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The Embodied Mind in Early Development: Sitting Postural Control and Visual Attention in Infants with Typical Development and Infants with Delays

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THE EMBODIED MIND IN EARLY DEVELOPMENT: SITTING POSTURAL CONTROL AND VISUAL ATTENTION IN INFANTS WITH TYPICAL DEVELOPMENT AND INFANTS WITH DELAYS

by

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As infants learn to sit between the ages of 5 and 8 months, they undergo many changes in their bodies as well as in their minds, creating conditions for the emergence of skills that allow greater interaction with their environment. The present study focused on the interaction of developing postural control in sitting with cognition, exemplifying the concept of the embodied mind. Look time, or the time an infant looks at an object, served as a proxy for the construct of cognitive processing. Three experiments examined developmental changes in sitting postural control and looking. The first experiment examined archival data of typical infants who were followed longitudinally as they learned to sit. Look time was found to decrease as sitting emerged. Postural control variables changed toward greater stability and regularity as sitting independence emerged. Using an age-held-constant design, infants at the age of 6 months who sat independently had significantly shorter look times when compared to their same-age peers who were not independent in sitting. Analysis showed that look time was consistently shorter for infants who had more postural stability at any sitting stage. Experiment 2 examined look time from archival data of infants with motor delay as sitting developed. Infants with delays exhibited the same changes in look time as the infants with typical development during sitting development. Lastly, a third experiment with typical infants beginning to sit found no difference in look time between the two conditions of unsupported sitting, and supported sitting, showing that simply being provided mechanical stability does not shorten look time. By exploring the interaction of maturation, postural control and look time, the present study reveals that sitting postural control interacts with looking in a way that drives cognitive change by expanding the infant's ability to visually explore the environment. Developmental changes in look time

are not simply due to maturation, but rather are due to interactions with experiences and movement opportunities.

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CHAPTER 1: INTRODUCTION

The Embodied Mind in Early Development: Sitting Postural Control and Visual Attention in Infants with Typical Development and Infants with Delays

Traditional theories of intelligence rely on notions of representation, symbolic thought, and computation, all of which exist in some type of static form akin to a computer program which is separate from the body (Newell & Simon, 1972). However, evidence from infant studies suggests that the mind is embodied, meaning that a strong linkage exists between what we know and what our bodies can do (Smith & Gasser, 2005; Campos et al, 2000, Thelen, 2000). In essence, the interplay between acting on the environment and gathering information about how the world works creates the intellect. One of the first acts of body control for an infant is learning to sit. Upright and vertical control of the body heralds a new phase in infant development. Unlike an infant who succumbs to gravitational force and must be supported externally, an infant who can sit independently can maintain his orientation to the rest of the world and begin control of his surroundings (Gabbard et al, 2007; Thelen & Spencer, 1998). Thus, the ability to orient to the verticality of the world allows the infant to perceive and act on people and objects so that lessons about the world can be learned.

Infants perceive much information about the world through visual attention (Columbo, 2001). By looking at the environment, objects, and people, the infant picks up information. Looking is supported by the ability of the child to orient his body, which allows the infant to select the object of his attention. Looking is therefore a window to the infant's intellectual processing, and can be used to evaluate cognition and cognitive change as the child grows (Cohen & Cashon, 2003). The focus of the present study was developing sitting postural control and visual attention, because these two developing systems are postulated to interact for cognitive change.

The interaction of postural control in sitting and visual attention in infancy may be critical for future cognitive development when viewed from the perspective of the embodiment hypothesis. Evidence supports the idea that visual attention contributes to future cognitive skill (Borstein et al, 2006), and that early sitting postural control in preterm infants predicts cognitive scores and problem solving behavior at 18 months (Wijnrocs & van Veldhoven, 2003). The embodiment hypothesis can be used to explain these relationships. In contrast to early theories of information processing wherein the nervous system processes information through sensory systems via connections in the brain, and then acts on the world as a separate system, embodiment brings the body, the mind and the environment together as a dynamic and flexible entity (Figure 1; Thelen, 2000).

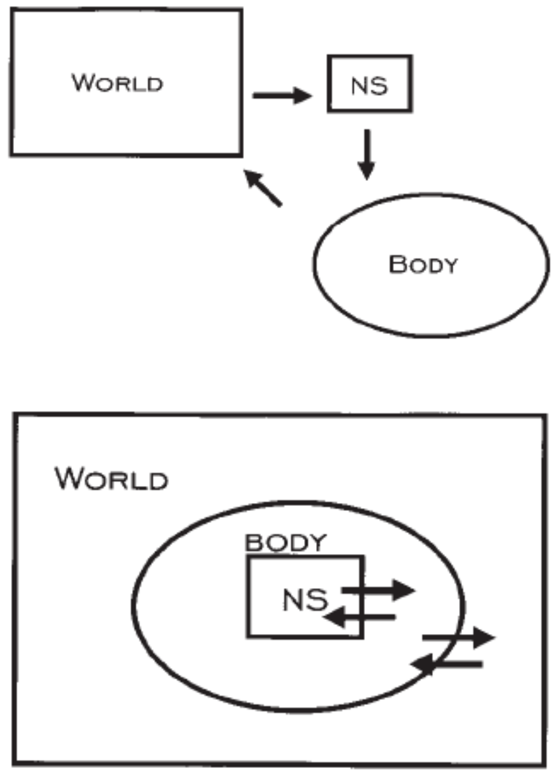

Figure 1. Taken from Thelen (2000) Grounded in the world: Developmental origins of the embodied mind. The top panel depicts the view that the world is separate from the nervous system and the mind, with the world providing information to the nervous system, which then directs the body to interact with the world. The lower panel depicts the idea of the embodied mind. The interactions between the world, the body and the nervous system are interactive and reciprocal. Adapted from *Trends in Neuroscience, 20,* "The brain has a body: Adaptive behavior emerges from interactions of nervous system, body, and environment," 553-557.

So how is a baby built? In order to understand the application of the embodiment hypothesis to the developmental problem of learning to interact with the world in an efficient and functional posture, we can learn from those attempting to build humanoid robots that can accomplish this function (Brooks et al, 1998). Initial attempts to build robots that could serve humans functionally drew upon the assumption that a monolithic controller was needed, and that internal representations reflected what was in the world. In actuality, humans do not work this way because they do not start out with all the materials needed for functioning in the world. Artificial intelligence researchers have revised their assumptions now to include a developmental model (Smith & Gasser, 2005). Humans are not smart at birth, but learning proceeds incrementally from the simple to the complex, adapting along the way. Sensory systems, motor systems, and thinking systems all change incrementally and do not create entirely new systems, but build on simpler beginnings. Figure 2, modified from Smith & Gasser (2005), depicts the concept that vision and haptics interact bi-directionally with each other and with the object to create understanding in a redundant way. The figure denotes posture as an additional component to the system because posture interacts bi-directionally with vision and other sensory systems to help the organism gain knowledge about the world. The idea that cognition is embodied stems from findings that thoughts, ideas and problem-solving come from interactions of the body with the environment, and is supported by work in neuronal selectionism (Sporns & Edelman, 1993), adaptive behavior (Chiel & Beer, 1997), and cortical modeling (Almassy, Edelman & Sporns, 1998).

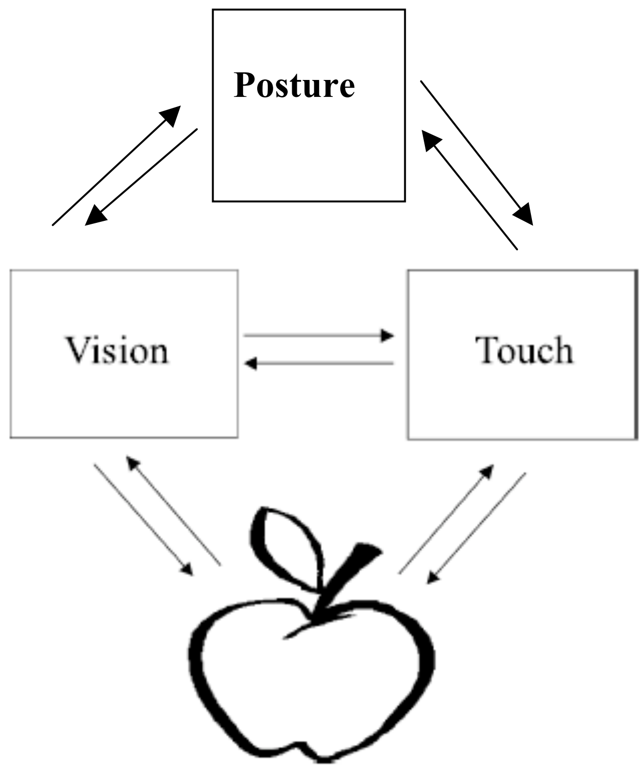

Figure 2. Adapted from Smith & Gasser, 2005. The original figure did not contain the posture factor, and was meant to show how sensory systems interact in a reciprocal fashion to understand objects in the world. The added factor of posture shows that posture interacts reciprocally through the sensory systems to understand the world and progress developmentally, which describes the embodiment hypothesis.

Investigators using the embodiment perspective seek critical periods in infant development where a specific cognitive skill follows a known trajectory, which can be altered by the advent of a new motor skill. It was this embodiment perspective that was explored in the present study, specifically to investigate the trajectory of look duration as a reflection of cognitive change during the critical period of sitting development.

I will first review the research on sitting postural control in infants. Secondly, visual attention in typical infants and its potential effect on cognitive changes during the time of sitting development, and on future cognitive skill will be reviewed. Lastly, the theory of the embodied mind and supporting evidence will be discussed as a framework for the present study.

Correlates to Motor Development from the 4th through the 8th Month

From the 4th through the 8th month, infants develop postural control in a vertically oriented sitting position (Folio & Fewell, 2000). Corresponding changes are taking place in the areas of cognition, social skills, and perceptual skills. Although many developmental tests list changes in these skill areas in a timeline format for normative comparisons, no standardized test shows the correlations between motor and cognitive skills at any particular time. Therefore, no studies have examined specific changes in cognitive, perceptual or social skill as components of sitting develop. Table 1 lists sitting, cognitive, and social changes from 4 to 8 months, collated from several standardized developmental tests and personal observations (Peabody Developmental Scales [Folio & Fewell, 200], Denver Developmental Screening Test [Frankenburg et al, 1992], Bayley Test of Infant Development [Bayley, 1969]). However, achievement of each of these skills is known to be variable and occur within a range of ages (Folio & Fewell, 2000).

Table 1.

Sitting, Cognitive, Social and Perceptual Skills Summarized from Standardized Tests

P=Peabody Gross Motor ScaleII , O=Observation, D=Denver Screening Test, B=Bayley Test of Infant Development

Age	Sitting Skill	Cognitive	Social	Perceptual
4 months	Prop sits for several seconds if placed (P)	Orients to sounds and speech (D)	Social smile (D)	Regards own hands (B, D)
	Keeps head erect and rotates head to follow toy when hips are lightly supported (P)	Regards object for at least 5 seconds (B)	Interest in toy (B, D)	Grasps rattle (P)
	Controls head when pulled to sit from supine by adult (O)	Reacts to disappearance of face (B)	Displays anticipatory excitement (B)	Shifts attention from one object to another (B)
	Reaches in supported sitting (O)	Habituates within 30 sec (B)		
5 months	Maintains sitting balance with hands placed on floor beside knees for 8 second (P)	Persistently reaches for object (B)	Displays awareness of novel surroundings (B)	Explores object (B)
	Beginning to sit for a few seconds without arm support (O)			
6 months	Sits unsupported for 60 seconds without propping on hands (P)	Plays with mirror image by looking, smiling, patting, mouthing (B)	Works for toy (D)	Shakes rattle (P)
	Reaches for toy in sitting while maintaining balance and extending both arms for the toy for 8 seconds (P)	Plays with string on toy (B)	Feeds self (D)	
7 months	Leans over to retrieve a toy and comes back to upright position (P)	Bangs toys during play(B)	May be anxious with strangers Plays social games like peek-a-boo	Looks for source of sounds (D)
8 months	Maintains balance in sitting while playing with a toy with both hands (P) with control (O)	Looks toward fallen toy by looking toward floor (B)	Plays pat-a-cake (D) Indicates wants (D)	Holds 2 blocks simultaneously for 3 sec (B)

It is also notable that test items in areas outside of the motor area are, never the less, dependent on the motor system. For example, grasping a rattle at the age of 4 months is dependent on the motor skills of controlling the head and arm to see and contact the toy, as well as controlling the eyes to target the toy in the first place. All of the cognitive items on standard infant tests are somehow dependent on the motor system, without a single item being motor-free. Therefore, if an infant is unable or inefficient in activating and controlling his motor system, he is unable to display the cognitive processes that externally indicate the workings of the mind. At the very least, the infant needs to be able to direct the eyes toward an object or face and maintain that gaze using the eye muscles for several seconds. Eye gaze and looking duration will be described in detail later in the present study as a focus of investigating cognitive change through visual attention during motor development.

Several major areas have been investigated in relation to the achievement of sitting postural control. The emergence of postural responses to a perturbation in sitting has been described, as well as the variability inherent in the continuous control of the sitting position. Sitting and the development of reaching and grasping are logically tied, and this relationship has been investigated due to its potential importance for object manipulation and exploration. Visual perception and sitting postural control have been researched to examine the developing dynamics of perception of the environment and maintaining orientation to the world. These studies will be reviewed to detail skill and perceptual development surrounding the development of sitting postural control. This will serve as a background for the research questions examining sitting control and visual attention.

