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Self-Sitting and Reaching in 5- to 8-Month-Old Infants: The Impact of Posture and Its Development on Early Eye-Hand Coordination

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ABSTRACT. The relation between progress in the control of posture (i.e., the achievement of self-sitting posture) and the developmental transition from two-handed to one-handed engagement in infant reaching was investigated. Two groups of 5- to 8-month-old infants, who were either able or yet unable to sit on their own, were videotaped while they reached for objects in four different posture conditions that provided varying amounts of body support. Videotapes of infant reaches were microanalyzed to determine the relative engagement of both hands during reaches. Results demonstrate the interaction between postural development and the morphology of infant reaching. Nonsitting infants displayed symmetrical and synergistic engagement of both arms and hands while reaching in all but the seated posture condition. Sitting infants, by contrast, showed asymmetrical and lateralized (one-handed) reaches in all posture conditions. Results also show that, aside from posture, the perceived spatial arrangement of the object display is a determinant of infant reaching. Combined, these results are discussed as evidence for the interaction between postural and perceptual development in the control of early eye-hand coordination.

Key words: development, infancy, posture, reaching

Progress in the control of body posture is a major achievement of early development. As infants learn to sit, crawl, stand, and eventually walk, they discover new balances and postures that both use and compensate for gravitational forces. This progress has far-reaching consequences for later motor, sensorimotor, perceptual, and cognitive development (Gesell, 1940). With growing control over posture, infants free themselves from reliance on external body supports, opening up new possibilities for action and exploration.

From the onset of development, posture is an important determinant of action. Bullinger and Jouen (1983) report that peripheral detection of a moving target by newborns and young infants varies according to the alignment of the head in relation to the trunk, at the onset of target presentation. Study of early oral activity indicates that the rate of nonnutritive sucking changes significantly in relation to the baby's centered, left, or right head posture (Bullinger & Rochat, 1984).

Further observations demonstrate the importance of postural support and control in the development of early action. Fentress (1981), for example, reported that when mouse puppies are provided with postural support, they exhibit precocious forelimb behaviors that are components of adult grooming activities. Thelen and Fisher (1982) showed that newborn stepping can be restored in 1- and 3-month-old infants by submerging their legs in water, a condition that simultaneously compensates for their low muscle-to-fat ratio and diminishes the effects of gravity. Gustafson (1984), studying prelocomotive infants placed in a "baby walker" device, found that the postural support and mobility provided by the walker was associated with a spontaneous reorganization and apparent maturation of exploratory patterns.

In a series of clinical observations made by Amiel-Tison (1985) and Grenier (1980; 1981), neonates showed striking sensorimotor aptitudes when experimentally provided with postural support remedying their "neck impotence." Grenier was reportedly able to elicit reaching patterns toward an object lying on a table by holding the neonate's head firmly along the axis of its trunk. According to Grenier, the apparent sensorimotor clumsiness and obligatory responses of the neonate are linked to poor neck control.

Although findings suggest that the manifestations of early behavior depend heavily on postural support and control, the relation between developing control of posture and

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developing functional action in infancy remains remarkably underinvestigated. Researchers investigating early eye–hand coordination have commonly limited their analysis to the reaching behaviors of infants confined to a well-supported sitting posture. Reports of precocious perceptual–motor capacities have been predicated on adequate external body support provided to the young infant by the experimenter (usually in the form of an adjustable infant seat that compensates for lack of head/neck control, see Bower, 1989, for discussion). Indeed, the effect of postural control on perception and action is an issue that has received little attention from students of infancy.

Clearly, the question of how posture and action interact in development is of profound importance. Without studies on the relation between postural and action development in infancy, views on the construction of movement and its control remain incomplete.

The present research was designed to broaden existing studies on early eye-hand coordination. Its focus is on (a) the impact of posture on early reaching, (b) the relation between infant reaching and self-sitting ability, and (c) consideration of infant reaching as an overall bodily engagement, including potential coordination of both arms and hands toward an object target.

