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Sitting and Looking: The Development of Stability and Visual Exploration

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Abstract

This longitudinal study focused on the interaction of developing sitting postural control with look time, which served as a measure for cognitive processing. Twenty-eight typically developing infants and 16 infants with motor delays were evaluated using center-of-pressure measures to assess stability of sitting postural control and videography to assess look time at objects, at three progressive stages of sitting development. Results indicated that look time decreased significantly in conjunction with a significant increase in postural stability in both groups as sitting progressed to independence. Infants with motor delays showed significantly longer looks when compared to typical infants at the middle stage of sitting. We conclude that developmental changes in look time are related to changes in sitting postural control, and infants with motor delay may have greater difficulty looking during emerging postural control skills in sitting. Early interventionists may use look time as an indicator of sitting effort and cognitive processing during assessment and program planning.

Keywords: Infants, look time, motor development, postural control, sitting

Introduction

In order to detect, extract and process information from the world, infants need to look efficiently and quickly at an object. “Look time” is simply the time a person looks at an object before they look away (Columbo, 2001). Developmentally, look time decreases between 3 and 8 months. Researchers postulate that look time decreases during infancy because the speed of cognitive information processing accelerates as the infant matures (Bornstein, 1998). Thus, look time serves as a proxy for cognitive processing (Bornstein & Ludemann, 1989), and is therefore a variable of interest in examining how infants understand the world around them. Early look time and visual attention appear to have a relatively strong link to later cognition, lending further evidence to the construct that look time reflects core information processing skill (Rose et al 1995, 2005). Visual habituation is the phenomenon of decreasing look time to repeated presentations of the same object (Bornstein, 1998). Look duration, and infant visual habituation at 4 months of age play a part in predicting intelligence scores in later childhood (Rose et al, 2005; Bornstein et al, 2006). Thus, short look times, or the ability to look and pick up information quickly in infancy, have an enduring effect on a child’s ability to process information within their environment.

Inherent in the tasks of spatial orienting and looking at object features is the motor skill of postural control. Neuromuscular control of the head, eyes, and trunk is necessary for the infant to gaze, scan, focus, and pick up information from the world (Bertenthal & von Hofsten, 1998). Previously, the postural control aspect of looking has been assumed as an innate factor (Columbo, 2001). In fact, postural control is “under construction” and changing rapidly in the first year, especially during the same time when look time is

decreasing. Motor abilities combine with other factors, such as alertness and information processing abilities to support visual attention to object features (see Figure 1). The coemergence of shortening look times and improvement in a stable sitting posture, and the coordination of the two, may be a critical factor for successful learning. However, the interaction of postural control and looking has not been investigated before. This study examines the interaction and coemergence of sitting postural control and look time.

The interaction of postural control in sitting and visual attention in infancy may be foundational for future cognitive development when viewed from the perspective of the embodiment hypothesis, also known as “grounded cognition” (Lobo, Harbourne, Dusing, & Westcott McCoy, 2013). The embodiment hypothesis states that thoughts, ideas, and problem-solving come from interactions of the body with the environment (Thelen, 2000), an idea supported by work in neuronal selectionism (Sporns & Edelman, 1993), adaptive behavior (Chiel & Beer, 1997), and cortical modeling (Alm´assy, Edelman, & Sporns, 1998). Grounded cognition is the concept in which “perceptual motor experience within environmental, social and cultural contexts actively builds, maintains and alters cognition” (Lobo et al., 2013, p. 95). In other words, cognition, or intelligence, is not an innate characteristic; rather, cognitive skill emerges in the context of the body’s iterative interactions with the world over time, which has been shown in developmental studies (Barsalou, 2010; Smith & Gasser, 2005; Soska, Adolph, & Johnson, 2010). Examples of the interaction of motor skill advancement with cognitive progression provide evidence for motor control/cognitive links that support the grounding of cognition in motor experience. Crawling (self-mobility) supports the emergence of cognitive processing related to object permanence (Campos et al., 2000; Kermoian & Campos, 1988).

Specifically, when infants with motor impairments were given mobility by means of an assistive device, they gained skill in the cognitive area of object permanence (Campos et al., 2000). Intervention to accelerate the attainment of locomotion in infants with typical development was related to higher cognitive scores (Lagerspatz, Nygard, & Strandvik, 1971). Conversely, preterm infants classified with abnormal postures in sitting (excessive neck, trunk, or arm hyperextension) scored lower in cognitive and problem solving skills than preterm infants who had normal posture in sitting (Wijnroks & van Veldhoven, 2003). Thus, research supports the idea that cognition and motor skills are developmentally linked, in support of the grounded cognition concept. However, a very early indicator of cognitive advancement or information processing, look time, has historically been studied without demanding postural control from infants during testing. There are no previous studies comparing unsupported infants and supported infants in look time measures, and only one study tested infants in both supine and supported sitting within a session, with no difference noted in look time between positions (Bornstein, Pecheux, & Lecuyer, 1988).

