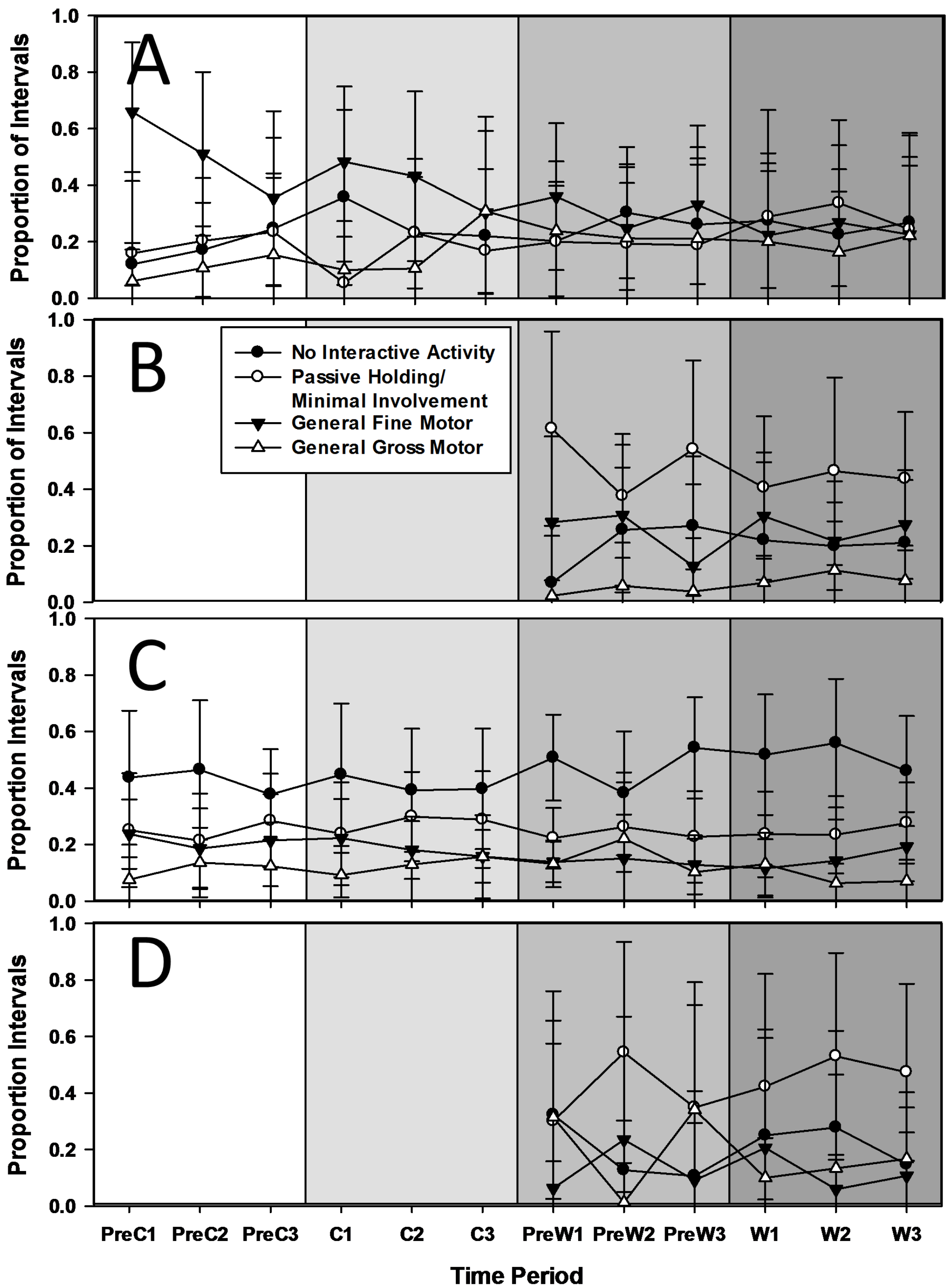

Figure 14. Longitudinal trajectories of the proportion of intervals per session that participants engaged in manipulation activities. Solid lines with black circles, white circles, black triangles, and white triangles represent the average proportion of intervals spent engaging in no interactive activities, passive holding/minimal involvement in manipulatory activities, general fine motor manipulation, and general gross motor manipulation. (A) Infant sitting intervals. (B) Infant standing intervals. (C) Mother sitting intervals. (D) Mother standing intervals.