Existing developmental studies focusing on the emergence of eye–hand coordination report that at around 2–3 months infants start clasping their hands at midline in an attempt to touch an object they see (Bruner & Koslowski, 1972; White, Castle, & Held, 1964). Most studies, however, reduce infant reaching to a one-handed action toward an object-target (see Fetters & Todd, 1987; Hofsten & Fazel-Zandy, 1984; Hofsten & Lindhagen, 1979; Hofsten & Spelke, 1985; Lockman, Ashmead, & Bushnell, 1984; Yonas & Grandrud, 1985), although infants are two-handed by constitution and show a precocious inclination for two-handed reaching (Rochat, 1989; Rochat & Senders, 1991. Indeed, the development of eye–hand and hand–mouth coordination in 2- to 6-month-old infants suggests a developmental precedence of bimanual synergism over lateralized, one-handed engagement. Observations suggest that from around 2 months of age, when infants reach for an object or bring an object to the mouth, they do so by using both hands, and only later do they develop a one-handed reach (Rochat, in press; Rochat & Senders, 1991).

The present study explores the relation between progress in the control of posture, in particular the achievement of self-sitting posture, and the developmental transition from two-handed to one-handed engagement in infant reaching.

Two groups of 5- to 8-month-old infants, either able or yet unable to sit on their own, were recorded while they reached for objects, in four different posture conditions providing varying amounts of body support. Videotapes of infant reaches were microanalyzed to determine the relative engagement of both hands during reaches (alignment of, and distance between hands).

The general hypothesis guiding this research was that the relative coordination between hands in infant reaching depends on both the developing ability of the infant to maintain self-sitting and the amount of external body support provided to the infant while reaching.

Method

Subjects

Thirty-two infants were divided into two groups according to their ability or inability to maintain a sitting posture. Fourteen "sitters," aged between 6–8 months (9 boys and 5 girls, ranging in age from 28 to 38 weeks, with a mean age of 33.5 weeks), and 18 "nonsitters," aged between 5–6 months (7 boys and 11 girls, ranging in age from 22 to 26 weeks, with a mean age of 24.6 weeks), were tested.

Eleven additional infants were tested but not included in the final sample because of poor state ($n = 6$) or failure to reach for the object displays ($n = 5$).

Group attribution (nonsitters and sitters) was based on a videotaped pretest examination during which each infant was placed in a sitting posture on a thin blanket. Infants able to maintain a self-sitting posture with hands above the ground for at least 30 s were qualified as sitters; those who could not, as nonsitters. Group attribution was systematically confirmed by the infant's parent(s) in a subsequent interview.

All tested infants were healthy on the day of testing, and parents reported a normal course of development following a term birth. Infants were recruited from published birth records in the Springfield, Massachusetts area.

Object Displays

During their first semester, infants manifest greater bimanual engagement when presented with large-sized objects than with small ones (Bruner & Koslowski, 1972; Clifton, Rochat, Litovsky & Perris, 1991). Pilot observations also revealed instances in which the morphology of infant reaching appeared to depend on the spatial characteristics of the object-target, in particular whether it was a single object, a group of spatially connected objects, or a group of objects that were separated as discrete units. The variety of object displays used in the present study was aimed at controlling for size, relative location in prehensile space, and spatial unity of target object.

Five different object displays were used. These consisted of one, two, three, or seven colorful hollow plastic balls (approximately 4 cm in diameter), each containing a 2-mm steel ball-bearing rattle. The balls were set in five different spatial arrangements (Object Displays 1–5, see Figure 1) and affixed with Velcro to a transparent Plexiglas surface resembling a window (60 cm × 30 cm, and 3 mm thick).