Sitting and Looking Development in Infancy

The development of sitting postural control in typical infants between 4 and 8 months has received extensive and detailed study. Instability and a lack of regularity in posture control characterize early attempts at maintaining an upright position in sitting. Over time, experience, practice, errors, and selection of successful strategies build the capability to sit stably (Harbourne, Giuliani, & Mac Neela, 1993). During the time when this gradually increasing postural control proceeds, the visual attention of the infant is

undergoing changes as well (Columbo, 2001; Courage, Reynolds, & Richards, 2006; Harbourne, 2009). It is well established that infants initially have a high variability of response to a perturbation in sitting (Hadders-Algra, Brogren, & Forsberg, 1996; Harbourne et al., 1993; Hirschfeld & Forsberg, 1994; Woollacott, Debu, & Mowatt, 1987). The high variability of muscle response reduces over time to selective and appropriate reactions when sitting stability is challenged. However, these studies include an external perturbation to the child; this does not tell us what the child does in a continuous, ongoing way to stay oriented to the world. Measuring the continuous control of posture requires an alteration of the experimental paradigm. Thus, center of pressure (COP) data from the base of support have been used to examine the development of early postural control in sitting, allowing examination of the spontaneous and unconstrained movements of infants (Deffeyes, Harbourne, Kyvelidou, Stuberg, & Stergiou, 2009; Harbourne & Stergiou, 2003; Harbourne, Willett, Kyvelidou, Deffeyes, & Stergiou, 2010). This paradigm allows the measurement of the continuous and dynamic process of postural control using nonlinear analysis techniques. Sitting stability during development can thus be quantified with force plate data to measure ongoing shifts in the COP (Harbourne & Stergiou, 2009). Between 4 and 8 months of age, infants with typical development exhibit changes in stability and regularity of the COP during sitting attempts (Harbourne & Stergiou, 2003). Stability of sitting posture increases as an infant learns to sit independently, and the regularity of shifts in the COP increases when infants achieve full independence in sitting (Harbourne et al., 2010). These postural characteristics have also been used to distinguish typical from atypical development (Deffeyes et al., 2009).

Look time can be explained as the amount of time an infant takes to extract and

process information from a visual stimulus. Very young infants have long look times and take a relatively long time to habituate, or begin to look away from a familiar visual stimulus (Bornstein, 1998). As infants mature, look time decreases (Bornstein et al., 1988). Basically, older infants require less time than younger infants to extract information from a repeated, constant, or non-novel stimulus, a finding that is robust using different methodologies (Courage et al., 2006).

Variations on the look time procedure include using pictures of faces, moving targets, real objects, and colored targets to examine differences in looking. All of these variations yield the same result: a robust developmental change from long looking times at younger ages (3 months old) to short looking times as infants age (8 months old) (Courage et al., 2006). Across cultures (Bornstein & Ludemann, 1989) and environments (Bornstein, 1985; Tamis-LeMonda & Bornstein, 1989), the tendency for look times to decrease between 4 and 7 months of age is consistent. Testing of infants at risk of cognitive delays reveals longer look times, supporting the interpretation of look duration as a reflection of information processing efficiency (Cohen, 1981). In all of these studies, infants were tested in supported sitting. We were interested in the look time progression of infants when they did not receive support while learning to sit.

The overall goal of this longitudinal study was to examine the relationship between the development of sitting postural control and look time. One group of infants was typically developing and between 4 and 8 months of age; a second group consisted of infants with motor delays and 12–18 months of age. All the children were followed throughout the time of sitting development from beginning prop sitting to mature independent sitting. Variables representing stability and regularity of sitting postural

control were compared over time along with the look time variable, to determine if significant changes occur concurrently in sitting and looking over time. We hypothesized that postural stability would increase over time and that look time would decrease incrementally as posture becomes more stable. The importance of shorter look times lies in their representation of less time needed for information processing and more opportunities to gather information from the environment. By testing infants with motor delay, we expected to rule out the effect of neuromaturation as the cause of the changes seen in both sitting and look time.

The present study

The overall goal of the present study was to test the embodiment perspective by examining the relationship between the development of sitting postural control and look time. Two experiments were conducted. Experiment 1 utilized archival data and was longitudinal in design. This first experiment documented the sitting and looking skills of two groups of infants. One group of infants was typically developing and between 4 to 7 months of age; a second group consisted of infants with motor delays between 1 and 2 years of age. All the children were followed throughout the time of sitting development from beginning prop sitting to mature independent sitting. 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. We hypothesized that postural stability increases over time, and that look time decreases incrementally as posture becomes more stable. By testing infants with motor delay we expected to rule out the effect of neuromaturation driving the changes seen in both sitting and look time. Experiment 2 focused on typically developing infants who were just

beginning to sit. This experiment examined the effect of mechanical stability in upright as being the driving influence on look time. Following the embodiment hypothesis, we hypothesized that a reduction in look time during supported sitting would not occur immediately when sitting was externally stabilized.