Past Research on the Development of Sitting Postural Control

The development of sitting posture control has been studied using various experimental paradigms. Most of these paradigms involve a perturbation to the infant, either by support surface translation, trunk release, or a moving visual surround. Platform perturbation studies are the most prevalent, being favored by several research groups (Hadders-Algra, Brogren, & Forssberg, 1996; Hirschfeld & Forssberg, 1994; Woollacott, Debu & Mowatt, 1987). Stemming from an innate controller perspective, these studies search for a neural maturation mechanism driving sitting postural development, such as a built-in group of neurons programmed to respond in an automated way to a stimulus. These "central pattern generators" are postulated to drive reflexive movement or repetitive cyclical movements, such as walking, kicking, and chewing. To examine these central pattern generators, surface electromyography is used to reveal the onset or offset of postural muscles in response to the perturbation, and conclusions are drawn from the order of muscle firing. Woollacott et al (1987) studied four infants between the ages of 3.5 and five months and reported that neck muscles activated inconsistently in a directionally appropriate manner, and that only five month olds had occasional trunk activation. When directionally appropriate muscles were not activated, either inappropriate muscles were activated, or no muscle activation pattern could be discerned because of highly variable muscle activity. Hirshfeld & Forssberg (1994) studied 15 infants between the ages of five and eight months. Electromyography recordings revealed a large variety of muscle patterns and latencies in children not yet sitting independently.

Although the researchers concluded that a postural central pattern generator was activated just prior to the emergence of independent sitting, it is not evident how such a neural system can be specified from the variability of the many muscle patterns identified. In all of these studies, variability is interpreted as random noise. Hadders-Algra, et al. (1996) examined 11 healthy infants in a longitudinal study, with data collection at the ages of 5-6, 7-8, and 9-10 months of age. They investigated whether centrally-generated, direction-specific muscle activation patterns were evident from the first recording age onwards. They selected only trials for analysis with specific, experimenter defined activation patterns to prevent confounding by pattern variation. In essence, variability was removed from the data because variability was equated with noise. Again, a large variety of muscle firing patterns was noted. With increasing age, the variety of muscle patterns decreased, with a greater percent of the trials having a common pattern. Although it was clear that the muscle activation pattern to improve postural control increased in frequency at 9-10 months, it was not clear that the decrease in variability was due simply to the maturation of a central pattern generator, as concluded by the authors. More efficient muscle activity for sitting posture could be driven cognitively, by virtue of the infant discovering efficient strategies that allow him to obtain information from the environment with less effort. Learning to be more skillful and coordinate the degrees of freedom of the body during upright posture could also produce the findings of this study. In fact, other studies (Hopkins & Westra, 1988; Hadders-Algra et al, 1996) have also shown that infants can be trained to achieve independent sitting earlier, as a result of the handling practices of the caregivers. If sitting can be accelerated by handling and practice, it is difficult to make an argument that maturation of a neural central pattern generator is responsible for independent sitting.

Harbourne et al (1993), using a different paradigm of release of trunk support, analyzed seven healthy infants at two stages of sitting development (supported sitting at approximately 4 months and prop sitting at approximately 5 months). The handling of the infants was designed to simulate the natural movement of the infant by the caregiver during dressing or position change. They found decreased trunk velocity after trunk release between the two stages, and a gradual organization of postural muscle responses as infants matured. In the first stage, the infants used ten to 30 different combinations of muscle activity to maintain posture. From the first stage to the second, some muscle synergies were eliminated, and each infant developed a preferred synergy that was used most frequently when the trunk was released. This synergy was a combination of hamstrings and low back extensor activation. The second most frequently used synergy was a combination of low back extensors and quadriceps. It was concluded that the infant strives to keep the segments of the body together, and maintain the center of mass over the base of support, which would effectively decrease the associated degrees of freedom. Use of the predominant synergies of low back-hamstring and low back-quadriceps indicated that the infants were keeping the trunk aligned over the pelvis while keeping the pelvis from falling too far forward or too far backward from the leg segment. Although this study did not specifically address the issue of stability in the development of upright posture, the underlying assumption was that the infants sought stability to maintain postural control through a variety of muscle synergies. Variability was examined through description of muscle patterns, and was noted to decrease as control of the degrees of freedom increased.

The above studies provide information about the gradual organization of posture during and after a perturbation. However, strategies controlling a reaction to imposed perturbation may be different from control strategies used for self-initiated movement and continuous control of a stable posture. In addition, the above studies treated variability as error rather than information that may be important when evaluating a dynamically adapting organism within the environment. Because postural control is necessarily dynamic to adapt to changing conditions, variability should be examined as part of the behavior of maintaining orientation to important features of the environment.

Dynamic postural control and the importance of variability. Studies in children and adults using the center of pressure (COP) as a reflection of overall postural control have provided insight regarding the processes of postural control, age differences, and development of body segment control during continuously adapting behavior. However, many of these studies have used linear measures to quantify the COP, with the general rule that stability is a desired state. To examine changes in stability, measures of the amount of sway decrease to indicate increasing stability. Linear measures include the length of the COP path, excursion of the COP path, and area of the COP path, along with the standard deviations of these variables. These measures provide a value for the amount of body sway over the base of support, but have proven inadequate when studies are compared for consistent results. Palmiere (2002), in a review of postural control studies using the COP methodology, argued that linear measures of the COP do not quantify stability of the postural control system, because it is possible to have a large area of the COP path while having a stable posture (Hughes et al, 1996) or unstable posture (Oppenheimer et al, 1999). Correlations of clinical tests of postural control to the amount of sway have been weak and inconsistent (Duncan et al, 1992). Because of inconsistency in the interpretation of linear measures of the COP, the lack of clinical correlation to other postural measures, and a lack of standardization, Palmieri (2002) maintained that current linear measures are not useful to characterize postural stability, and that new measures are needed to examine the COP signal and quantify changes over time.

Cavanaugh et al (2005) point out that conventional, linear measures of postural stability such as the length of path, range, and area, may be related to stability, but are not measuring stability of the system itself. Stability is the response of the postural system to a perturbation, which can be internal from the natural sway of the body, or externally generated from the environment. A more important construct to measure is dynamic stability, which can be quantified by measuring the local behavior of trajectories of the system within a state space by using a nonlinear measure. Dynamic stability is a feature of a complex system. Increasingly, the variability of other physiological time series is being examined in terms of complexity and measured by using nonlinear mathematical tools (Lipsitz, 2002; Pincus, Cummins, Haddad, 1993; Stergiou et al, 2003). These nonlinear variables reveal the complexity inherent in the system being evaluated and measure different aspects of the system than linear variables can not capture. Nonlinear techniques have been used to analyze cardiac rhythms (Fleisher, Pincus & Rosenbaum, 1993), brain activity and neuronal networks (Skarda & Freeman, 1987), as well as other motor control issues (Timmer et al, 2000; Morrison & Newell, 1996). By using nonlinear techniques, all these studies reveal complexity in physiological signals over time, which is a feature of healthy systems.

Recently, center of pressure data has been used by Harbourne & Stergiou (2003) to examine the development of early postural control in sitting, allowing examination of the spontaneous and unconstrained movements of infants. These researchers examined the continuous, dynamic and adaptive process of developing postural control using nonlinear analysis techniques which had not been used in past research. This paradigm allowed the infants to sit as independently as possible, while collecting time series data on the center of pressure. With monthly data collections from 4-8 months of age, infants showed an increase in stability and regularity of the COP, measured using the nonlinear tools of the Lyapunov Exponent, and the Approximate Entropy. The standard linear measures of the COP, such as the range or area of the COP, did not show any developmental trends.

Measures of physiological systems taken repeatedly over time allow inspection of the health of the system by examining variability. Healthy systems, whether referring to heart rate or the COP time series, have a "just right" level of variability within the system, which is not too regular, and not too random (Stergiou et al, 2006). This allows the system to have a relatively predictable course which can adapt if a change in the environment occurs. Without this complexity, adaptability would suffer. Nonlinear measures such as the Approximate Entropy (Pincus, 1991) and the Lyapunov Exponent are tools useful in describing variability, and therefore can be used to characterize postural stability. These tools will be described further in the methods section.

In summary, past research of developing sitting in typical infants reveals initial variability of postural reactions when trying to control upright posture. In addition to the variability present when posture is perturbed, infants have high variability of movement when initially learning to sit, which can be visually observed as "wiggly" movement. As the infants mature (or learn) and sitting improves, the variability of postural reactions and movements appears to decrease, and the stability and regularity of posture increases. However, the pervasiveness of variability during normal development of sitting suggests that measures characterizing variability can be used to quantify the stability or control of posture as it changes over time. Although the above cited studies provide information on the motor aspect of sitting development, the researchers did not examine skills in other areas such as reaching, looking and attention, areas that may be directly affected by changing postural skill.

Sitting control and reaching. Control of sitting posture is correlated with developmental change in reaching and manipulation skills. Rochat & Goubet (2000) investigated the effect of postural control in sitting on reaching using sitter and non-sitter infants. They found that infants who were already sitting used trunk lean along with arm reach significantly more than the non-sitting infants. They also showed that infants who could not yet sit independently could use more mature reaching patterns when provided the "affordance" of pelvic stability by an external stabilization device substituting for muscular stability. This substitute for postural control also affected perceptual skill. Infants reached with only one hand when the pelvic support was not provided, but reached bilaterally when postural stability was provided. Obviously the infants perceived the affordance of pelvic stability, leading to a new action of bilateral reach. We can speculate that as infants perceive their own developing pelvic stability and learn control, they begin to explore new movements with their body and are able to gain more information from the environment. This may lead to changes in cognitive skill as the infant has new abilities for manipulation and exploration.

Thelen and Spencer (1998) studied 4 infants weekly from the age of 3 weeks to 1 year. They noted that infants achieved controlled stability of the head as a component of upright postural control a few weeks before reaching began. The stability of the head and visual stability was postulated as a necessary condition for successful reaching, even as beginning reaches occurred. Kamm (1995) followed 5 infants from 8 weeks of age until they had one month of sitting experience. She found that vertical orientation had a facilitative effect on the frequency and skill of reaching, although infants used a variety of reaching strategies. She concluded that postural control and reaching develop as a unit as the infant learns control of the head and body for vertical orientation. These longitudinal studies of typical infants support the concept that postural control is essential for the infant to begin a dynamic interaction with the environment.

Visual-spatial perception emerges concurrently with sitting postural control. Researchers have extensively investigated vision and its relationship to the development of postural control in sitting. The most prevalent experimental situation is the moving room paradigm (Butterworth & Hicks, 1977). This paradigm consists of placing the infant in a sitting position inside a special room with moving walls and ceiling. The infant stays stable, but visual information from the moving visual surroundings causes the perception of body sway, and the infant's head and trunk move to counteract this sway. The room provides a perceptual perturbation, similar to the effect noted when one is in a stationary car and a large vehicle in peripheral view moves, causing the sensation of self-movement. With infants, the experimenters oscillate the room and examine the timing differences between the room and the infants' movement. Even prior to independent sitting, infants are reacting to the room movement (Barela, Godoi, Junior & Polastri, 2000). In fact, Barela et al found that the linkage between head and trunk movement and the wall movement does not change significantly over time. However, the youngest infants in the Barela et al study were 6-months-old, an age when many infants are already sitting independently, at least for short periods. Therefore, the infants may have enough experience to have already learned about appropriate postural reactions. This paradigm reveals the early bi-directionality and interaction of postural control and the environment leading to functional competency for orienting to the environment in an ongoing, continuously evolving manner.

Visual Attention and Cognitive Development

Visual attention has been studied extensively in infant cognitive research. Measures of visual attention are noted to be useful in determining the efficacy of interventions or in quantifying cognitive function that will have some continuity through early childhood and into adolescence and adulthood (Columbo, 2001). The theoretical underpinning of visual attention research postulates the existence of four components: an alerting function, spatial orienting, attention to object features, and endogenous attention (Columbo, 2001). The alertness function has to do with the state of preparedness of the organism, and in infants relates more to the infant's state of arousal than with higher order attention mechanisms (Thoman, 1990). The spatial orienting function includes visual tracking, shifting of attention and the disengagement of attention. This function is closely tied to the motor system, and appears to be fairly well established by 6 months of age (Posner & Cohen, 1980). The system for attention to object features functions to process visual properties of objects for information processing and identification, as well as memory for future recognition (Webster & Ungerleider, 1998). The final functional area is endogenous attention, which relates to more voluntary attention focus, perseverance, and distractibility. In the proposed study, the measures will not tease out which of these four functional components of visual attention are being utilized, because looking behavior is the primary interest. However, global measures of visual attention, such as looking duration and habituation time, are prevalent in infant cognitive research as a reflection of overall cognitive status. The proposed research will focus on simple looking duration.

There has been an explosion of infant perception and cognition research in the past 40 years since the advent of looking paradigm methodology, with looking duration a central component of all paradigms. Looking duration is considered to be a reflection of the infants' ability to process information, and has been shown to correlate with other measures of infant cognition, as well as relate significantly to later measures of intelligence in childhood (Bornstein et al, 2006). Many paradigms utilize looking, including visual preference paradigms (Fantz, 1958), the visual habituation paradigm (Fantz, 1964; Hunter & Ames, 1988), the violation of expectation paradigm (Spelke, 2000), and the focused attention paradigm (Ruff & Cappazolli, 2003). I will summarize the findings from this body of research, and describe in greater detail a few studies that have a direct influence on the present investigation.