Object Display 1 consisted of a single ball attached to the center of the Plexiglas surface. Object Display 2 consisted of two balls aligned horizontally, 30 cm apart, equidistant from the center of the Plexiglas surface. Object Display 3, which consisted of three balls aligned horizontally, the two outer balls each 15 cm from the inner, which was placed at the center of the Plexiglas surface. Object Display 4 con-

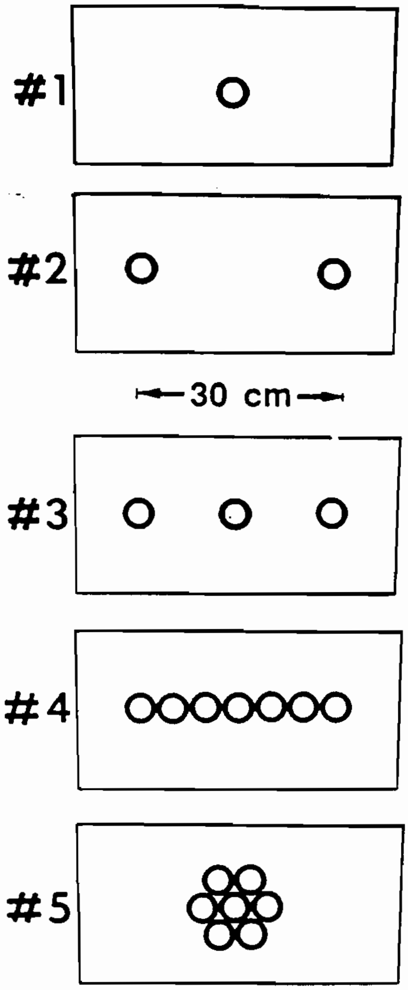

FIGURE 1. The five different object displays successively presented to each infant for reaching. They consisted of colorful balls affixed with Velcro to a transparent Plexiglas surface, set in five different spatial arrangements (Object Displays 1–5).

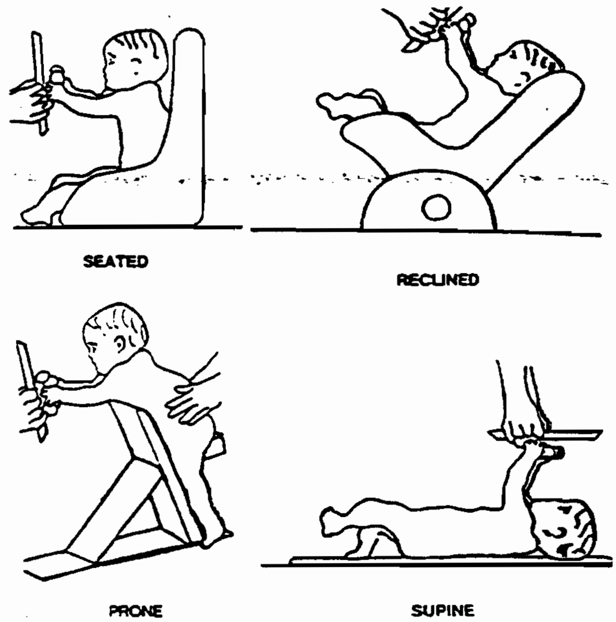

FIGURE 2. Illustration of the four posture conditions: seated, reclined, supine, and prone. These posture conditions provided different types and amounts of external body support to the infant.

sisted of seven balls aligned in a horizontal row 30 cm long. Object Display 5 consisted of six balls arranged in a tight circle around a central ball affixed to the center of the Plexiglas surface.

Procedure

Each infant was successively presented with the five object displays in each of four posture conditions. Object 1 was presented first and last for baseline comparison. The order of object presentation and posture conditions was counterbalanced among infants of each group (nonsitters and sitters). Illustrations of an infant in each of the four posture conditions are presented in Figure 2.

In the *seated* posture condition, the infant was seated in an infant seat with low armrests, allowing free arm movements. The back of the infant seat was reclined approximately 80° relative to the floor. In the *reclined* posture condition, the infant was seated in the same seat as in the seated condition, but reclined approximately 45° relative to the floor. In the *supine* condition, the infant was placed flat on her back on a rubber floor-mat (2 cm thick). In the *prone* condition, the infant was placed prone against a padded board inclined 75° relative to the floor. A padded, 10-in. 2 × 4, affixed to the board, supported the infant between her legs and prevented sliding. To prevent the infant from falling sideways, an experimenter gently pressed her lower to mid-back against the board (see Figure 2). The infant was placed head up, with the upper edge of the board at breast height, allowing free arm movements.