Experiment 1

Methods

Experiment 1 utilized archival data of typically developing infants and infants with motor delays from a previous study (Harbourne et al, 2010).

Participants. Archival data on 28 infants with typical development and 16 infants with motor delays were analyzed in this study. The infants participated in a clinical trial comparing two methods of early intervention to improve sitting postural control (Harbourne et al., 2010). The clinical trial was approved by the University of Nebraska Medical Center Institutional Review Board. All parents of participating infants gave written informed consent. Infants were recruited for the clinical trial when they could prop sit for 30 s, categorized as Stage 1 sitting (Deffeyes et al., 2009; Harbourne et al., 2010). Infants with typical development were recruited from employee announcements at the University of Nebraska Medical Center and the University of Nebraska at Omaha campuses and word of mouth. Infants with delays were recruited from the early intervention programs of the surrounding communities.

Inclusion criteria for the infants with typical development were as follows: (a) 5 months of age (+/- 1 month) at the time of initial data collection, (b) a score within 0.5 *SD* (standard deviation) of the mean on the Peabody Gross Motor Scale II (Folio

& Fewell, 2000), and (c) sitting skills as described for Stage 1 sitting. Exclusion criteria were a diagnosed visual or musculoskeletal impairment.

Inclusion criteria for the infants with motor delays were as follows: (a) 6–24 months of age, (b) a score greater than -1.5 *SD* below the mean for corrected age on the Peabody Gross Motor Scale II, and (c) Stage 1 sitting skills. Exclusion criteria were a diagnosed visual impairment or a diagnosed hip dislocation or subluxation greater than 50%.

Data from infants in the clinical trial (Harbourne et al., 2010) who progressed to Stage 3 sitting were selected for analysis in this study. The mean age that infants with typical development and infants with motor delays achieved at each stage of sitting is presented in Table 1. Of the 16 infants, 7 had a history of prematurity, 5 had a diagnosis of mild cerebral palsy, 1 had a diagnosis of Noonan's syndrome, 1 had a traumatic brain injury at 1 month of age, and 9 had no diagnosis other than delayed development. The infants with motor delays received intervention to advance sitting skill as part of the clinical trial comparing two methods of early intervention (Harbourne et al., 2010). The infants with motor delays were receiving physical therapy, occupational therapy, and special education services. Per the usual standard of care in early intervention, age appropriate toys, social interaction, and environmental supports were all engaged to advance sitting postural control.

Table 1.

Mean Age and Standard Deviation (in parentheses) 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)

Procedures.

Data were collected at each of three progressive stages of sitting, defined in Table 1 (Harbourne & Stergiou, 2003). Sitting Stages 1, 2, and 3 reflect increasing control and independence in sitting and have been used in previous research (Harbourne & Stergiou, 2003; Harbourne et al., 1993). All sitting stages were coded by the primary investigator. Data were collected longitudinally over 4 months and each child exhibited all three stages of sitting over that time period. The timing of each lab visit was determined either by phone calls to the parent to monitor sitting skill or visits for the children with motor delays.

For all data collection sessions, infants were allowed time to get used to the laboratory setting and were at their parents 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 in the infant (Brazelton, 1984).

Infants were undressed for data collection.

COP analysis in sitting was performed using a force platform, which was embedded in the floor of the lab. The infant was held in the sitting position in the middle of the plate. 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 infant was held at the trunk for support and gradually guided into a sitting position. Once the examiner released support, data were collected for 10 s or longer while the infant attempted to maintain sitting postural control. Infants who were able to sit without support for an extended time were left alone and data were collected continuously for up to 3 min.

Three trials that met the criteria for our sitting posture variables were completed, as tolerated by the infant. During the sitting trials, single toys, chosen because they were found to be of interest to young infants, were presented to encourage the infant to remain sitting still and looking forward but not reaching for the toy. This is because we were interested in only the sitting behavior, not sitting and reaching. Following the procedure to measure look time (Bornstein et al., 1988), toys were presented at a standard distance (4 inches beyond the arm's length of the child) and within a circumscribed space (within 12 inches of the floor surface and at the center of the child's body axis).

Instrumentation.

Data were collected at the Munroe-Meyer Institute for Genetics and Rehabilitation Motion Analysis Laboratory at the University of Nebraska Medical Center by using a 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 subfloor concrete slab to prevent vibration interference. Data acquisition and processing was

controlled through Vicon software. Component forces (F_x , F_y , F_z) and moments (M_x , M_y , M_z) were each sampled at 240 Hz and were amplified using an AMTI mode IMCA6 Amplifier. Calculation of 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 240 Hz. Data were exported in ASCII (American Standard Code for Information Interchange) format, which was used for nonlinear analysis. Video of each trial was collected using two Panasonic video cameras (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 (see Figure 2). Video and force plate data were synchronized within the Vicon data collection software.