Summary of looking paradigm findings in investigations of infant cognition. Infants' preferences for certain visual stimuli were among the first findings of researchers using looking as a methodology. Fantz (1962) found that measures of infant looking such as total looking time were reliable, and determined that infants had natural preferences for patterned surfaces rather than uniform surfaces, and complex patterns over simple patterns. In addition, when infants show a preference for one object over another, the assumption can be made that they can discriminate between two pictures or objects. Following the investigations of natural preferences, researchers moved to the visual habituation paradigm. The method here is to show the infant the same stimuli until the infant habituates, or looks at the stimuli at least 50% below baseline (first look). Then, the examiner adds a new stimulus, and the infants' attention and looking resumes. By the resumption of looking, or looking at the novel stimuli preferentially over the familiar stimuli, researchers establish that the infant can differentiate between the two. This visual preference paradigm has been used to investigate the capability of infants to have particular knowledge about objects, memory, or understand categories and numbers. A caveat is that not all infants prefer novelty; some infants will look preferentially at a familiar stimulus. However, in general, familiarity preferences should vary according to complexity within an age group (Hunter & Ames, 1988). Infants over 6 months of age should be shown moderately complex stimuli to exhibit the classic habituation to the familiar, and infants younger than 6 months require very simple stimuli to habituate to the familiar stimuli. One last paradigm is the focused attention method (Ruff & Cappazolli, 2003), in which specific criteria for focused attention vs. casual attention are used to time look durations. This paradigm is used with older infants and toddlers who are capable of handling objects and moving within the environment.

Standardized tests have been developed using habituation and dishabituation. One of the pioneers in using this methodology was Joseph Fagan, who developed a test called the Fagan Test of Infant Intelligence (Fagan, 1991). This test has been shown to be significantly correlated to later intelligence test scores (Fagan & Detterman, 1992). Infants look at two pictures of the same face until the infant habituates, or stops looking at the faces. Then a different face is added and the examiner notes the amount of time the infant attends to the novel face (dishabituation). Both abstract designs and faces have been used by Fagan, but he states that the test with just faces has better reliability and validity (Fagan, 1992). Reliability of trained observers to score the infants' visual fixation is .94, with a range from .80 - 1.00. The above tests require a laboratory environment with a specific, standardized procedure to present the items to the infant. The infants are well supported during this testing, and are not required to control their own posture.

Look duration can be explained as the amount of time an infant takes to extrapolate the information from a visual stimulus. Although there is a greater quantity of infant cognitive research using the habituation paradigm than a simple looking time paradigm, the findings regarding looking time values are the same. Very young infants have long looking times, and take a relatively long time to habituate (Bornstein, 1998). As they mature, looking times decrease and it takes less time for them to habituate (Bornstein, Pecheux & Lecuyer, 1988). Basically, the infants require less time to extract the necessary information from a repeated, constant or non-novel stimulus. It is worth noting here that all infant looking time or habituation studies provide postural support to the infant when they are too young to sit independently. Generally the infant is held in the parent's lap, but infant seats are sometimes used (Bornstein, 1998).

Various procedures for eliciting looking time have been developed. Photos of faces or 2-dimensional abstract figures on a screen are the primary targets for infant looking. However, variations on this procedure include moving targets, real objects, and color differences between looking targets. All of these variations yield essentially the same result, which is the developmental change from long looking times at younger ages (3 months old), to short looking times as infant's age (8 months old) (Courage, Reynolds & Richards, 2006). In addition, testing of infants born at risk for cognitive developmental delay reveals longer looking times and a slowness of habituation, or a failure to habituate, supporting the interpretation of look duration as a reflection of information processing efficiency (Cohen, 1981).

Looking generalized to objects and faces. As noted above, most of the tests for infants investigating the basis of cognition and the continuity of intelligence capacity over time utilize looking to pictures of faces. However, can the trend of looking time decreasing from 4 to 8 months generalize to looking at stimuli other than faces?

Shaddy & Colombo (2004) examined 4 and 6-month-old infants and their responses to both dynamic and static stimuli. Infants looked longer to dynamic stimuli with an audio track than they did to static stimuli. However, the trend over time was the same as for static faces. The researchers found that infants showed the same trend of decreasing looking time from 4 to 6 months for dynamic stimuli as found for the static stimuli. Another study by Courage, Reynolds & Richards (2006) verified that the trend of decreasing looking time from 4 to 7 months was consistent for static and dynamic faces, Sesame Street material, and achromatic patterns. These researchers followed infants until 1 year of age, and found that after 7 months, look times increased for dynamic Sesame Street material and faces, but declined for static stimuli.

Does this tendency for infants to have shorter looking times generalize to situations outside the laboratory? Bornstein & Ludemann (1989) answered this question by studying infants in their homes, looking at their mother and at a toy. They studied infants in American homes and in Japanese homes to determine whether this naturalistic observation applied across different cultures. They found the home data replicated the laboratory findings for both cultures. Specifically, infants habituated to either faces or objects within 3 minutes, and showed the same type of qualitative variation noted in the laboratory. This variation includes 3 types: 60% of infants show an exponential decrease in looking, 10% show an increase followed by a decrease, and 30% fluctuate. They concluded that habituation is likely to be a commonplace event for infants in their natural environment. It is also likely to affect the behavior of parents (Bornstein, 1985; Tamis-LeMonda & Bornstein, 1989), in that parents may encourage infants and toddlers in different ways depending on the age of the child and the object of attention. This implies a different type of interaction between the infant and the environment, a social interaction that can affect the evolving cognitive skill of the infant.

Relationship to future cognitive skill. Rose et al (1995, 2005) have studied the relationship of several aspects of looking and attention to future cognitive skill, and have found a relatively strong link between looking skills and cognition, which is interpreted to reflect a basis in core information processing skill. The two strongest indicators of future cognitive ability at 3 years of age were speed of processing, moderated by visual recognition memory. Speed of processing was strongly related to look duration and shift rate, or the ability to look between 2 objects or images and quickly compare them. These abilities were strongly correlated ($r=-.79$) at both the age of 2 years and the age of 3 years (Rose et al, 2005). In addition, visual recognition memory was strongly correlated ($r=.41$) to IQ at 8 years of age (Rose et al, 1995)

Aside from the above correlations, how stable is cognition across childhood? Although standardized infant cognitive tests, such as the Bayley, have not been shown to be predictive of later IQ (DiLalla et al, 1990), recent multivariate, longitudinal studies are finding some stability in cognitive abilities through childhood. The results of a multivariate, prospective, longitudinal study (Bornstein et al, 2006) indicate that infancy provides a base of cognitive skill that carries forward throughout early childhood. These findings are based on the proposition that cognitive skill is grounded in information processing, which is based on being able to gather important information from the world efficiently, and connect that information to other ideas, concepts and memories that allow appropriate action. The ALSPAC study (2006) examined infant habituation at 4-months-old, and then used different tests each year until 4 years of age to determine adaptive responding, general mental development, language, and standard psychometrically assessed intelligence in 375 children. They found that infant habituation had a small but significant effect on intelligence at 4 years of age, distinct from exogenous effects such as home environment and mother's education (Figure 3). Therefore, short looking, or the ability to look and pick up information quickly in infancy has an enduring effect on the child's skills for processing information to learn within his environment. The importance of looking and orienting in the world is part of the child's evolving intellectual system. This brings us to the idea of the embodied mind.

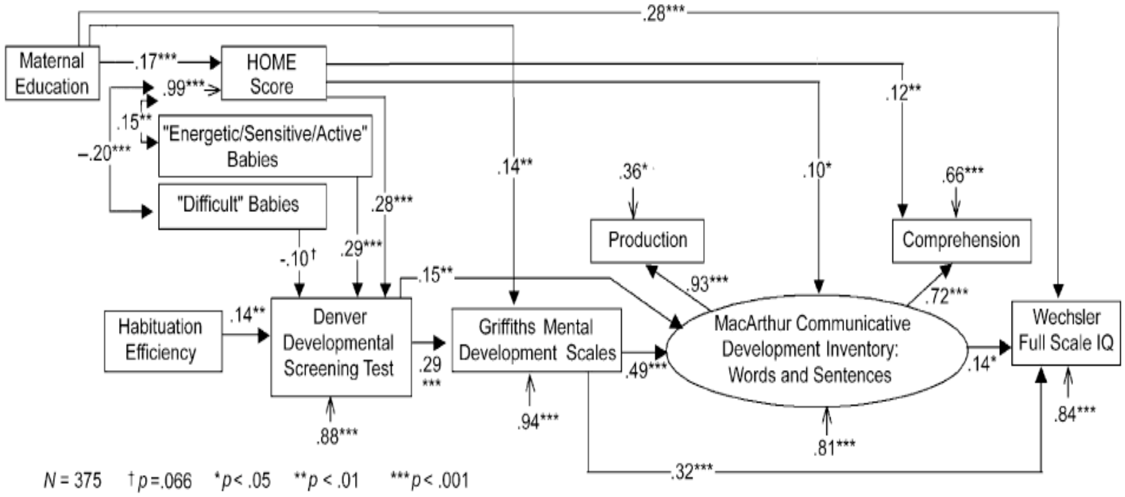

Figure 3. Taken from Bornstein, M. H., Hahn, C., Bell, C., Haynes, O. M., Slater, A., Golding, J., Wolke, D. (2006). Stability through early childhood is shown by the significant contribution of habituation efficiency at 4-months-old to tests of cognition up until 4-years-old.

The Embodied Mind

Smith and Gasser (2005) offered this description of the embodiment hypothesis: "The central idea behind the embodiment hypothesis is that intelligence emerges in the interaction of an agent with an environment and as a result of sensorimotor activity". They describe several lessons from infants on embodied cognition. One is that babies live in a physical world with much regularity that organizes perception and thought. They learn these regularities through physical interaction with the environment. Another lesson important to the present study is that babies explore in variable ways that often seem random to the observer; but this exploration leads to discoveries and inventive solutions to problems encountered, building intelligence in the process. These lessons are based on experimental evidence from research with developing infants that explores the links between physical experience and what infants know. Motor skill change and the interaction of that change with typical cognitive progression is a typical way to investigate the hypothesis of the embodied mind.

Campos et al (2000), in a seminal paper chronicling the onset of infant locomotion and subsequent experiences leading to cognitive change, describe the motor act of crawling as a control parameter for cognitive change. As infants begin prone progression, a family of experiences fuels the mind's expansion in perception, socializing, emotional regulation, and cognition. The cognitive task used in one study (Kermoian & Campos, 1988) was a test of object permanence, using an age-held constant design. They studied ninety-six 8.5 month-old infants, and assigned them to three groups based on their locomotor history. One-third of the babies were assigned to each group: a prelocomotor group who were unable to locomote; a prelocomotor/walker-assisted group who could not independently locomote, but who had used a walker an average of 2 hours per day; and a locomotor hands and knees group. They found that both infants with walker experience and hands and knees locomotion capability scored higher on the object permanence task than the infants with no locomotor experience. The amount of time spent locomoting had a significant effect on improved spatial skills as measured by their object-permanence scale.

In another study of locomotor acceleration, Lagerspatz et al (1971) taught one group of typically developing infants to crawl via daily practice of 15 minutes, and another group of infants spent an equal amount of daily time in a social situation with an adult. The infants in the crawling practice group not only crawled earlier than the social experience group, but they also walked earlier. Surprisingly, they also found superior cognitive skills in the crawling practice group. This suggests a link between the advanced movement skills available to the crawling infants, and their ability to explore and pick up information from the environment.

A recent study has examined a very large cohort of individuals (N=5,362) from infancy into late adulthood for the relationship between early milestones and intelligence (Murray et al, 2007). This study links the achievement of two early motor milestones, standing and walking, with intelligence at age 8 and reading comprehension at age 26. Earlier standers and walkers had higher IQ's and reading comprehension. This effect was lessened when the slower developing outliers were removed from the analysis, but there was still a significant relationship. Although this study does not link specific motor development with specific cognitive change, the implication is that movement and cognition are linked in early development, which then has an effect on later cognitive skill.

Vertical posture, looking, and attention. Although few studies have examined looking duration during developing sitting posture without physical support for the infant, the evidence indicates a link between posture and visual attention. Levit (2006) examined 9 infants longitudinally at 5 motor milestones: sitting, standing, walking, and 3 and 6 months post walk onset. Levit compared situations in which the infants had the support of their hands to stabilize their posture, vs. no hand support. Levit found that infants had longer visual attention when they used hand support, and speculated that the stabilizing influence of hand support allowed more visual information pick-up. It was concluded that infants modified their postural behavior to support the capacity of the visual system.

Levit also noted that infant's postural sway was attenuated during times of strong visual attention. She concluded that infant's perception, action, and cognition were linked into a mind-body system that created a flexible yet stable action system.

Sitting behavior and infant perception of environment. Motor behaviors match, in a task-specific way, the infant's perception of the environment. Adolph (2000) examined nineteen 9-month-old infants while reaching across a spatial gap. Infants who were experienced in the sitting position, but inexperienced in crawling were placed in sitting at the edge of an adjustable gap, with a toy dangling across the gap. The infants were encouraged to lean across the gap to get the toy at increasing distances of the gap. Experienced sitters knew exactly how far they could safely lean when reaching, and did not fall into the open space. Nevertheless, those same infants who were just beginning to crawl fall into the chasm when reaching in the new crawling position. Many of the infants fell into the gap trial after trial, even though they had been able to perceive the unsafe gap in the sitting position. The authors concluded that infants have specificity of knowledge of spatial characteristics which is strongly correlated to their experience of a posture. The above studies provide information on typically developing infants; does the support for the embodiment hypothesis hold up when applied to infants and children with problems controlling their bodies?