Trial presentations consisted of an experimenter's presenting the object display frontally to the infant. The displays were held and shaken out of the infant's reach, approximately 1.5 m away, until the infant was actively attending to the object (up to 20 s). After holding the infant's attention for 2 s, the experimenter slowly brought the object display to within the infant's reach (approximately 40 cm from torso). The object was discontinuously shaken during it's approach to hold the infant's attention. A trial presentation ended with the infant either touching, grasping, or detaching the object from its Plexiglas support. If an infant showed no attempt to touch the object, the display was intermittently shaken and finally removed from within reach of the infant after 30 s.

Infants received a total of six object presentations per posture condition, including two baseline presentations of Object Display 1, giving a total of 24 trials for each infant.

The time interval between object presentations was approximately 20 s. The time interval between the posture conditions was approximately 3 min. Testing sessions for infants lasted between 20 and 30 min.

During testing, infants were videotaped with one camera (Panasonic AG-170) placed directly overhead, approximately 2 m away from the top of the infant's head. Camera position was changed for each posture condition to provide a clear overhead view of the infant during trials. A digital clock, accurate to .01 s, was superimposed on each tape.

Scoring and Analysis

Scoring combined an on-line qualitative analysis of infant reaching and a quantitative frame-by-frame analysis of hand engagement during the approach phase of the reach. The on-line analysis (A) provided a global assessment of whether the infants mobilized one or two hands in manually contacting the object. In complement, the frame-by-frame analysis (B) quantified the dynamic of the approach phase of the reach.

(A) For the on-line analysis of infant grasping, two independent scorers noted whether the trial presentation ended either with a bimanual or one-handed contact. A bimanual contact (grasp) was operationally defined as manual contact with both hands touching the object simultaneously or one hand touching the object, immediately followed by the other within 2 s or less. A one-handed contact was defined as a manual contact with only one hand touching the object for 2 s or more after first contact. Percentage agreement, calculated between two independent scorers over 424 randomly picked trials that included infants of both groups in each posture condition, was over 93%.

(B) Videotapes of the 2 s preceding each hand-object contact were sampled every 200 ms (11 frames/trial) and analyzed to determine the alignment of and distance between hands. For each trial presentation, the video frame containing the first manual contact with the object was first determined. For each analyzed frame of the 2 s preceding first contact, the alignment of the infant's hands was calculated in terms of an angle (α), as shown in Figure 3.