Variables Measured:

Sitting Stability

Segments of trials were selected based on the following criteria: infant was not crying or vocalizing or flapping/waving/reaching with arms or legs, infant was not in the process of falling, and infant was not leaning further than 45 degrees in any direction. The selected segments were all 8.3 s long, the shortest time allowable for the nonlinear analysis based on our sampling rate (Harbourne, Deffeyes, Kyvelidou, & Stergiou, 2009; Kyvelidou, Harbourne, Shostrom, & Stergiou, 2010). This time window allowed for a time series of approximately 2,000 points for each segment, which is necessary for

nonlinear analysis. Details on the calculations of the nonlinear variables can be found in Harbourne et al. (2009). The COP time series from the first three segments meeting our selection criteria were chosen from each session and may have been consecutive if the infant sat long enough. Subject means were generated by averaging the three selected segments from each session. The following nonlinear variables were analyzed.

Lyapunov Exponent (LyE).

In the present study, as in our previous articles, we define stability using the variable Lyapunov exponent (LyE) (Deffeyes et al., 2009; Harbourne & Stergiou, 2003). The LyE is a nonlinear measure that can characterize the temporal structure of variability in a time series, in this case COP data (Stergiou, Harbourne, & Cavanaugh, 2006). The LyE measures the divergence of the data trajectories in phase space. Lower LyE values indicate greater stability in sitting postural control. Values for the LyE range from 0 for completely periodic data to 2 for random data. The LyE value describing purely sinusoidal data with no divergence in the data trajectories is 0 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. LyE values for both anterior–posterior (forward–backward) and medial–lateral (side-to-side) directions were used.

Approximate Entropy (ApEn).

Approximate entropy (ApEn) is a nonlinear measure used to quantify regularity, which is related to stability (Pincus, 1991). Regularity is defined as the repeatability of a signal over time; lower values indicate greater regularity (Dusing&Harbourne, 2010;

Harbourne & Stergiou, 2009). ApEn values for both anterior–posterior and medial–lateral directions were calculated.

Look time.

The video segments from the first 5 min of data collection were used to measure look time. The segments included the intervals used to measure sitting stability. Look time, however, often exceeded the length of time that sitting stability was measured. We used the criteria for measurement of look time by Bornstein et al. (1988). A look was defined as the length of time the infant fixed vision on an object without shifting the gaze. Once an infant looked at an object for at least .5 s, the look was acceptable and the .5 s was included in the look time. Look time ended when the infant looked away from the object for at least 1.5 s or fell. An infant's mean look time was the average of all look times within each stage of sitting. The type of stimulus used to encourage looking was recorded. The four objects used to encourage infants to look are described in the next section.

Inter-Rater 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. There were four outlier look times in the group that were over three standard deviations from the mean. These were excluded from the analysis.

Comparison over time

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 sitting stages were coded by the primary investigator. Data was collected longitudinally over four months and each child exhibited all three stages of sitting over that time period.

Statistical Analysis

We tested for main effects of group and sitting stage using a general linear model (GLM) repeated-measures procedure for each dependent variable with group (typical, and delayed motor groups) as the between subject variable and time (from sitting stages 1, 2 and 3) as the within-subjects variable. Significant interactions were followed by post-hoc analysis using Fisher's Least Significant Difference (LSD) approach and planned paired contrasts between groups for each sitting stage.

In addition, the typically developing infants were examined using an age-held-constant design. These infants were split into those who were early independent sitters at six months, and those who were not yet sitting, and look times compared between groups. Two infants were excluded from this analysis because they only had two viable looks at

this age, which was considered an unlikely representation of their skill. All other infants had from 4 to 12 looks, which were averaged for their look time value. Look times were compared between groups using a Student's T-test. Pearson correlations were also performed between the nonlinear measures, look times, and sitting stage at the 6 month age session.

Results for Experiments 1

Nonlinear Measures

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 ($F(1,42)=34.13$, $P<0.00$), as did ApEn ($F(1,42)=18.82$, $P<0.00$). The groups did not differ significantly overall as they changed over time ($F(1,42)=1.58$, $P=0.22$) (Figures 2 and 3, respectively). However, paired comparisons at each sitting stage revealed a significant difference at stage 1 of sitting both in the LyE variable ($F(1,42)=8.67$, $P=0.01$) and in the ApEn variable ($F(1,42)=4.78$, $P=0.03$) but not for stages 2 and 3. There were no significant findings for these measures in the medial lateral direction across time.

Look time

The hypothesis that look time decreases significantly as sitting progresses from Stage 1 to Stage 3 was supported. This comparison included the mean for look time for each child at each stage of sitting. Using a Group by Stage analysis of variance, with repeated measures on Stage, there was a main effect of Group ($F(1,42)=5.49$, $P=0.02$),

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 a Tukey post hoc analysis revealing a significant difference between Stage 2 and Stage 3 ($F(1,42)=12.73, P<0.00$). 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 4). Paired comparisons between groups at each stage of sitting indicated a significant difference between groups only at stage 2 of sitting ($F(1,42)=6.19, P=0.02$).