Infants with movement dysfunction. Lefevre (2002) studied infants who were undiagnosed, but who she classified into normal tone and hypotonic (low tone) categories. Using an adapted seat which tilted in space, she examined visual attention in 5-month-old infants in a supine sitting position and an upright sitting position, comparing the normal tone to the low tone infants. There were no differences between the two infant groups, but all infants showed shorter looking durations in a more upright position. Although the author interpreted these shorter looking times as decreased attention, other researchers have indicated that shorter looking durations can be interpreted as faster information processing, and this speed of processing relates to future cognitive skill.

In another study, Barela (2006) studied infants with Down syndrome using the moving room paradigm. Inexperienced sitters were compared to experienced sitters over 4 sessions of practice within 10 days. In the first session the inexperienced sitters were significantly different from the experienced sitters, and were not linked to the room movement. However, all sessions after that showed that all infants were synchronized with the room movement, indicating that even infants with movement problems can quickly learn environmental linkages when given opportunities for motor experience.

Wijnroks & van Veldhoven (2003) examined 65 pre-term infants and categorized their sitting postural control as normal or abnormal. At 18 months, the typical pre-term infants and the infants that had been classified with abnormal postures in sitting (excessive neck, trunk or arm hyperextension) were compared, and were found to have lower cognitive and problem solving skills than the infants who had normal posture in sitting at a younger age. Although this study did not include measures of visual attention, the direct link between cognitive test scores and sitting posture compensations in this population of infants supports the embodiment hypothesis.

The above studies support the theory of the embodied mind, and that variables representing infant cognitive skill are inextricably linked to the motor system. Like locomotion, independence in sitting has the capacity to bring a new world of information to the infant by allowing controlled orientation of the visual system to pick up information. The reciprocal connection between posture control and looking was examined in the present study.

Present Study

The overall goal of the present study was to reveal linkages between the development of sitting postural control and cognition in support of the embodiment perspective. The relationship between sitting postural control and cognition as measured by look time was examined to emphasize the importance of sitting as a developmental transition in infancy. Three experiments were conducted. Experiments 1 and 2 utilized archival data and were longitudinal in design. The first experiment documented the developing sitting and looking skills of infants who were typically developing from the time of beginning prop sitting to mature independent sitting, which occurred between 5 and 8 months of age. Variables representing stability of postural control were compared over time along with look time variables, to determine if significant changes occur concurrently in sitting and looking over time. The second experiment examined infants with motor delays as they developed sitting, between 1 and 2 years of age. Repeating the analysis from Experiment 1 with typical infants, sitting stability variables were examined concurrent with the look time variable, to determine if the same changes occured over time, even though the infants were older than the infants in Experiment 1. Experiment 2 was meant to rule out the effect of neuromaturation driving the changes seen in both sitting and look time. The third Experiment focused on typically developing infants who were just beginning to sit. Experiment 3 compared look time during unsupported sitting, and when mechanical support was provided via an infant chair. This last experiment examined the effect of mechanical stability in upright as being the driving influence on look time. Following the embodiment hypothesis, a reduction in look time during supported sitting should not occur immediately, but rather change incrementally over time as postural control develops.

Experiment #1 Research Hypotheses

This experiment examined the naturally occurring changes in sitting postural control and look time as typical infants changed over time. In addition, changes in sitting postural control stability measures were examined over time, as well as correlations to look time changes in typical infants. Because infants attain sitting skills incrementally at different times and at different rates, comparisons were made between stages of sitting from the immature sitter to the mature sitter. Specific hypotheses were:

Hypothesis 1. A. Postural stability in sitting increases over time as indicated by decreasing values of the Lyapunov Exponent and Approximate Entropy variables from Stage 1 to Stage 3 of sitting.

Hypothesis 1. B. Look time decreases significantly as sitting progresses from Stage 1 to Stage 3.

Hypothesis 1. C. Sitting stability variables correlate significantly and positively with changes in look time; and sitting stage and look time correlate negatively.

Knowledge gap and rationale. Although looking duration (Courage et al, 2006) and sitting stability (Harbourne & Stergiou, 2003) have been studied separately using longitudinal designs, and trends of change over time established, no previous study has examined these two constructs together with the same infants in a longitudinal manner. In addition, looking studies have provided postural support to infants (Bornstein, 1998), so it has not been established whether look times show a decreasing trend when infants must control their own posture as they learn to sit.

A separate comparison examined, using an age-held-constant design (Campos et al, 2000), whether infants who sit independently at a later age have concomitant later achievement of short looking durations. The hypothesis was:

Hypothesis 1. D. Early sitters at 6 months of age exhibit shorter look times than infants who are 6 months old but not yet sitting independently.

Knowledge gap and rationale: Comparison of “early” typical sitters and “late” typical sitters and their respective looking behavior has not been done. The comparison of early and later sitters separated the effect of age or neural maturation from the effect of sitting postural control on looking behavior. The rationale was to eliminate age as the control parameter and examine developing postural control as a possible control parameter for looking duration.

A last comparison of the typically developing infants contrasted whether the infants with “high” stability/regularity postural control in sitting versus “low” stability/regularity had differences in look duration. This comparison determined whether high stability sitters within any of the three sitting stages had shorter looking times than infants who were not as stable. Infants were classified at each sitting stage as high stability if they were below the median in the Lyapunov Exponent variable or the Approximate Entropy variable, and low stability if they were above the median.

Hypothesis 1. E. Infants who show greater stability (by a lower Lyapunov Exponent in the anterior posterior direction) and greater regularity (by a lower

Approximate Entropy value in the anterior posterior direction) have shorter look times than infants with less stability or regularity.

Knowledge gap and rationale. All past studies of infant looking time have given support to the infants who could not sit (Bornstein, 1998), so no data is available on looking as sitting stability develops. In addition to this gap in knowledge, newer nonlinear measures quantifying sitting postural control have not been previously available to determine small increments of increasing control over time as looking duration is measured. One infant may be a stable sitter in Stage 1 sitting, while another infant is much less stable. This hypothesis predicted that the stability of the posture, rather than the ability to simply hold a vertical position, affects the infants' capacity to look and attend to environmental information. Quantification of postural control with more accurate and sensitive measures may allow a determination of the specific effects of postural control on look times.

Experiment #2 Research Hypotheses

This experiment examined the sitting development and look times of infants with motor delays. The same first two hypotheses as made for the typical infants, examining change over time, were posed, as well as a third hypothesis regarding differences between Stages of sitting:

Hypothesis 2. A. Infants with motor delays show the same trend in look time as sitting develops as typically developing infants.

Hypothesis 2. B. Infants with motor delays show the same trend in sitting stability variables as they learn to sit, and the trend is the same as that in look time.

Hypothesis 2. C. Change over time, from Stage 1 sitting to Stage 3 sitting follows the same trajectory in infants with motor delays as in typical infants.

Knowledge gap and rationale: Infants with motor delays have not been studied to determine if look duration is also delayed in developing. If these infants show the same changes as the typical infants, the evidence increases that sitting postural control is tightly linked to the ability to control the pick-up of information visually. Delays in sitting control would thus lead to a cascade of problems in cognitive and social development, just as Campos et al (2000) showed in the study of infant crawling and locomotion. This relationship is important so that early intervention can address potential future problems in the cognitive and social arena when early delays are seen in motor skills.

Experiment # 3Research Hypothesis

This experiment involved the collection of new data with typical infants. In this experiment, look time was measured in unsupported immature sitting, and in a supportive infant seat that was slightly reclined. These conditions contrasted the dependence on sitting stability of look duration. A significant difference in look time between the two conditions, with look time shorter in the supported condition, indicated that mechanical stability contributed to efficiency in looking. However, equal look times in both conditions indicated that efficiency in information processing was not simply due to mechanical support. The hypothesis was:

Hypothesis 3: There is no significant difference in look time between the two conditions of supported sit and unsupported sit in infants who are not yet sitting independently.

Knowledge gap and rationale. Looking time has been measured with infants with poor or beginning postural control who are being provided support. If providing these infants artificial support changes looking time to that of a stable sitter (shorter look duration), it would be clear that it is simply a mechanical issue of stabilizing the head and trunk for looking, rather than an interactive, reciprocally developing skill of learning to coordinate action and perceptual systems. If looking skills do not change significantly with the support condition, then it would seem to be the development of a perception-action system over time that guides looking to extract important information from the environment quickly and reduce looking time.

CHAPTER 2: METHODS

Experiment #1

Experiment 1 utilized archival data of typically developing infants from a previous study.

Participants. Twenty-eight typically developing infants were recruited for a previous longitudinal study (Investigation of the dynamics of development of sitting postural control in infants with cerebral palsy, funded by National Institute of Disability and Rehabilitation Research and the National Institute of Child Health Development) on sitting postural control. Infants were recruited when they were just beginning to prop sit. Typical infants were followed from the age of approximately 5 months to eight months, the time when infants are learning to sit independently. Mean age and standard deviation of the group of typical infants at each stage of sitting is reported in Table 2. The typically developing infants were recruited from employee announcements at the University of Nebraska Medical Center and the University of Nebraska at Omaha campuses and word of mouth. Parental consent was obtained prior to any testing or data collection.

Table 2.

Mean Age and Standard Deviation in days and Stage of Sitting

	Stage 1	Stage 2	Stage 3
Typical	162 (21)	195 (21)	230 (23)
Delayed	360 (77)	425 (95)	432 (62)

Inclusion criteria for entry into the study for the typically developing infants were: a score on the Peabody Gross Motor Scale of within 0.5 SD of the mean, age of five months at the time of initial data collection, and sitting skills as described below in beginning sitting. Exclusion criteria for the sample of infants who were typically developing were: a score on the Peabody Gross Motor Scale II greater than 0.5 SD below the mean, diagnosed visual deficits, or diagnosed musculoskeletal problems.

Procedures: For all data collection sessions, the infants were allowed time to get used to the laboratory setting, and were at their parent's side for preparation and data collection. Infants were provided with a standard set of infant toys for distraction and comfort. All attempts were made to maintain a calm, alert state by allowing the infant to eat if hungry, be held by a parent for comforting, or adapting the temperature of the room to the infant's comfort level. Testing proceeded when the infant was in a quiet and alert state (Brazelton, 1984).

Center of pressure analysis in sitting was done using an AMTI force plate, which was embedded in the floor of the motion analysis lab. The baby was held in the sitting position in the middle of the plate when calm and in state four of the Brazelton scale (Brazelton, 1984). The investigator and the parent remained at one side and in front of the infant respectively during the data collection, to assure the infant did not fall or become insecure. The child was held at the trunk for support, and gradually guided into a sitting position while being distracted by toys presented by the parent. Once the examiner released support of the infant, data was collected for 10 seconds or longer while the child attempted to maintain sitting postural control. If the infant was able to sit without support for extended time, they were left alone and data was collected continuously for up to 3 minutes. Three trials that were acceptable for our criteria were collected, as tolerated by the infant. If the child became irritated the session was halted for comforting by the parent or a chance for feeding, and then resumed only when the child was again in a calm state.

Instrumentation. Data was collected at the Munroe-Meyer Institute for Genetics and Rehabilitation Motion Analysis Laboratory at the University of Nebraska Medical Center using an AMTI force platform (Advanced Mechanical Technology Inc., Model OR6-7-1000), and a Vicon 370 3D Motion Capture System. The force platform is mounted to a sub-floor concrete slab to prevent vibration interference. The Vicon 370 Motion Capture System includes a 64 channel 12 bit A-D converter and a computer (1 GHz PC; Vicon Motion Systems). Data acquisition and processing was controlled through Vicon software. Component forces (Fx, Fy, Fz) and moments (Mx, My, Mz) were each sampled at 200 Hz and were amplified using an AMTI Model MCA6 Amplifier. Calculation of center of pressure (COP) coordinates from the forces and moments occurred through the Vicon software. A frequency analysis of both the medial-lateral and anterior-posterior components of all the COP time series from preliminary data indicated that the range of signal frequencies that contain 99.99% of the overall signal power was between 1 and 29 Hz. Therefore, the sampling frequency was set at 200 Hz. Data was exported in ASCII format which was used for nonlinear analysis. Video of each trial was collected using two Panasonic videocameras (Model 5100 HS) and a Panasonic Digital AV Mixer (Model WJ-MX30). The cameras were positioned to record a side and a rear view of the subject.

Measures

Sitting stability measures. Segments of trials were selected based on the following criteria: infant was not crying or vocalizing or flapping/waving arms or legs; infant was not in the process of falling; infant was not leaning further than 45 degrees in any direction. The selected segments are all 8.3 seconds long, the shortest time allowable for the nonlinear analysis based on our necessary sampling rate. This time window allowed for a time series of 2000 points for each segment. The first three segments that followed our selection criteria were chosen from each session. These segments were analyzed for linear and nonlinear variables. Each 8.3 second segment has values for the following variables. The three selected segments from a session were averaged for the variables described below.

Lyapunov Exponent. The Lyapunov Exponent (LyE) is a nonlinear measure that can characterize the temporal structure of variability in a time series. The LyE measures the divergence of the data trajectories in phase space. The LyE value describing purely sinusoidal data with no divergence in the data trajectories is zero because the trajectories overlap rather than diverging in phase space. This shows minimal change in the structure of the variability over time in the data. The LyE for random data indicates greater divergence in the data trajectories. Lower LyE values indicate greater stability in sitting postural control. LyE values for both anterior posterior (forward-backward) and medial lateral (side-to-side) directions were used.

Approximate Entropy. Approximate entropy (ApEn) is a measure used to quantify the regularity of a time series or predictability of a time series. Increasing ApEn values reveal greater irregularity and increased randomness. Conversely, lower values reveal a more regular or periodic signal. Lower values (closer to zero) indicate greater postural stability. ApEn values for both anterior posterior and medial lateral directions were used.