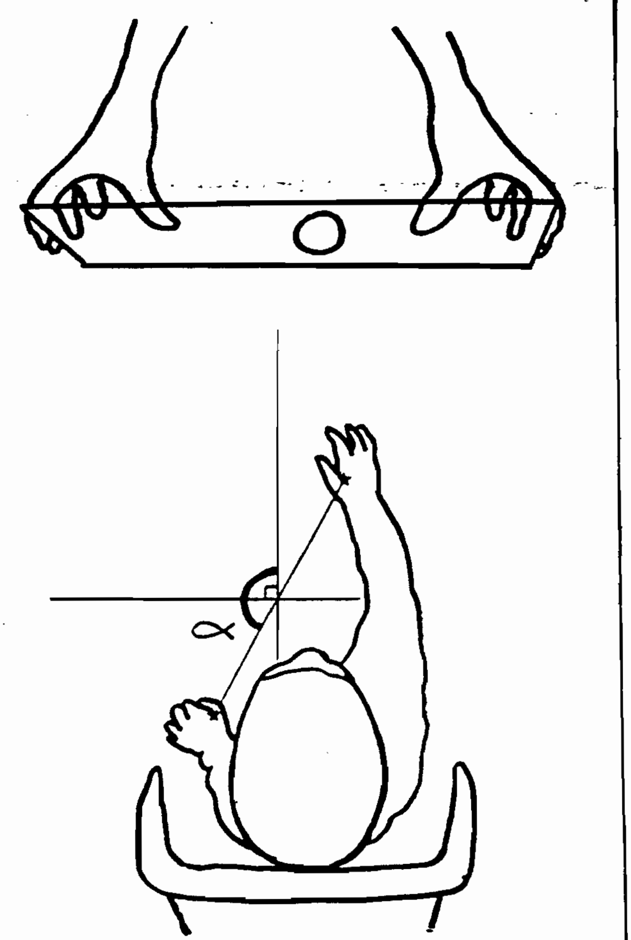

FIGURE 3. Illustration of the geometry used to calculate the relative alignment of the infant's reaching hands. For each analyzed frame of the 2 s preceding first contact with the object display, angle α was calculated. An α angle value of 90° corresponded to a perfect alignment of the hands in a two-handed reach. An α angle value deviating from 90° toward either 0° or 180° indicated that the infant was engaged in a one-handed reach, with left or right hand forward.

Angle α measures the angulation of a straight line (defined by the infant's two hands—in particular, the apex of the junction of the infant's thumb and index fingers) as it is bisected by an imaginary line projecting frontally from the infant. The angle α thus corresponds to the alignment of the infant's hands relative to the object display. An α of 90° corresponds to a perfect alignment of the hands in a bimanual reach. An α approaching 0° indicates that the infant's left hand was ahead of the right, and, conversely, an α approaching 180° indicates that the infant's right hand was forward.

In addition to the alignment of the hands (α angle values) during the approach phase of the infant's reach, the distance between hands was computed, using the following technique. Each frame of the video record was projected onto a computer monitor and a computer mouse was used to code the x and y coordinates of the infant's hands. For each scored frame, the computed values of α were recorded, as was the distance between hands (recorded in computer units [CU], relative to a reference space of 650 × 400 CU [approximately 40 × 25 cm]) (see Page, Figuet, & Bullinger, 1989, for a detailed description of the technique).

For measurements of α and distance between hands, reliabilities between two independent scorers were calculated using Pearson r moment correlation coefficients. The scoring of the frames containing the moment of contact of 88 trial presentations (22 in each of the four posture conditions, half randomly picked from the group of nonsitter infants and the other from the group of sitters) was used in this calculation. Pearson rs were, respectively, .93 for trials in the seated condition, .96 in the reclined condition, .97 in the prone condition, and .91 in the supine condition.

Results

Frequency of Successful Reaches

Out of 768 trial presentations (32 × 4 × 6 [Infant × Posture Condition × Object Presentation]), 711 (93%) ended with the infant manually contacting the object and were thus included in the analysis.

Nonsitter infants contacted the object in 89% of overall trial presentations. Sitter infants contacted the object in 98% of the overall trial presentations. For both groups of nonsitter and sitter infants, the supine condition was associated with the smallest percentage of manual contacts with the object (respectively, 78% and 94%).

Proportion of One- Versus Two-Handed Grasping

Based on the operational definitions of one-handed versus bimanual grasping (see scoring and analysis section), the relative frequency of these two behaviors was calculated. Figure 4 presents the relative frequency in percentages for nonsitter (4A) and sitter infants (4B), in each of the four posture conditions. Results indicate that except in the seated posture, nonsitter infants show a noticeable trend toward more two-handed reaches than do sitter infants.

For both groups, the relative frequency of either one-handed or bimanual grasping remained comparable for first and last presentation of Object Display 1, indicating an overall stability of response. Furthermore, at this first qualitative level of analysis, there was no evidence of an object-display effect.

A significant posture effect was observed for nonsitter infants placed in the seated posture, in which they exhibited a significant decrease in proportion of two-handed reaches, compared with the other posture conditions, $F(3, 51) = 4.306$, $p < .008$.

Change in Hand Alignment During the Approach Phase

Morphology of the infants' reaches, relative to group, posture condition, and object display was further analyzed, using the angle measure α (see Figure 3). Figure 5 presents the mean deviation from 90° of the α angle value (α DEV), disregarding the sign so that increasing scores indicate that one hand (left or right) is more forward relative to the object display.