Sitting and Looking

Using an age-held-constant method for the typical infants, we separated early sitters at 6 months of age from infants of the same age who did not yet sit independently. The early sitters were in Stage 3 sitting at the age of 6 months, and the late sitters were at the transitional stage of sitting (stage 2) at the age of 6 months. Look times from early sitters and late sitters at 6 months were compared between these 2 groups using a Student T-test. Look times from infants who sat early, within the 6th month, were significantly shorter than look times from infants at the same age who were not yet sitting independently (Figure 5). Thus, look times from infants who were at stage 3 of sitting at 6 months of age were significantly shorter ($T(2,24)=2.37, P=0.03$) than look times from infants who were still losing balance and occasionally falling at the same age (stage 2). Therefore, when age was held constant, infants who had greater postural control in sitting were looking at objects with shorter look times.

For typical infants in the transitional stage between prop sitting and sitting upright, greater regularity in sitting posture control as indicated by ApEn values of the

COP partially explained shorter looking times. There was a significant correlation between look time and ApEn in both the anterior/posterior and medial/lateral directions ($r=0.50$ and 0.47 respectively, $P=0.05$). Linear regression indicated that 30% of the variance in looking times was explained by ApEn scores, with the longer look times being produced by the children with a less regular postural sway ($F=4.89$, $P=0.02$; $r^2=0.30$).

Overall Discussion

Our results support our hypotheses that postural stability in sitting increases over time and look time decreases as sitting stability increases, thus relating stable postural control to changes in look time. If look time can be taken as a measure for information processing efficiency, our results support the importance of addressing early postural control in infants with motor delays.

All infants in our study started in early sitting (Stage 1) with values of the nonlinear variables closer to random organization, as opposed to periodic, and all moved toward greater stability over time. Increasing stability, as indicated by the nonlinear variables, may allow the freeing of some resources to engage the head and eyes to move quickly. The greater regularity and stability of the infants with motor delays in Stage 1 sitting when compared to the infants with typical development should not be interpreted as advanced. On the contrary, early irregularity and instability is optimal for exploration and the discovery of strategies prior to selection of a successful strategy (Dusing & Harbourne, 2010; Harbourne et al., 1993). However, in this sample, both groups of infants advanced to sitting independently with greater stability at Stage 3 sitting.

Our findings strengthen the evidence that infants with motor delays mirror the changes in look time seen in infants with typical development but with complications arising from the interaction of the postural control system with the visual attention mechanism. Infants with motor delays exhibited a nonlinear progression of look time as sitting developed, with an increase in look time from Stage 1 to Stage 2, then a decrease in look time to the same level as the infants with typical development at Stage 3 sitting. Our impression is that the increase in look time at Stage 2 for infants with motor delays was due to the increased demands of sitting without arm support. The new and challenging postural task of sitting independently took attentional resources, such that the infants needed longer looks to process information.

Our results indicate that as sitting emerges, look time decreases regardless of the age at which sitting postural control is attained. Among 6-month-old infants with typical development, those at Stage 3 sitting had shorter look times than infants at Stage 2. Thus, sitting independence may support the ability to look at an object and pick up information quickly. This is important because shorter look times indicate that less time needed for information processing and more opportunities to gather information from the environment. Greater regularity of postural control, as seen in these early sitters at 6 months of age, may allow attention to shift from controlling posture to visual information processing. Faster information processing means the infant does not need to look as long. Thus, as stability is attained, cognitive resources may be reallocated to allow for faster visual information 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. Infants also become more adept at acting on objects as sitting becomes controllable and begin to initiate movement out of sitting to explore the environment (Goldfield, 1989).

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 from our results. However, our findings support previous research reporting longer look times or decreased ability to habituate to visual stimuli in infants at high risk of cognitive delays (Cohen, 1981). Brian, Landry, Szatmari, Nicchols, and Bryson (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 of infants in our study may reflect the fact that some of the infants with motor delays have a comorbid condition, such as a cognitive impairment that limits information processing.

There were several limitations in this study. We did not track other activities of the infants, such as the amount of toy exposure, or play activities, which could have influenced look time. Intervention for the infants with motor delays could also have influenced look time. Look time and sit time did not coincide for every trial because our methods for sitting COP analysis required a fixed length of time of 8.3 s, and the look times often exceeded that number. We could not separate the infants with delays into the

two intervention groups from the previous study because of the small number of participants, and thus we cannot discern confounding influences of intervention on sitting and look time between groups (Harbourne et al., 2010).