Look time measure. Data segments for the look time measure were selected by starting with the already selected segments for the sitting stability measures. These segments of video were examined for looking behavior. However, the look times did not always include the segments selected for the sitting stability variables. Because the infant looking times were longer than 8.3 seconds, segments of looking data were sought that were as long as possible, within the first 5 minutes of the data collection sessions. The sitting stability variables as previously measured in 8.3 second segments were used as a representation of the sitting postural control of the infant during that session. Therefore, the look times do not correspond exactly in time to the segments selected for the sitting stability measures.

Look time. Look time was measured as the time an infant fixates vision on an object without shifting gaze for more than .5 seconds. Minimum look time was set at .5 seconds, and to terminate a look, the infant had to look away from the object for at least 1.5 seconds. All valid look times within the selected window of time (3 minutes from the beginning of the already selected sitting stability segment) were recorded, and the *longest looks* within that window of time and the *mean look time* were derived from the measured looks. The mean look time was the average of all the look times within each stage of sitting for each child. Longest looks were the looks longer than the median look time for the given stage of sitting in the group. The type of stimulus was also recorded. Only 4 selected objects were used for looks (see below).

Reliability of the look time measure. Inter-rater reliability was determined by another coder re-coding 10% of the sample after training by the primary investigator. Training consisted of viewing the videotaped segments together and discussing look duration behaviors, practicing timing looks, and repeating the training session after one week for retention checking. The coding procedure was modified several times to reach an acceptable level. The initial number of looks per child was reduced eventually so that only looks to four specific objects were coded: a DVD player with a “Baby Einstein” video, a “Happy Apple” toy, a caterpillar toy and a spinning toy. The object needed to be directly in front of the infant, without another object on top of it or immediately beside it so the rater could clearly see what the infant was looking at. Inter-rater reliability was thus refined so that there was 95% agreement.

Independent Variables

Stage of sitting. Stages 1, 2, and 3 reflect increasing control and independence in sitting, and are behavioral categories that have been used in previous research (Harbourne & Stergiou, 2003; Harbourne et al, 1993). All stages were coded by the primary investigator. These stages and one intermediate stage are defined below.

Stage 1 reflects beginning sitting skills. Head control is maintained for over one minute without bobbing when the trunk is supported at the mid-trunk; the infant can track an object across midline without losing head control; the infant may prop his hands on the floor or his own legs to lean on the arms, but the infant should not be able to reach and maintain balance in the prop sit position. When the infant is supported in sitting he can reach for a toy. The infant should be able to prop on his elbows in the prone position for at least 30 seconds.

The next stage of sitting is labeled as Stage 2. At this stage the infant is making consistent attempts to sit without propping on the arms, but makes many errors and is likely to fall. Excursions of the trunk can be large in attempts to find a balance point. The infant may hold the arms stiffly in the air to stabilize. The infant can balance up to 30 seconds independently without falling and without arm support, but not longer than 30 seconds.

Stage 2.5 was another intermediate stage of sitting. This stage included sitting attempts that were not using the arms, but that were between 30 seconds and 1 minute duration. Parents reported that the infant still could not be left sitting alone without supervision because they occasionally fell backward or to the side. This stage was only used for hypothesis 1. D. Otherwise, Stage 2 and 2.5 were collapsed into Stage 2.

Mature sitting is labeled Stage 3. The infant can sit without falling, and can reach for toys in independent sitting with both hands without disrupting balance. The parent is not concerned about falling from sitting position at this stage, and will leave the child alone in the sitting position without protection. The infant is generally not crawling yet, and not yet moving in and out of the sitting position independently.

Experiment # 2.

Participants. Sixteen infants with delayed motor development were recruited as part of a previous study (Investigation of the dynamics of development of sitting postural control in infants with cerebral palsy, funded by National Institute of Disability and Rehabilitation Research). Inclusion criteria were: age from five months to two years, score greater than 1.5 SD below the mean for their corrected age on the Peabody Gross Motor Scale II, and sitting skills as described above for beginning sitting. In addition, the infants with delays progressed to the stage of independent sitting during the previous study to be included in the present study. Therefore, infants with severe delays were excluded because sitting independence was not attained by the conclusion of the previous study. Other exclusion criteria were: age over two years, a score greater than 1.5 SD below the mean for their corrected age on the Peabody Gross Motor Scale, a diagnosed visual impairment, or a diagnosed hip dislocation or subluxation greater than 50%. Mean age for the infants with delays at the start of the previous study was 12 months; mean ages and standard deviations for the infants with delays at progressive stages of sitting are listed in Table 2. The archival data for these subjects was analyzed for sitting control variables and look time variables using the same procedure and measurement methods as in Experiment 1.

Experiment #3

This experiment involved the collection of new data. The design compared behavior in two support conditions during one session.

Participants. Five infants developing typically between the ages of 4 and 5 months were recruited by word of mouth. Infants were screened using the Peabody Gross Motor Scales II, as described in the previous study, and scored within average range for their age. Selection criteria were the same as in Experiment 1 for typically developing infants.

Instrumentation. Each infant was videotaped from the front with one camera for the entire session. The camera distance was standardized to provide a view of the infant and the toys used for look stimulation. A standard set of toys was provided, and the toys were held constant between children for the two conditions. A commercially available infant seat, the *Infant to Toddler Feeding Seat (The First Years)* was used as a supportive seat for the support condition, and was reclined slightly with a tray for additional trunk support.

Procedure. Each infant was presented two toys in each of the two conditions. The order of the conditions was counter balanced, alternating with each infant. The unsupported condition was the prop sitting position on an exercise mat. The investigator was beside the infant to position him/her and guard against falling. The infant's mother sat to the other side of the infant. After the infant was sitting independently in either condition, and all support was released, toys were presented one at a time at the front of the infant but out of their reach. When the infant looked away from the toy for more than 5 seconds, that toy was removed and replaced with another toy. This was repeated for a total of 5 minutes. Then the procedure was repeated for the remaining condition. The infant was provided a rest by lying down or being held by the parent after each condition, or if he/she was showing any signs of stress such as fussing, crying, or yawning.

Measures. The same procedure for coding look time as described in Experiment 1 was used. All looks for both conditions were recorded.

CHAPTER 3: RESULTS

Each archived video record was examined for looks that met the criteria established in the reliability portion of the study. Because the previous study was not designed to collect look time data, some of the children did not have any looks that met criteria in one or more of the sitting stages. The number of acceptable looks varied widely between children from session to session. The following results report the overall values of the groups by sitting stage. Individual trajectories were not attempted because of the wide variability in numbers of looks per child.

Experiment 1

Hypothesis 1. A. Postural stability in sitting increases over time as indicated by decreasing values of the Lyapunov Exponent and Approximate Entropy variables.

This hypothesis was supported by the data. Each variable was compared across sitting stages using a repeated measures ANOVA model. Post-hoc pair-wise comparisons between the sitting stages were made using the Tukey method. To adjust for the analysis of multiple outcome measurements, a Bonferonni adjustment was used, resulting in an alpha level of 0.025.

This comparison included the mean for each variable for each child at each stage of sitting. Significant changes occurred in the nonlinear variables of Lyapunov Exponent and Approximate Entropy. In the anterior-posterior direction, LyE decreased across stages significantly ($F\ (1, 27)=46.338$, $P=0.000$), as did ApEn ($F(1,27)=23.344$ $P=0.000$). Significant differences were noted between stages 1 and 2, between stages 2 and 3, and between stages 1 and 3 (Figures 4 & 6 respectively). In the medial lateral direction, ApEn showed an increasing trend, but the changes were not significant

(F(1,27)=2.785, P=0.107) (Figure 7). There were no significant changes or trend in LyE in the medial lateral direction (F(1,27)=0.892, P=.892) (Figure 5).

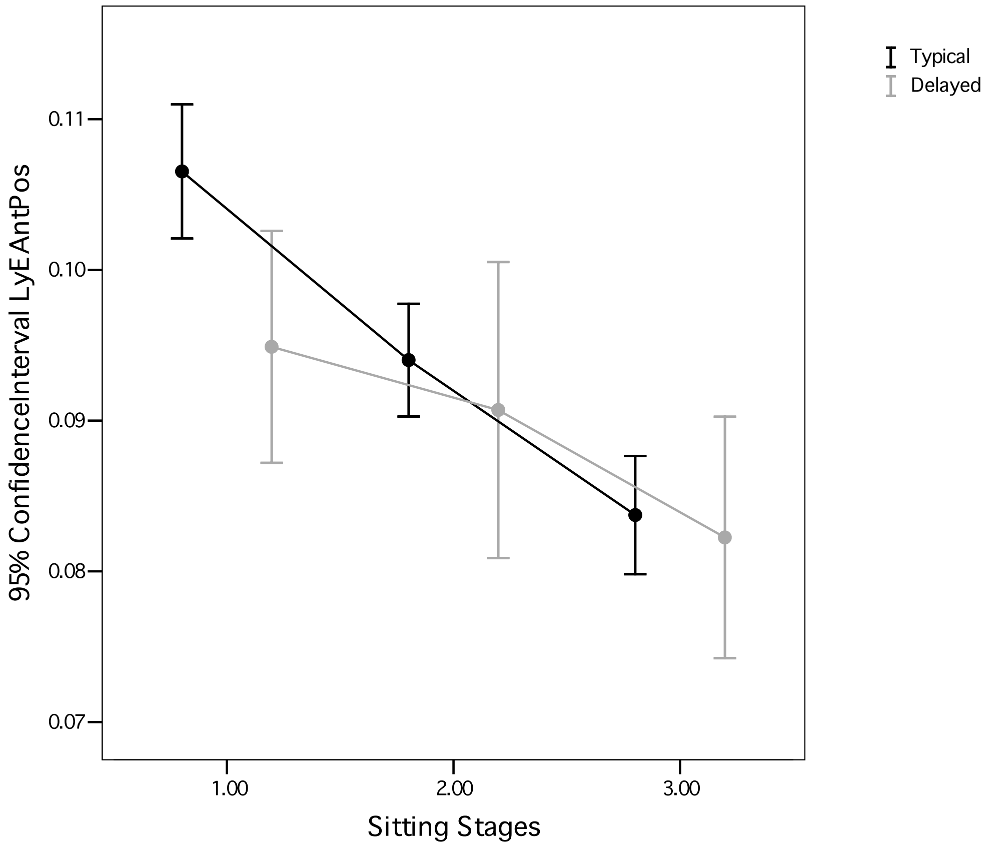

Figure 4. The dark line represents the group mean values over three stages of sitting for infants developing typically, and the light line represents the same group mean for infants with delayed development for the Lyapunov Exponent, in the anterior-posterior direction. Vertical lines represent 95% confidence intervals for each group at each stage of sitting.

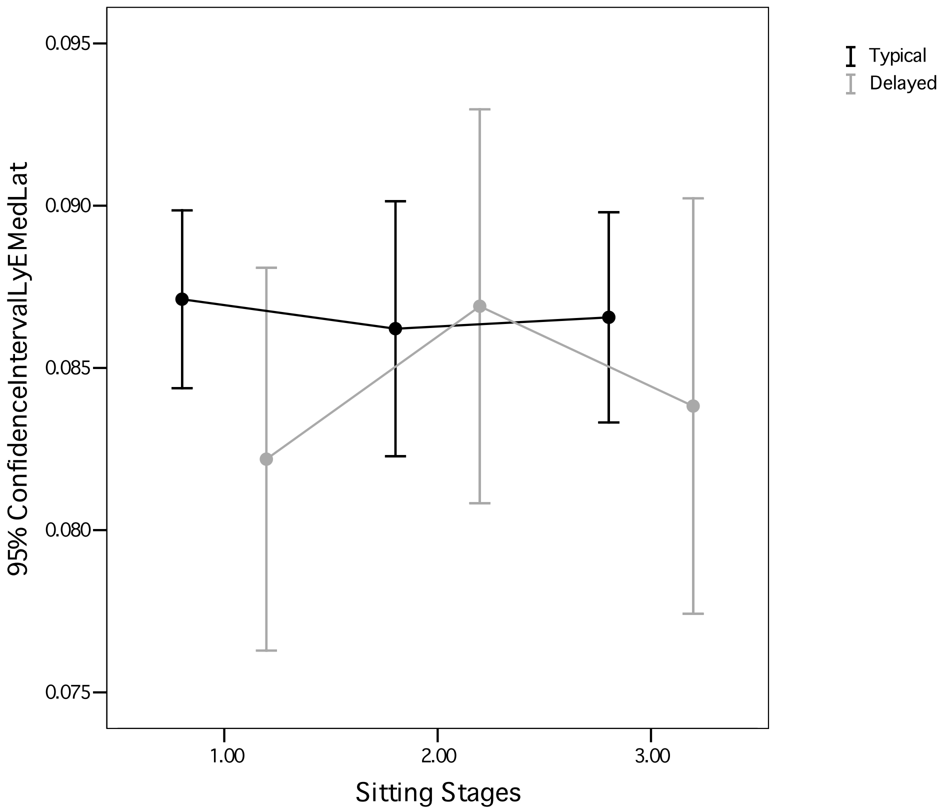

Figure 5. The dark line represents the group mean values over three stages of sitting for infants developing typically, and the light line represents the same group mean for infants with delayed development for the Lyapunov Exponent, in the medial-lateral direction. Vertical lines represent 95% confidence intervals for each group at each stage of sitting.