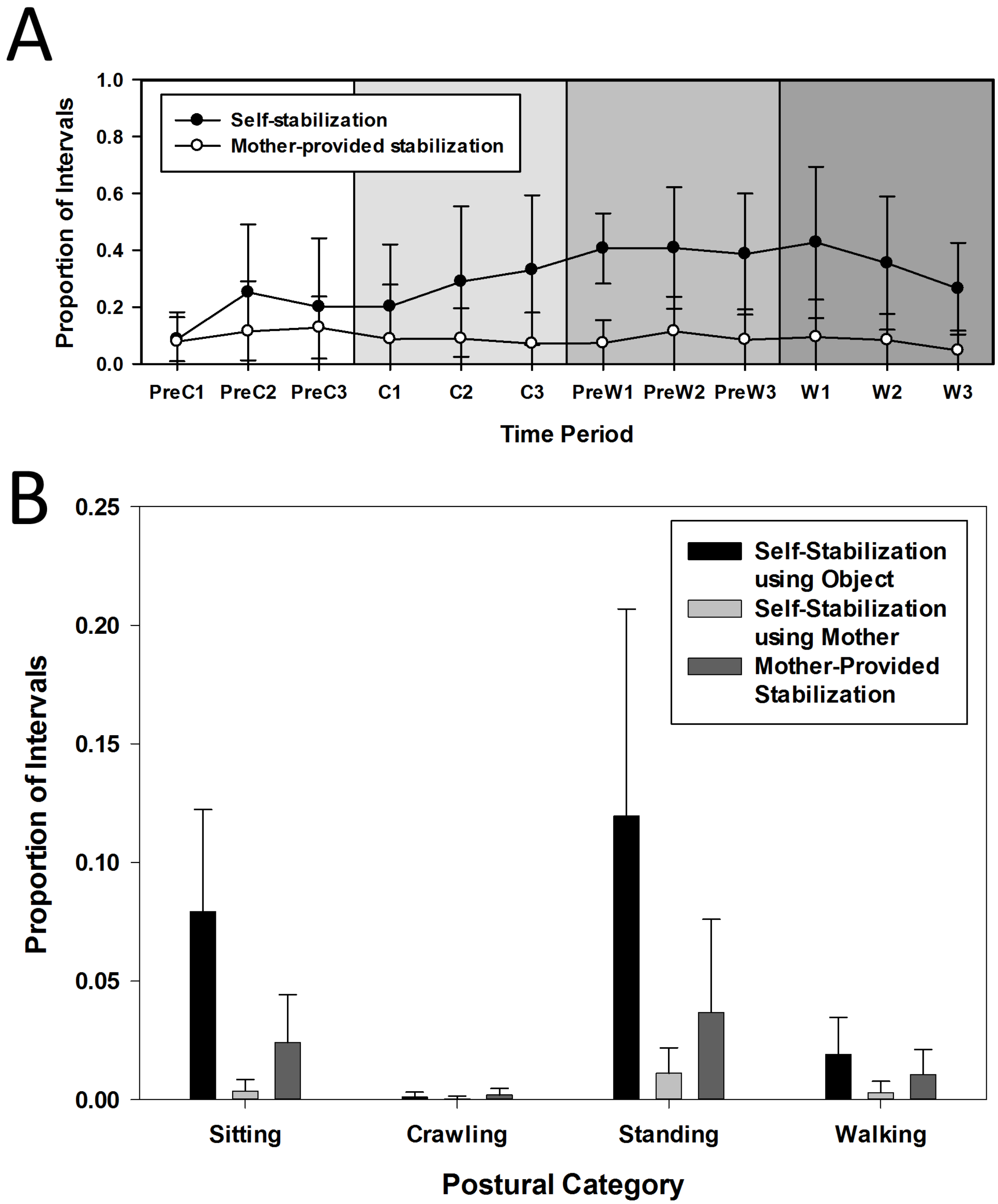

Figure 15. (A) Longitudinal trajectories of the proportion of each interval that infants' postures were stabilized across motor milestones. Self-stabilization is designated with black symbols and mother-provided stabilization is designates with white symbols. Lines are averages with standard deviations of the mean. (B) Distribution of proportion of intervals per session that different postures were stabilized during free play sessions. Bars represent averages of each dyad's average across all 12 sessions. Self-stabilization using objects is represented with black bars, self-stabilization using the mother is represented with light gray bars, and mother-provided stabilization is represented with dark gray bars. Error bars represent the standard deviation of the mean.

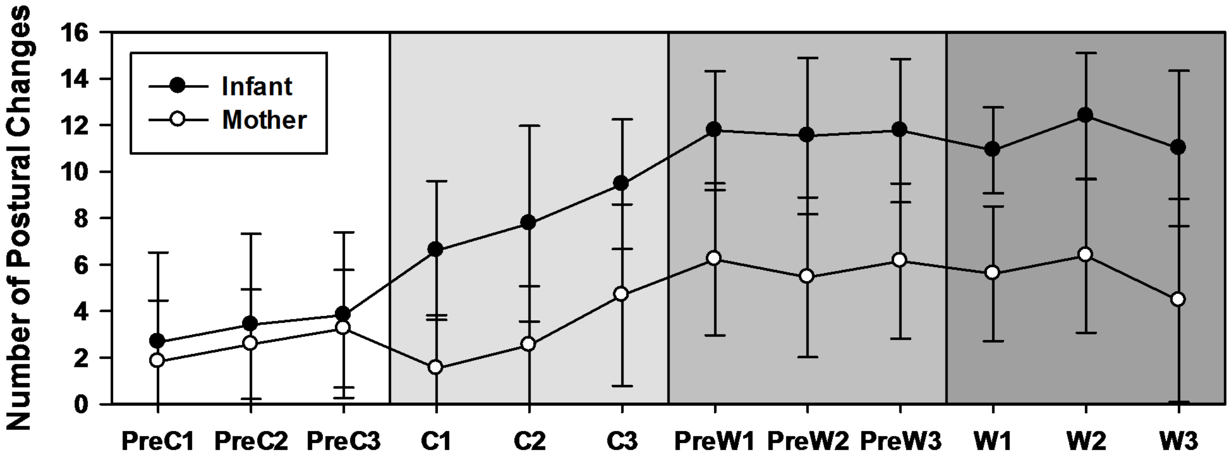

Figure 16. Longitudinal trajectories of the number of postural changes per session across motor milestones. Infants are designated with black symbols and mothers are white symbols. Lines are averages with standard deviations.

Vita

Sabrina Thurman was born in Valdese, North Carolina to Cynthia Van Donsel. She is a sister to Sarah Willix and John Epps. She attended Salem Elementary, and continued to Liberty Middle and Freedom High in Morganton, North Carolina. After graduation, she attended the University of North Carolina at Greensboro, where she was introduced to developmental psychology and experimental research. Sabrina completed international honors by studying abroad in Ecuador, South America, and disciplinary honors in psychology by working with Dr. Janet Boseovski on an independent research project. She obtained a Bachelor of Arts degree with Full University Honors at the University of North Carolina at Greensboro in May 2011 in Psychology with a minor in Biology. She accepted a graduate research assistantship at the University of Tennessee, Knoxville in the experimental psychology program in the Infant Perception-Action Laboratory, directed by Dr. Daniela Corbetta. Sabrina received a Master of Arts degree in Psychology at the University of Tennessee Knoxville in December 2014.