Conclusions

Our findings suggest that look time may be useful in examining the convergence of an emerging motor skill with developing cognitive skill. Although the phenomenon of decreasing looking time during the first year of life has long been known, the interaction of look time and developing postural control has not been explored previously. Our findings suggest a possible interaction between look time as a measure of information processing and developing sitting postural control. In particular, infants with motor delays may have a disadvantage in developing the ability to select visual information quickly while learning to sit. The suggestion that postural stability may be a factor that interacts with cognitive change during early development can contribute to new ideas in early infant assessment and intervention. Knowing the importance of interacting postural control and visual attention supports early intervention to advance sitting postural control, which may contribute to an acceleration of learning about the world for infants with motor delays. Look time may be a useful measure to examine the effects of intervention that targets early postural control. Therapists may consider measuring look time to familiar objects with an expectation that look time should decrease as the infant becomes more stable in an emerging posture. Changes in look time could also be useful as an indicator of advancing information processing, if examined over time and in a structured situation. Physical and occupational therapists should be mindful that early learning

during sitting development may require increased time for visual information processing, which may need to be a consideration in creating intervention programs.

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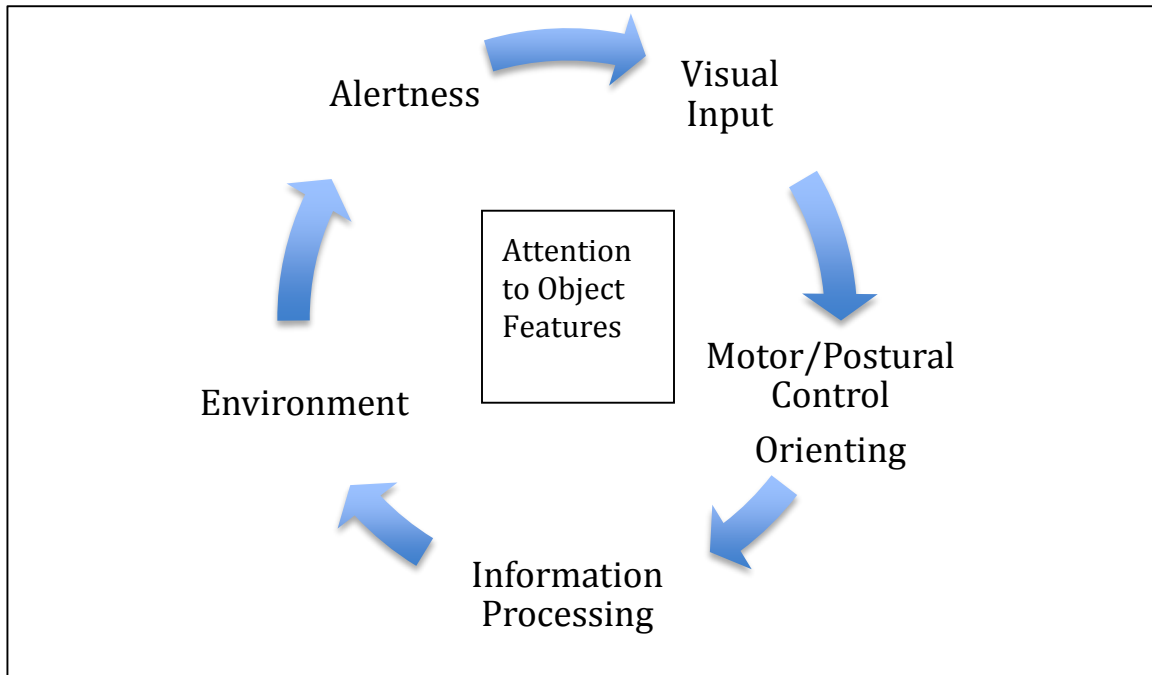


Figure 1. Conceptual framework for the development of looking and attention in infancy as motor skills develop. Adapted from Columbo, 2001.