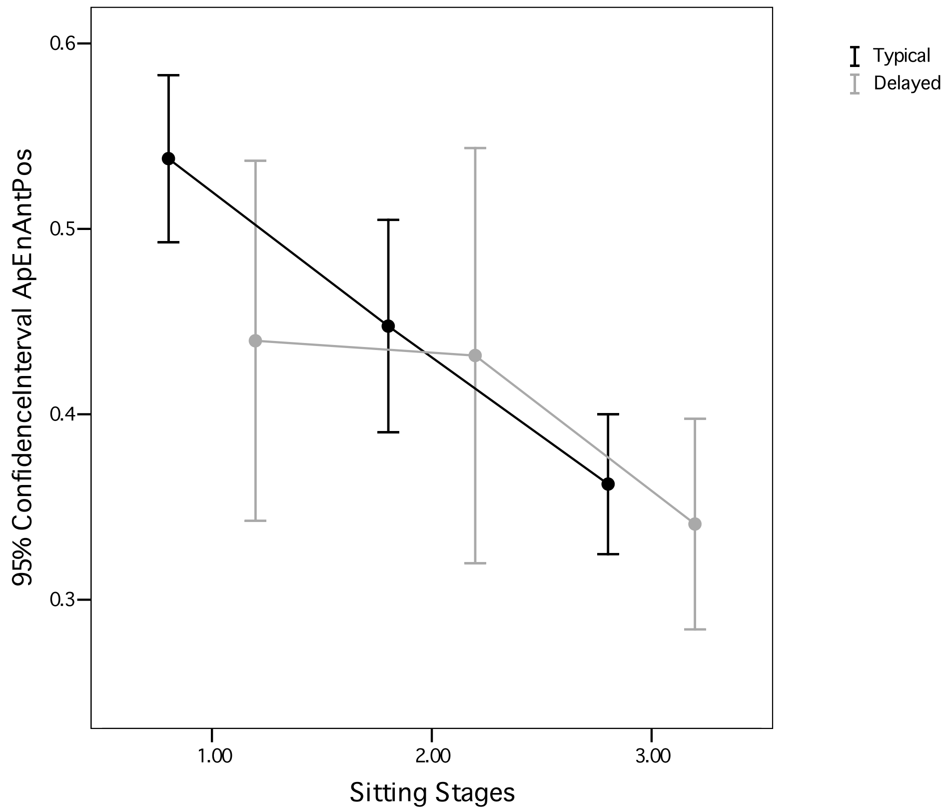

Figure 6. The dark line represents the group mean values over three stages of sitting for infants developing typically, and the light line represents the group mean for infants with delayed development for the Approximate Entropy, in the anterior-posterior direction. Vertical lines represent 95% confidence intervals for each group in each stage of sitting.

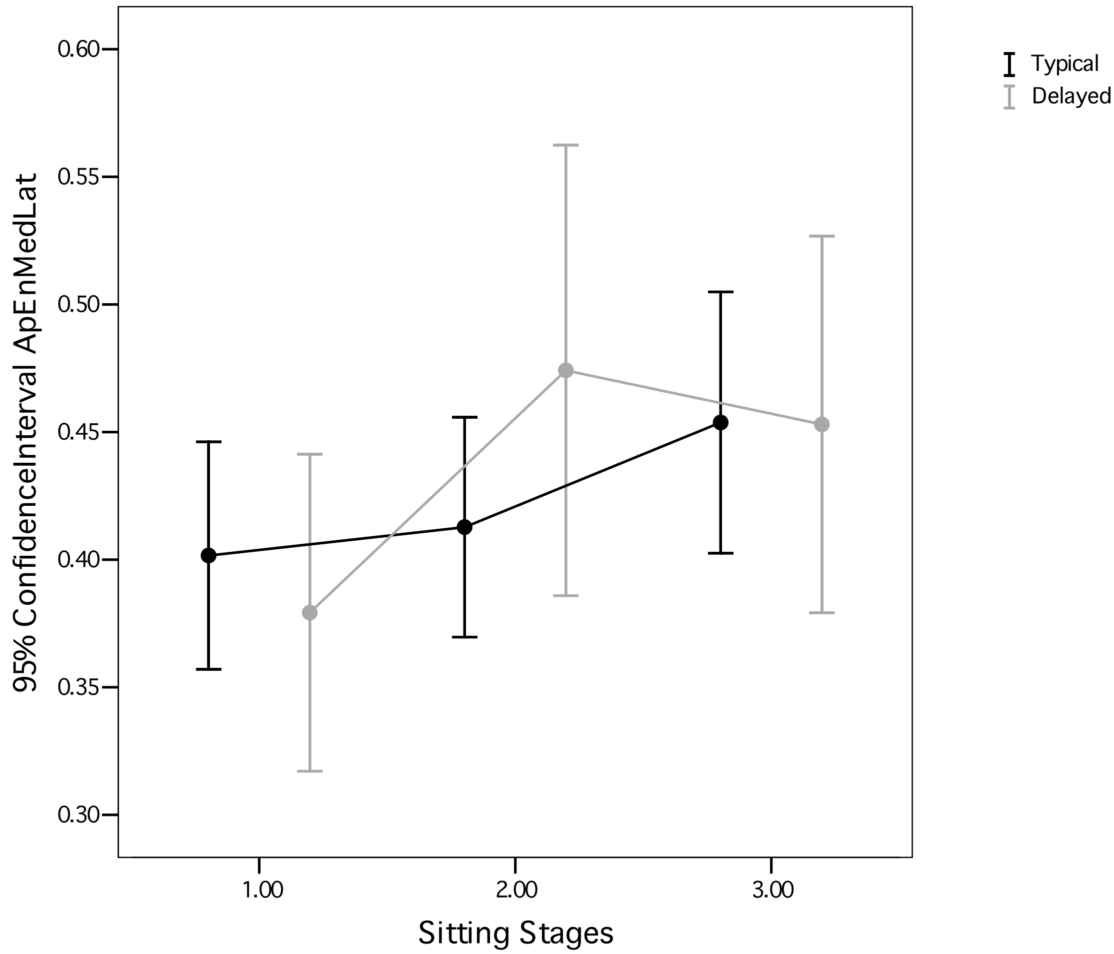

Figure 7. The dark line represents the group mean values over three stages of sitting for infants developing typically, and the light line represents the group mean for infants with delayed development for the Approximate Entropy, in the medial-lateral direction. Vertical bars represent 95% confidence intervals for the groups at each sitting stage.

Hypothesis 1. B. Look time decreases significantly as sitting progresses from Stage 1 to Stage 3.

This hypothesis was also supported. Repeated measures ANOVA was again used for look time and longest look, with paired comparisons analyzed post hoc using the Tukey method. Bonferroni correction yielded an alpha level of 0.025. There were significant changes (F(1,27)=5.871, P=0.022) between sitting stages 1 & 3 and 2 & 3 in average look time (Figure 7), but not between sitting stages 1 and 2. Longest looks were determined by including all looks above the median for the entire group of looks. Longest looks showed the same changes over time as average look time, with the longest looks decreasing over time across sitting stages. However, the change between stages in longest looks was not significant (F(2,318)=3.18, P=0.043).

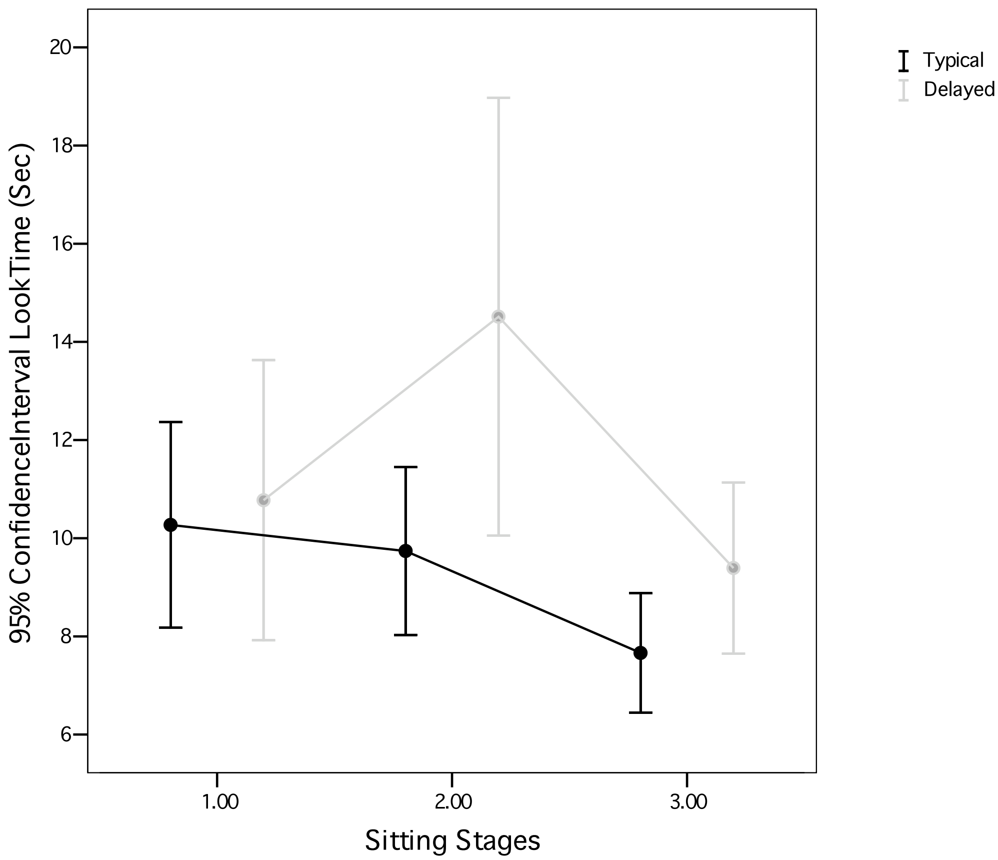

Figure 8. The dark line represents the group mean values over three stages of sitting for infants developing typically, and the light line represents the group mean for infants with delayed development for the look time variable. Vertical bars represent 95% confidence intervals for the groups at each sitting stage.

Hypothesis 1. C. Sitting stability variables correlate significantly and positively with changes in look time; and sitting stage and look time correlate negatively.

The Pearson correlation coefficient was used to determine relationships between the variables of interest. The hypothesis was not strongly supported. Even though these correlations were in the predicted direction, the sitting stability variables did not correlate strongly with look time. Sitting stability as measured by nonlinear variables varied with look time in a positive correlation (Table 3). Looks became shorter as sitting stage increased and the infants were able to independently sit. LyeE in the anterior-posterior direction decreased over time, indicating an increase in stability, which correlated positively with a decrease in looking time. LyE in the medial-lateral direction did not correlate with the look durations, and did not change over time. The ApEn variable in both directions correlated positively with decreasing looking time.

Intercorrelations Between Variables for Infants with Typical Development

Table 3.

Variables	1	2	3	4	5	6	7
1. Age (days)	_	-.12	.78	-.46	.04	-.31	.35
2. Look Time		_	-.15	.09	.01	.15	.09
3. SitStage123			_	-.58	.05	-.51	.23
4. LyEAP				_	.37	.61	-.11
5. LyEML					_	-.07	.20
6. ApEnAP						_	.30
7. ApEnML							_

Hypothesis 1. D. Early sitters at 6 months of age exhibit shorter look times than infants who are 6 months old but not yet sitting independently.

Infants were divided into early sitters (those infants who are in Stage 3 sitting at the age of 6-months) and late sitters (those who are not in Stage 3 at the age of 6 months). There were 4 outlier look times in the group that were extremely long. These were all look times to the DVD player. The few infants who had "outlier" long looks appeared to be actually watching the show on the DVD. These infants were known by interview of the parents to have learned to watch a computer or TV screen by sitting on the parent's lap and viewing, and seemed to have much previous experience with this activity. Because these looks were outliers and seemed different in nature from looking at the other objects, and there were only 4 looks out of 109, they were eliminated from the analysis. Look times from early sitters and late sitters at 6 months were compared between these 2 groups using a Student T-test.

Infants who sit early, within the 6^{th} month, had shorter looking times than infants at the same age who were not yet sitting independently. Although most infants who were typically developing were able to sit with some independence during the 6^{th} month, those who were completely independent (stage 3 sitting) had significantly shorter looks ($T(2,105)=2.152$, $P=0.034$) than infants who were still losing balance and occasionally falling at the same age (stage 2.5). Therefore, when age was held constant, infants who had greater postural control in sitting were looking at objects with shorter look times.

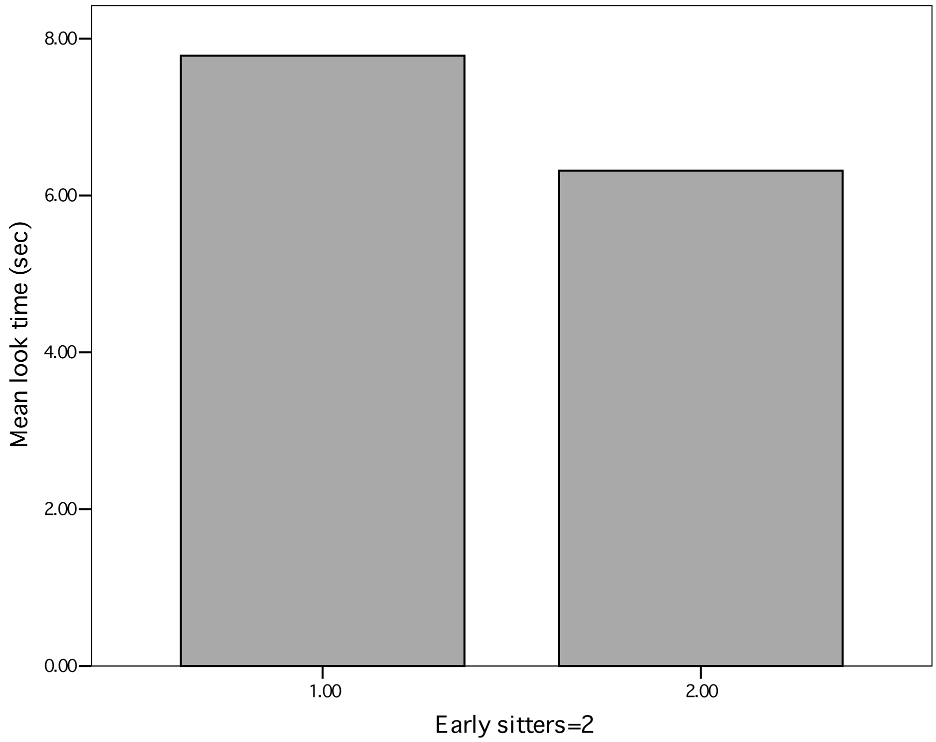

Figure 9. Infants who sat early (Stage 3 sitting at the age of 6 months) are group 2, and infants who were not yet independent sitters (Stage 2.5 sitting at the age of 6 months) are group 1. Compared on look time, the independent sitters have significantly shorter look times.