Figure 5 shows results for the four posture conditions and each analyzed frame of the 2 s preceding hand-object contact (i.e., 11 frames at 200-ms sampling), with α DEV values averaged over object-display presentations. Figure 5A shows the group data for nonsitter infants, Figure 5B for the sitters.

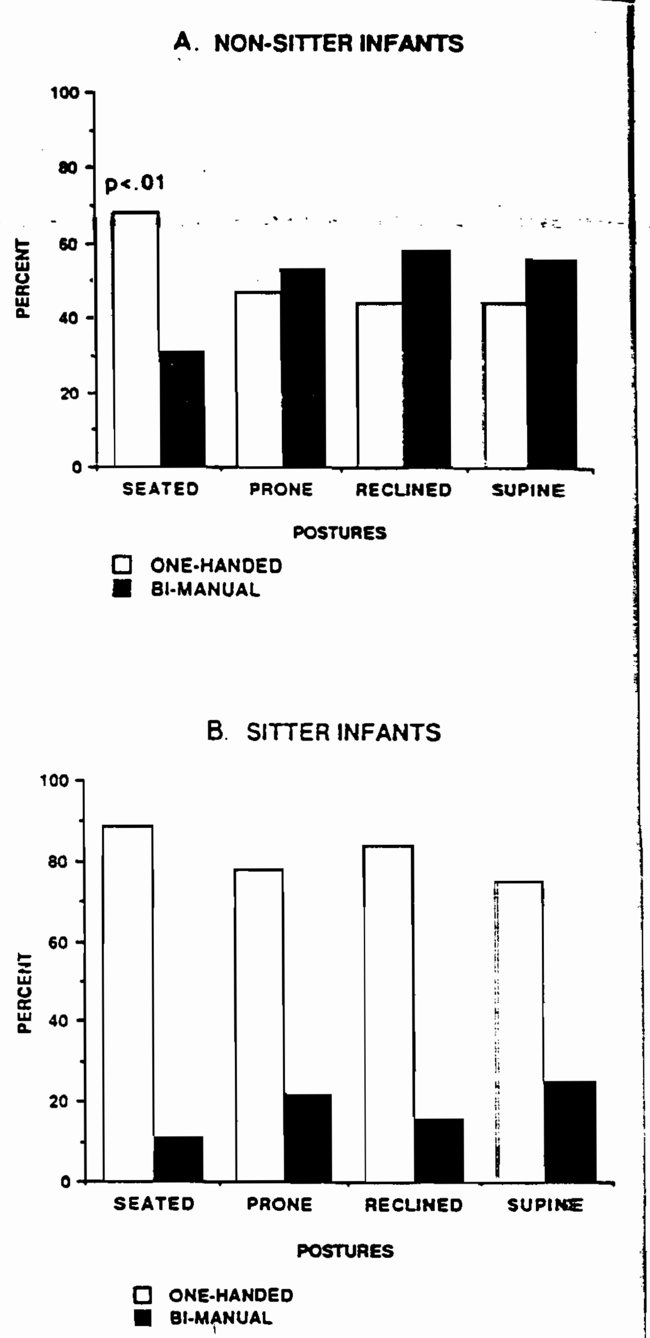

FIGURE 4. Proportion in percentage of one-handed and bimanual grasp of the objects in each of the four postural conditions. Figure 4A presents the group data for nonsitter infants and Figure 4B for sitter infants.

The mean α DEV remained relatively stable across frames for the nonsitter infants in the prone, reclined, and supine posture, but increased regularly in the seated posture. This means that in all but the seated posture, nonsitters tended to maintain a relatively stable hand alignment with an α value of close to 90°, indicating bimanual engagement. Figure 5B shows that sitter infants demonstrated a clear increase of α DEV in all posture conditions, the same tendency shown by nonsitter infants only in the seated posture.