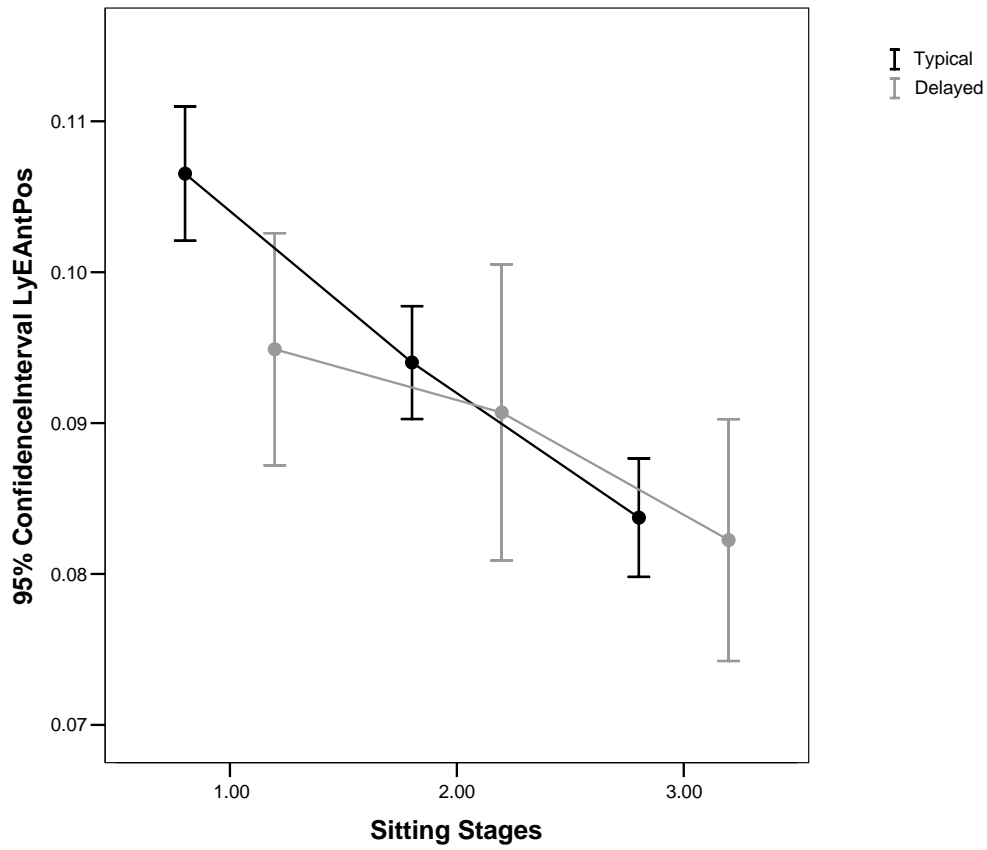


Figure 2. The dark line represents the group mean values over three stages of sitting for infants developing typically, and the light line represents the same group mean for infants with delayed development for the Lyapunov Exponent, in the anterior-posterior direction. Vertical lines represent 95% confidence intervals for each group at each stage of sitting.

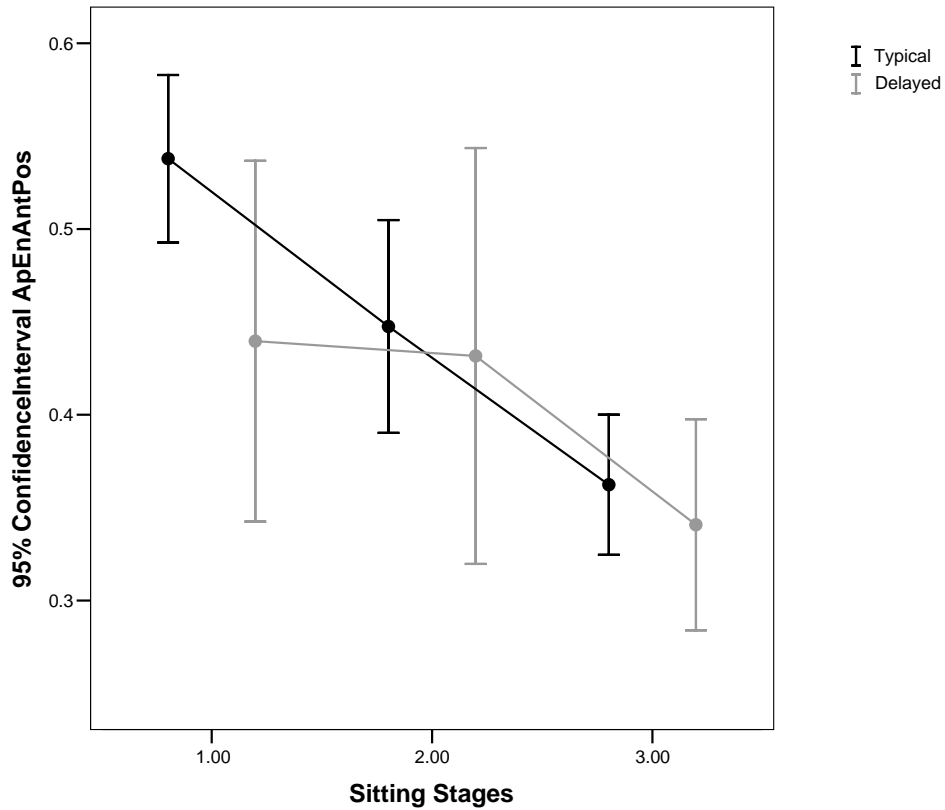


Figure 3. The dark line represents the group mean values over three stages of sitting for infants developing typically and the light line represents the group mean for infants with delayed development for the Approximate Entropy in the anterior-posterior direction. Vertical lines represent 95% confidence intervals for each group in each stage of sitting.