Hypothesis 1. E. Infants who show greater stability (by a lower Lyapunov Exponent in the anterior posterior direction) and greater regularity (by a lower Approximate Entropy value in the anterior posterior direction) have shorter look times than infants with less stability or regularity.

This hypothesis was generally supported by the data. For this analysis, the selection variable was the Lyapunov Exponent, dividing the looks at the median of the LyE values taken from each sitting stage into stable sitters and unstable sitters at each stage of sitting. Look times were analyzed in a one-way ANOVA for each stage of sitting, separately for the LyE and ApEn variables. Bonferroni adjustment for the 2 variables was alpha = 0.025.

Overall, in each stage of sitting, the infants with greater postural stability and regularity exhibited shorter look times. In Stage 1 sitting, significant differences were noted in ApEn in the anterior posterior direction ($F(3,178)=5.048$, $P=0.026$. In Stage 2 the comparisons did not reach significance, but there was a trend for shorter looks in the group with greater stability as indicated both by LyE and ApEn in both the anterior posterior and medial lateral directions. Significant differences were notable in Stage 3 sitting for LyE ($F(3, 225)=5.623$, $P=0.019$) and for ApEn in the medial-lateral direction ($F(3,225)=7.49$, $P=0.007$). ApEn in the anterior-posterior direction was close to significance ($F(3, 225)=4.566$, $P=0.034$). Infants with high stability and regularity scores, indicating greater postural control, were achieving shorter look times throughout the development of sitting (Figure 10).

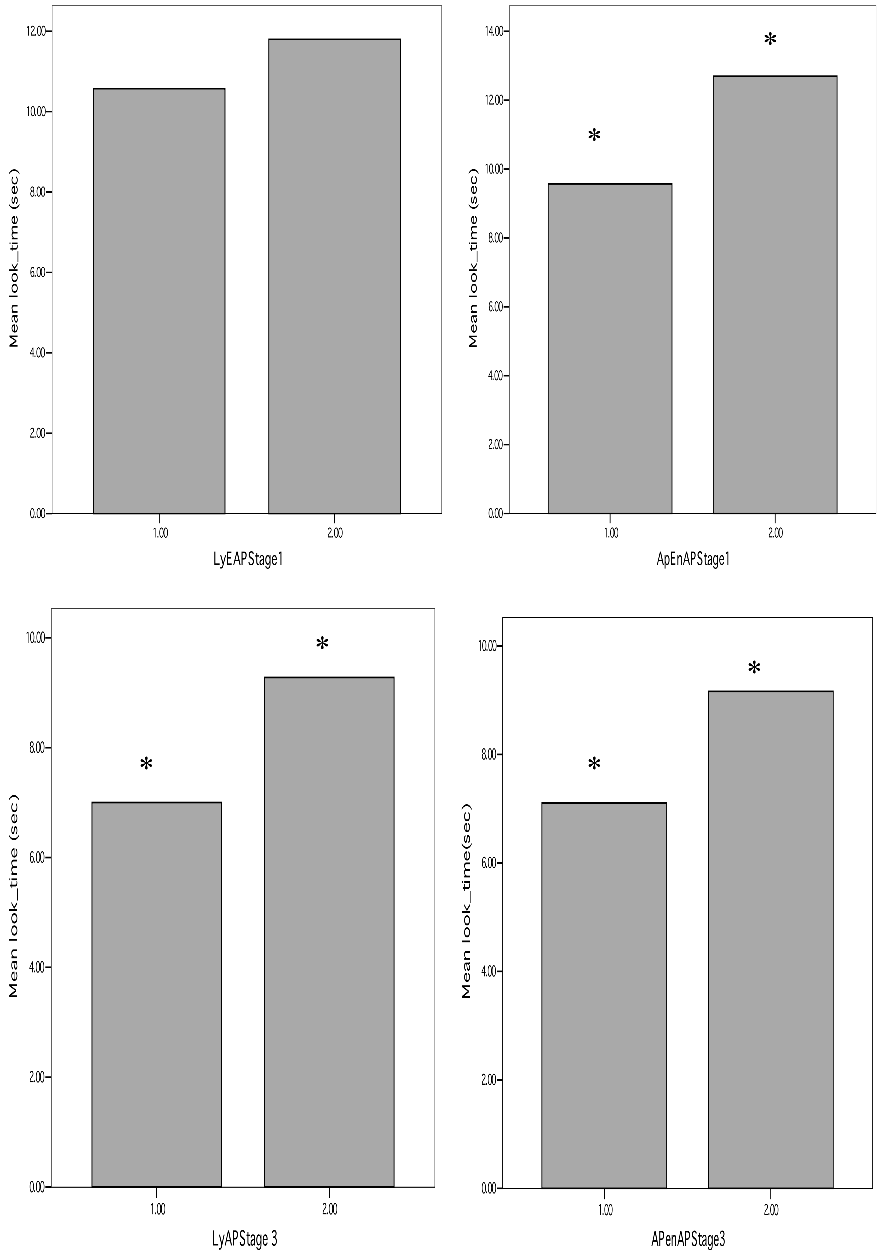

Figure 10. Top graphs depict Stage 1 sitting comparison of stable sitters (1.00) versus less stable sitters (2.00) on look time, with ApEn comparison showing significant difference between the two groups on look time. Bottom graphs depict Stage 3 comparison of stable sitters (1.00) versus less stable sitters (2.00) on look time, with both LyE and ApEn showing significant differences between groups. * indicates $P<0.05$.

Experiment 2

Hypothesis 2. A. Infants with motor delays show the same trend in look time as sitting develops as typically developing infants.

This hypothesis was supported. Infants with motor delays exhibit the same changes in look time as they develop the ability to sit, even though they are significantly older than the infants who are typically developing. However, infants with delays had overall longer look times than infants with typical development.

Using a Group by Stage analysis of variance, with repeated measures on Stage, there was a main effect of Group ($F(1, 42)=5.491$, $P=0.024$), with the infants with delays overall showing longer look times across all stages than the typical infants. There was no significant interaction effect. There was a significant main effect of Stage, with Tukey post hoc analysis revealing a significant difference between Stage 2 and Stage 3 ($F(1, 42)=12.732$, $P=0.001$). Unlike the typical infants, infants with delays showed an increase in mean look time from Stage 1 to Stage 2 of sitting, but then significantly decreased in Stage 3 (Figure 8).

Hypothesis 2. B. Infants with motor delays show the same trend in sitting stability variables as they learn to sit, and the trend is the same as that in look time.

A Group by Stage analysis of variance was used, with repeated measures on the Stage variable. Post-hoc pair-wise comparisons among the sitting stages were made using the Tukey method. To adjust for the analysis of multiple outcome measurements, a Bonferonni adjustment was used, alpha = 0.016.

For the LyE in the anterior posterior direction there was not a significant effect of Group. There was a significant main effect of Stage ($F(1, 42)=34.129$, $P=0.000$), with specific contrasts showing significant differences between Stage 1 and 2 ($F(1,42)=18.829$, $P=0.00$), and also between Stage 2 and 3 ($F(1,42)=20.218$, $P=0.00$), and between Stage 1 and 3 ($F(1,42)=34.129$, $P=.000$). There was not a significant interaction effect ($F(1,42)=4.673$, $P=0.036$). For ApEn in the anterior posterior direction, there was a significant main effect of Stage, but no interaction effect and no significant difference between groups. Stage 1 and 2 did not differ significantly ($F(1,42)=5.603$, $P=0.023$), but there was a significant difference between Stage 2 and 3 ($F(1,42)=13.871$, $P=0.001$), and between Stage 1 and 3 ($F(1,42)=18.815$, $P=.000$).See Figures 4 and 6 for a graphical depiction of the results for LyE and ApEn in the anterior posterior direction.

ApEn in the medial lateral direction showed no significant difference for Group and no interaction effect. There was a significant main effect for Stage, with specific contrast showing the significant difference between Stage 1 and 2 ($F(1, 42)=5.702$, $P=0.022$), and between Stage 1 and 3 ($F(1,42)=5.259$, $P=.009$). There were no significant findings for the LyE in the medial lateral direction ($F(1, 42)=.770$, $P=.466$) (Figure 5). See Figure 7 for a graphical comparison of the group by stage comparison for ApEn in the medial lateral direction.

Hypothesis 2. C. Change over time, from Stage 1 sitting to Stage 3 sitting is the same for look time in infants with motor delays as in typical infants.

The hypothesis was partially supported. Change scores for look time between stages were calculated, and the difference between Stage 1 and 2 was compared to the difference between Stage 2 and 3, in a 2 X 2 repeated measures, group by Stage score ANOVA. There was a significant difference of the change scores ($F(1,42)=6.318$, $P=0.016$), between groups. The infants with motor delays increased in look time between

Stages 1 and 2, giving them a negative value look time change, and the infants with typical development showed a slight decrease in look time, giving a positive value for look time change (Figure 11). However, both groups had positive change scores between Stages 2 and 3, indicating a decrease in look time during that interval.

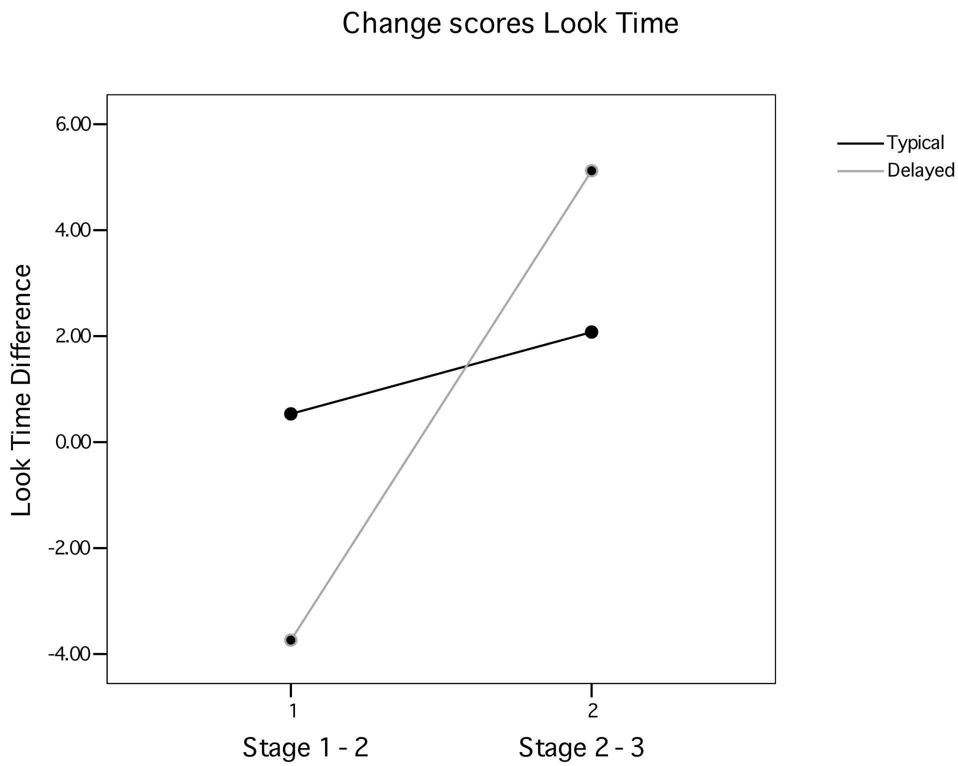

Figure 11. The dark line represents typically developing infants, and the gray line the infants with delays, showing change scores between sitting stages 1 & 2, and between sitting stages 2 & 3.

Experiment 3

Hypothesis 3: There is no significant difference in look time between the two conditions of supported sit and unsupported sit in infants who are not yet sitting independently.

This hypothesis was supported. Preliminary analysis showed that order of conditions did not affect look times; therefore, look times were compared between the two conditions (supported and unsupported) using a repeated measures ANOVA.

No significant differences were found between the conditions of supported sitting and sitting without assistance for the early sitter ($F(2, 5)=0.001$, $P=0.975$). Infants looked at novel objects for equal duration whether or not they had support regardless of which condition (supported or unsupported) occurred first. The effect size of the difference between the two conditions was very small (0.02) based on the data from 5 infants. Therefore, the originally planned10 infants would not have shown a significant difference between conditions, and data collection was stopped at 5 participants.

CHAPTER 4: DISCUSSION

The present study findings are summarized in the context of the literature in infant looking and cognition. Discussion of the findings from the present study is offered from three perspectives: contributions to the embodied mind theoretical model; implications for future studies needed to elucidate the structure and developing nature of cognition; and implications for intervention for children with developmental disorders. Limitations of the present study will also be discussed.