The trend expressed in Figures 5A and 5B is supported by statistical analysis comparing the α DEV value at Frame 1 (2 s prior to contact) and its value at Frame 11 (moment of contact), with values averaged over object-display pre-

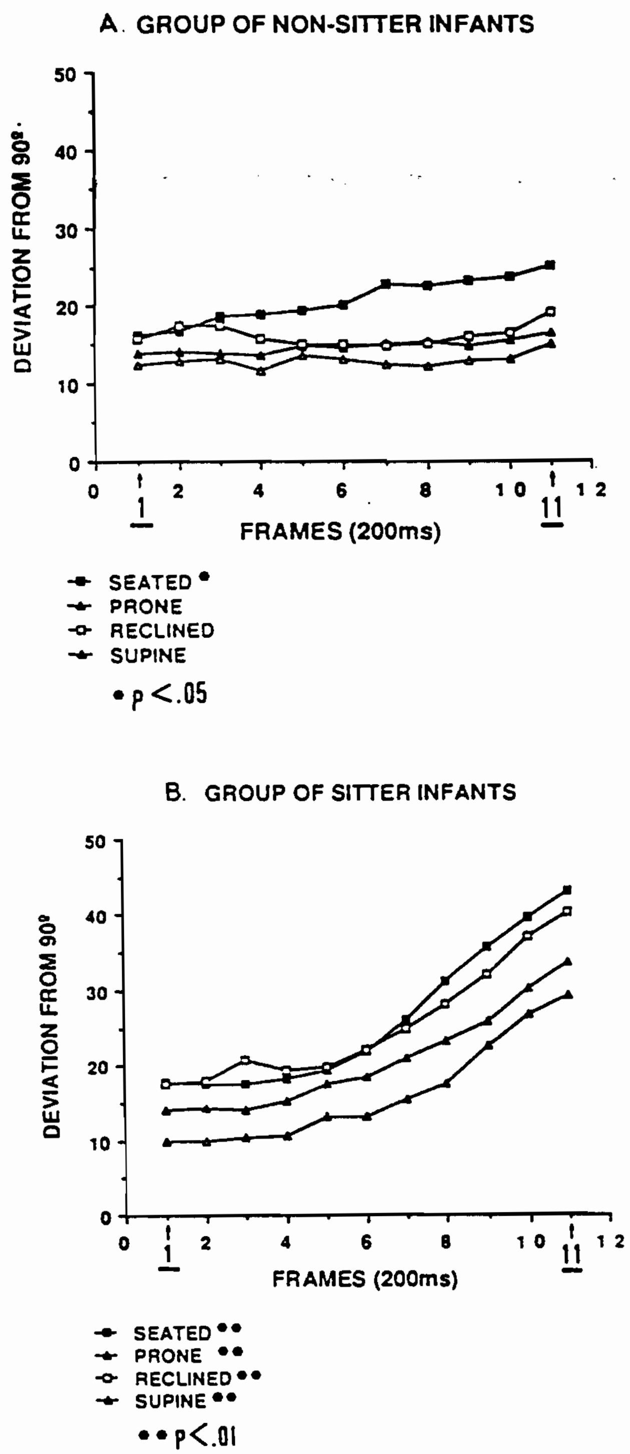

FIGURE 5. Hand-alignment analysis: Mean deviation from 90° (α DEV, see Figure 3) of the α angle value during the 2 s preceding first manual contact with the object (11 frames with 200-ms sampling). Figure 5A presents the group data for nonsitter infants, and Figure 5B for sitter infants, in each of the four posture conditions and with values averaged over object-display presentations.

sentations. A 2 × 4 × 2 (Group × Posture Condition × Frame) analysis of variance (ANOVA) yielded a significant main effect of frame, $F(1, 28) = 91.388$, $p < .0001$, and a significant Group × Frame interaction, $F(1, 28) = 41.123$, $p < .0001$. Simple effects analysis revealed a significant frame effect only for the group of sitter infants, $F(1, 28) = 29.897$, $p < .01$. When separate analyses were performed (i.e., each posture condition considered separately), the frame effect was found significant in the seated condition only for nonsitters, $F(1, 15) = 4.677$, $p < .047$, and significant in all posture conditions for sitter infants, $p < .001$.

Overall, the main feature of these results is that whereas sitter infants tended to reach with one hand forward in all posture conditions, nonsitters tended to reach with one hand in only the seated posture, reaching with both hands in all other posture conditions. In other words, group hand-alignment data show that nonsitter infants in the seated posture and sitters in all posture conditions exhibit progressive differentiation of hands in what are clearly one-handed reaches.