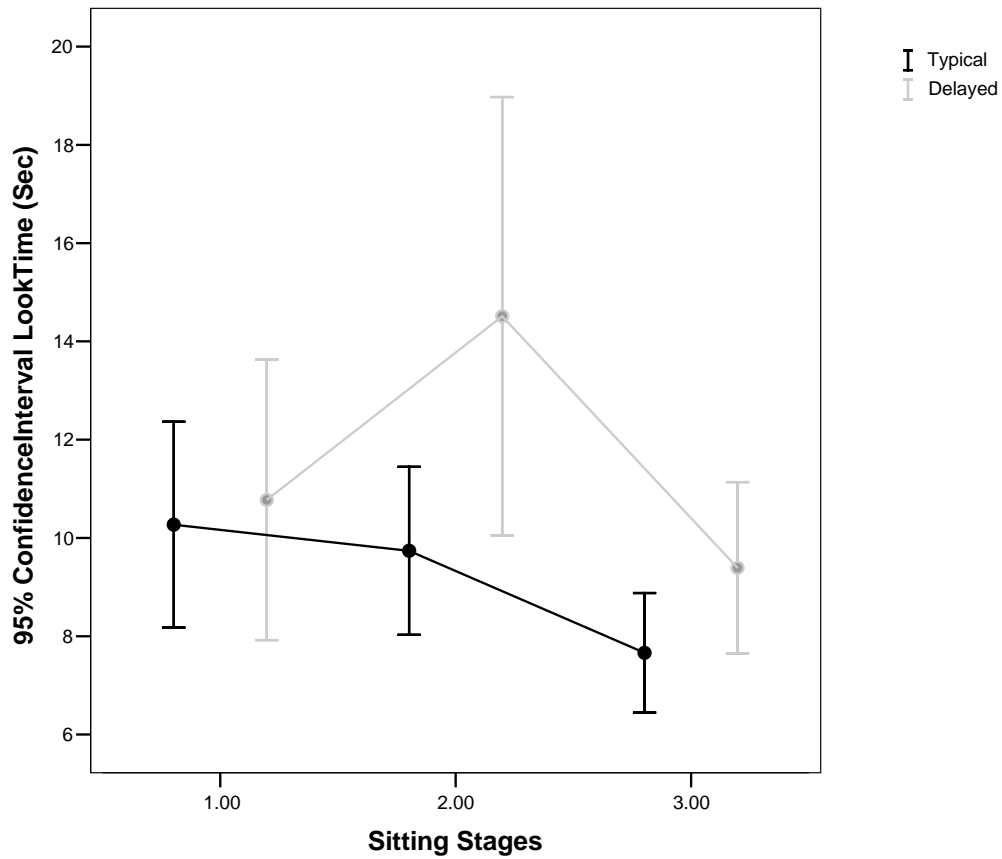


Figure 4. The dark line represents the group mean values over three stages of sitting for infants developing typically, and the light line represents the group mean for infants with delayed development for the look time variable. Vertical bars represent 95% confidence intervals for the groups at each sitting stage.

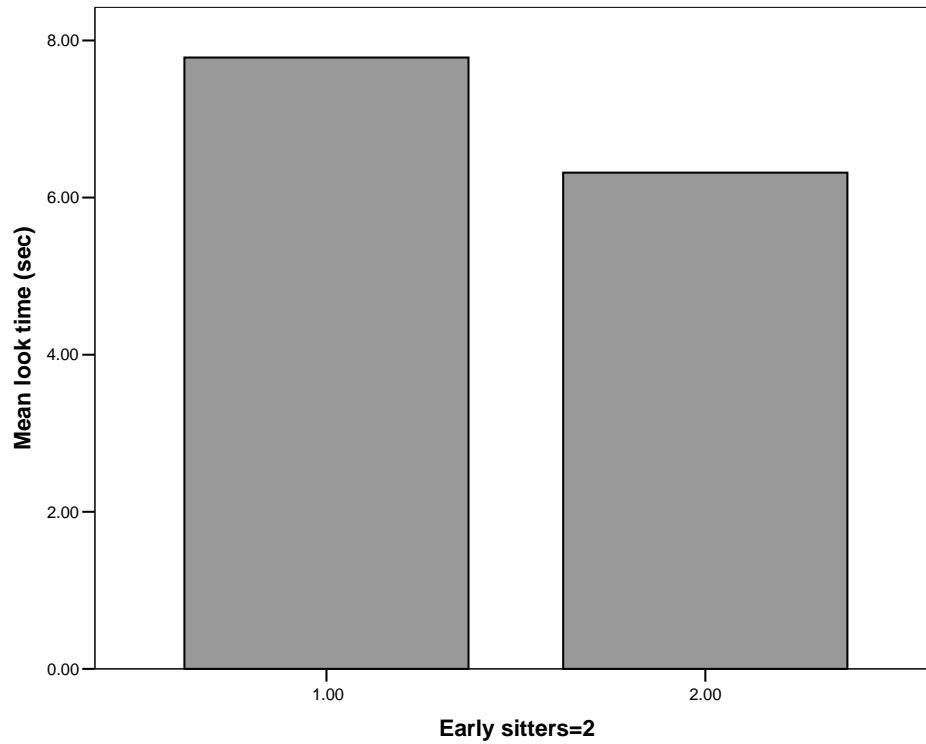


Figure 5. Infants who sat early (Stage 3 sitting at the age of 6 months) are group 2, and infants who were not yet independent sitters (Stage 2.5 sitting at the age of 6 months) are group 1. Compared on look time, the independent sitters have significantly shorter look times.