Summary of Results of the Present Study

The findings of the present study echo and support the body of research examining infant looking during early development, while also extending the understanding of infant looking to children with motor delays. This increased understanding allows translation of the findings to the clinic and early intervention realm, and may help to improve intervention for children with motor delays or disabilities.

Typical infants showed decreasing look time from Stage 1 to 2 to 3 of sitting, just as previous studies. However, the present study adds to the understanding of the infant looking phenomenon by explaining how postural control interacts with looking behavior. Sitting stability and regularity variables in the anterior posterior direction changed from early sitting to late sitting, reflecting an increase in stability. Infants who were already sitting at Stage 3 of sitting at 6 months of age had shorter look times than infants who were not yet sitting at 6 months of age. And at any stage of sitting, infants who had greater stability in the anterior posterior direction as measured by the nonlinear variables had shorter look times. Overall, look time was significantly correlated to stage of sitting, age, and sitting stability variables. The changes in look time that occurred over time could not be reproduced by simply mechanically supporting an infant who was learning to sit. Infants who had poor sitting balance displayed the same look times whether they were attempting to sit by themselves or sitting well supported in an infant seat. All of this evidence from the present study points toward postural control as being a control parameter for changes in look time during typical development. And, if look time can be taken as a proxy for information processing efficiency, the importance of addressing early postural control in infants who exhibit motor delays looms large for early interventionists.

In addition, the present study strengthens the evidence that infants with motor delays mirror the developmental changes in look time seen during typical development, but with complications arising from the interaction of the postural control system with the visual attention mechanism. Infants with motor delays reflected the same changes in the sitting stability and look time variables during sitting development as found in the typically developing infants. For infants with motor delays, look times were shorter at Stage 3 of sitting than at Stage 1 or 2. The progression of decreasing look time was slightly different from the typical infants, in that look time increased from Stage 1 to Stage 2, then decreased to the same level at Stage 3 as the typical infants. Nonlinear variables also changed as sitting progressed to reflect greater stability in the anterior posterior direction, just as in the typical infants.

The Embodied Mind

As presented in the introduction, there is strong evidence across cultures, types of stimuli, and environmental context that infant look times decrease markedly during the first year of life. The most consistent and pervasive decline in look time is within the time period of the 4th through the 8th month. Important milestones occur prior to this window, such as head control and rolling by the 4th month. Likewise, important milestones occur after this window, such as crawling by 8 months, pulling to stand at 9 months, and walking at 12 months. But the important milestone occurring around 6 months is sitting independence.

Simply put, the results of the present study indicate that as sitting emerges, look time decreases. This phenomenon is not due to maturation alone, because, as shown in the present study, children who are greatly delayed in motor skills experience the same decrease in look time as they learn to sit at an older age. Even when only typically developing children are considered, some children sit earlier than others. These "early sitting" children have shorter look times at 6 months than children who are not yet independent in sitting. Thus, sitting independence appears to be a control parameter that pushes visual attention to a new mode of operation. This is important because shorter look times indicate less time needed for information processing, and more opportunities to gather information from the environment. This ability to gather information quickly is described as "visual foraging" (Robertson et al, 2007).

Why does this relationship between sitting development and look time exist? Typically developing infants are offered many opportunities to experience verticality in the first few months of life as they are carried leaning on their parents shoulders, carried in infant seats, and positioned in equipment to occupy them for play. However, the timing of looks to objects and people begins to decrease from four months of age to eight months of age, a time of rapid motor development. During the first four months of life, the infant exhibits movements that have previously been considered random. In the embodiment hypothesis, Smith and Gasser (2005) suggest that these movements are not useless as the description random connotes, but rather are useful in the opportunities for infinite exploration of opportunities and strategies to seek information. As infants find workable and rewarding strategies within their random exploration of movement, they learn to control this movement to visually engage important aspects of their environment.

All infants in the present study started out in early sitting with values of the nonlinear variables closer to random organization, as opposed to periodic. One possibility is that increasing stability, as indicated by the nonlinear variables in the present study, allows the freeing of some degrees of freedom of the head and eyes to move quickly. Typical infants who showed greater stability in any stage of sitting were likely to have shorter look times. Less stable sitting may require a portion of the child's attention, so that processing visual information takes more time. As stability is attained, resources can be re-allocated to allow for faster visual information processing. Conversely, stability of sitting posture may allow disengagement of overt visual attention.

Robertson et al (2001) describes the coupling of overt visual attention to the change in rate of overall motor activity. They suggest that the intrinsic noise of sustained motor activity fluctuates in a just-right irregular way to facilitate shifts of gaze. They call upon the concept of chaos to describe this organization within movements that appear disorganized. From this perspective, the control parameter may not be postural control/stability per se, but rather learning to de-couple vision and movement quickly and with less effort so that information can be gathered efficiently. The principle of stochastic noise as a driver of central nervous system activity is key to this perspective. Data from studies examining looking and cyclical movement of infants in the first 3 months of life show that naturally occurring cycles of increased body movement tend to inhibit the looks of young infants (Robertson & Johnson, 2009). Movement and attention are thus coupled functionally so that general increases in movement cause vision to be more “interruptible”. This concept has implications for learning, memory, and overall cognitive processing. The ability to predict events in the world and the continuity of objects is dependent on the ability to visually attend to significant events and aspects of the environment (Bertenthal, Longo & Kenny, 2007). As infants learn optimal strategies to stabilize sitting posture, they also gain knowledge about how to interrupt visual attention and shift gaze between objects to learn the properties of objects and how objects and people interact. They also become more adept at acting on objects as sitting becomes controllable, and begin to initiate movement out of sitting to act on the world themselves.

The nonlinear variables used to examine sitting postural stability in the present study may give insight to the processes driving changes in look time and sitting control. Irregularity has been shown to be characteristic of immature organisms (Robertson et al, 2001). Using the Lyapunov exponent to examine generalized infant movement during the first few months of life, Robertson et al speculated that the early tendency toward randomness in infant movement might give rise to attentional shifts which might increase the efficiency of visual skill with which infants explore the world. Because irregular movement in infancy is pervasive in many species (Bacher et al, 2000), it is possible that understanding how changes occur over time in this shift from irregularity to regularity may help to understand the acquisition of skill during development. Perhaps the shift from irregular to regular in the present study is a driving force behind multiple systems including both postural control, and visual attention.

The problems encountered by infants with motor delay are varied. The question of why infants with delays would have longer look times, even though they follow the same overall trend of decreasing look time as sitting develops is difficult to answer with the current study. However, the present findings support previous research reporting longer look times or decreased ability to habituate to visual stimuli in infants at high risk for cognitive delays (Cohen, 1981). One underlying reason could be that the random, irregular movement seen early in life is absent in children with a motor delay. Without this irregular movement to interrupt vision, looks become less “interruptible” in children with poverty of movement or low movement variability. Brian et al (2003) also found longer look times for high-risk infants when using a looking habituation paradigm. They reported differences between children, with some responding in a linearly decreasing pattern and using shorter looks, and others with a nonlinear (increase then decrease) pattern and longer looks overall. The difference in look times in the present study may reflect the fact that some of the infants with delays have conditions, such as cerebral palsy or mental retardation, which have as inherent limitations a problem with information processing.

Implications for Intervention

There is a possibility that the reason infants with developmental delays showed similar changes in looking times across the development of sitting as typically developing infants is that the neurological maturation of these infants was delayed overall. However, there is no evidence in the literature that infants with prematurity or developmental delay have a delay in myelination (Candy et al, 1993), even though parts of the brain may have damage or malformation. Some of the infants in the delayed group were up to 2 months premature. Even considering this, the delayed group overall was delayed 200 days in sitting skill maturation, far more than 60 days. It seems unreasonable to assign the changes in looking time to just prematurity. It would also be unlikely that specific pre-programmed neuromaturation changes related to visual attention would coincide at the exact time of improvement in sitting postural control. Thus, it appears that the changes found in sitting stability in the present study may be responsible for changes in look time.

Early interventionists may take some implications for therapy from the findings in the present study. The fact that there was no difference in look times for typical infants whether or not they received support is important for occupational and physical therapists who treat children with motor delays. One of the most common interventions is to provide mechanical support in the sitting position to improve the attention and function of children who cannot sit. Many courses and written guidelines are available to instruct therapists in the proper way to “position” children in the seated posture for optimal function. The findings of the present study imply that static positioning in supported sitting is not an immediate solution for improving attention and information processing of a child. Although many children with disabilities may require additional seating support, therapists should not expect immediate results in function. A child will need time to incrementally learn to interact with the environment in order to fully utilize looking in a new position. Additionally, the active learning and movement adjustments required to control sitting may be key to acquiring skillful visual attending and information pick-up by adjusting looks appropriately.

Despite large investments in medical science directed toward the etiology and prevention of developmental disorders, the incidence of developmental disorders such as cerebral palsy and Down syndrome have not diminished over the past 30 years (Centers for Disease Control, 2008). Mandatory intervention for such disorders (IDEA) has shown some temporary effects on early childhood cognitive testing, but these effects disappear by school age (Orton et al, 2009). It is therefore of great importance that intervention be examined for the impact of each type of therapy on stimulating the best possible developmental outcome.

How can the present findings contribute to the above task? Certain times in development are likely critical for transitions in behavior or information processing. During these times, such as the appropriate time for learning to sit, intensive intervention may bring greater rewards than simply the acquisition of a motor skill. Skills such as sitting to encourage information gathering and visual foraging, and mobility for learning spatial skills, may pay larger dividends in the long run in terms of cognitive advancement.

Implications of the Findings to Future Research.

Further examination of the interaction of movement, postural control, looking behavior and information processing is necessary to truly apply the findings from typically developing infants to early intervention. Although there are continually new publications examining the skills of typical infants, the paradigms used to explore infant cognition are rarely employed to examine infants with special needs. Simple look time studies may provide more information about the information processing capabilities and changes in infants with delays after a period of intervention than standardized tests such as the Bayley Scale. Many standardized cognition scales for infants have not been found to be predictive or sensitive enough to show small increments of change to elucidate effects of short bouts of intervention.

Another strength of the present study was the longitudinal design. In order to understand changes over time for infants both typically developing and with special needs, it is necessary to have multiple measurement times for the same individuals. This allows an examination of the trajectory of developmental change, rather than just one-time differences. For example, the present study noted differences in the look times of infants with typical or atypical development, but also noted that changes over time were very similar. This allows translation to interventionists, who may assume that initial differences imply a static, unchanging trait of the individual, rather than a behavior that can be changed over time. Also, the initial rise of look time for the infants with motor delay might be interpreted as a sign that delay is increasing; but following in time beyond that increase shows eventual “catching up”. Examinations of infant behavior using longitudinal designs should be the focus of developmental questions because of the very nature of adaptation and change in information processing as the infant builds upon experience and follows a not necessarily linear course. By following the advancement of infants over time, improvements in understanding of the ontogeny of disability can be made. It is not enough to point out the differences between typically developing children and those with delays. Rather, taking the perspective of embodiment, investigations should determine how the skill is built incrementally, and how the building of a skill can stall or become inefficient when specific elements are not optimal.

The trajectory of look times over time for infants with motor delays differed from the trajectory for the typically developing infants in the present study. If this reflects problems in information processing when attention is split between a difficult motor act and cognitive effort, there are implications for the evaluation of infants in early intervention programs. If every new posture (sitting, standing) or motor milestone decreases ability to process information overall, intervention may need to take a different focus to keep a child from falling behind. Bouts of intensive intervention in motor skill may have greater payoffs in cognitive processing in the long run.

Limitations of the Study.

The use of archival data was a major limitation because the camera angle did not allow a consistent vantage point for time look duration. The camera viewed the infant from the side and the back, making any looks to the far side or out of the field of view of the side camera impossible to time. Because the original study had no aims related to looking, there was no attempt made to standardize the presentation of the viewed objects or to keep the field of view clear of distractions. Therefore, the number of looks per evaluation session was greatly reduced, and some infants could not be utilized at all. Another limitation of the study was the fact that look duration timing was stopped when the child lost balance and had to be caught by the examiner. Many times the infant continued to look at the selected object, but we terminated the timing because the child was being supported. Look time also could not be initiated when the therapist was touching the child, and the infant was often looking at the object prior to support being released.

Although the data was collected longitudinally, there was a rather long period of time between data collections, approximately one month. Thus, the linear representation of changes over time is unlikely to be a true reflection of the nonlinear changes typical of the growth of an individual. It may be that look time and stability variables fluctuate more than is represented in the present study, and therefore would be difficult to use as a reliable measure for developmental status on a one-time basis. However, because the values examined were taken longitudinally, rather than cross-sectionally, it is possibly a relatively good reflection of general developmental trends.

CHAPTER 5: CONCLUSIONS

The findings of the present study provide support for the theoretical framework of the embodied mind and expand the understanding of the use of looking as a measure of information processing in infancy. As a child becomes more stable when sitting postural control is developing, the ability to freely orient the head and eyes is enhanced. By virtue of the skill of orienting in a vertical posture, infants can look at objects in the environment and quickly scan for important information. Although the phenomenon of decreasing looking time as infants age during the first year of life has long been known, the interaction of look time and developing postural control has not been explored previously. The present study revealed that a decrease in look time, which indicates faster information processing, appears to be at least partially dependent on improvements in postural control. In particular, infants with motor delays have a disadvantage in developing the ability to select visual information quickly and switch visual attention from object to object to gather the most information possible from the environment. The mechanism for postural stability in infancy can thus be considered a control parameter for cognitive change during early development. Knowing the importance of interacting postural control and visual attention suggests early intervention to ameliorate sitting postural problems and encourage sitting independence, which may contribute to accelerations in learning about the world for infants with motor delays.

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Figure Captions