To assess object effects on hand alignment during the reach, I compared α DEV values at Frame 1 and Frame 11 for each object display presented in a particular postural condition, using a 2 × 6 × 6 (Group × Object Display × Frame), mixed ANOVA design. In this analysis, only infants that reached for all the object displays were included ($n = 12$ nonsitters and $n = 14$ sitters in the seated condition, $n = 15$ nonsitters and $n = 14$ sitters in the reclined condition, $n = 10$ nonsitters and $n = 12$ sitters in the supine condition, and $n = 14$ nonsitters and $n = 14$ sitters in the prone condition). The results of this analysis are presented by posture condition.

Seated Condition

The ANOVA revealed no significant object main effect but did show a significant Object × Frame interaction, $F(5, 120) = 3.285$, $p < .008$. Simple effects analysis revealed a significant effect of frame for all object displays, but comparatively less so for Object Display 2, $F(1, 24) = 5.595$, compared to F values between 14.834 and 47.233 for the other five object displays. This difference seems to account for the significant Object × Frame interaction. No significant Group × Object × Frame interaction was found. In general, results for the seated posture indicate that the α DEV increased significantly between Frame 1 (2 s prior to contact) and Frame 11 (at moment of contact), regardless of the object presented to the infant. Nevertheless, this trend was reduced when infants reached for Object Display 2.

Reclined Condition

The ANOVA revealed no significant object main effect but did show a significant Object × Frame interaction, $F(5, 130) = 5.038$, $p < .0003$. Simple effects analysis indicated significant frame effects for all object displays (at or below $p < .003$), except for Object Display 2, $F(1, 26) = 0.254$,

$p < .618$. As in the seated posture, when reaching for Object Display 2, infants tended to decrease α DEV from Frame 1 to Frame 11, indicating two-handed reaches.

Supine Condition

The ANOVA revealed no significant object main effect and no significant Object × Frame interaction. Simple effects analysis revealed a significant effect of frame for all object displays but 2 and 1 in its first presentation. No significant Group × Object × Frame interaction was found.

Prone Condition

Finally, the ANOVA showed no significant object main effect, nor any significant Object × Frame interaction. Simple effects analysis indicated significant effects of frame for Object Displays 1, 2, 3, and 5, and marginally significant effects for Objects 4, and 1 in its last presentation, $p < .08$. No significant Group × Object × Frame interaction was found.

In general, these results indicate that the morphology of reaching in terms of hand alignment (α DEV) varies according to the object display presented to the infant, regardless of the infant's sitting ability (no clear Group × Object × Frame interaction). In all but the prone condition, a consistent reduction of frame effect was found only when Object Display 2 was presented. These results suggest that the spatial arrangement of Object Display 2, where no object was present at the center of the infant's prehensile space, elicited two-handed engagement.

Change in Hand-to-Hand Distance During the Approach Phase

When infants reached bimanually, they appeared to be bringing their hands together at midline to contact the object. To capture the clasping or "crabbing" movement associated with a bimanual reach, we analyzed the change in distance between hands during the approach phase of the reach.

Figure 6 presents, for the four posture conditions and each analyzed frame of the 2 s preceding hand-object contact, the mean distance values (in CU) between hands. Figure 6A presents the group data for the nonsitter infants, Figure 6B for the sitters.

Figure 6A shows that nonsitters have a tendency to progressively reduce the distance between their hands as they reach, although this trend is reduced in the reclined and seated postures. In the prone and supine postures, nonsitter infants tended to clasp hands toward midline as they reached, demonstrating a synergistic and symmetrical involvement of the hands. Note that the prone and supine postures provided good support to the infant.

Figure 6B, by contrast, shows no comparable trend for the group of sitter infants; hand distance between the hands remained stable during the approach phase of the reach in all posture conditions.

The trend expressed in Figures 6A and 6B is supported by statistical analysis comparing the hand distance value at

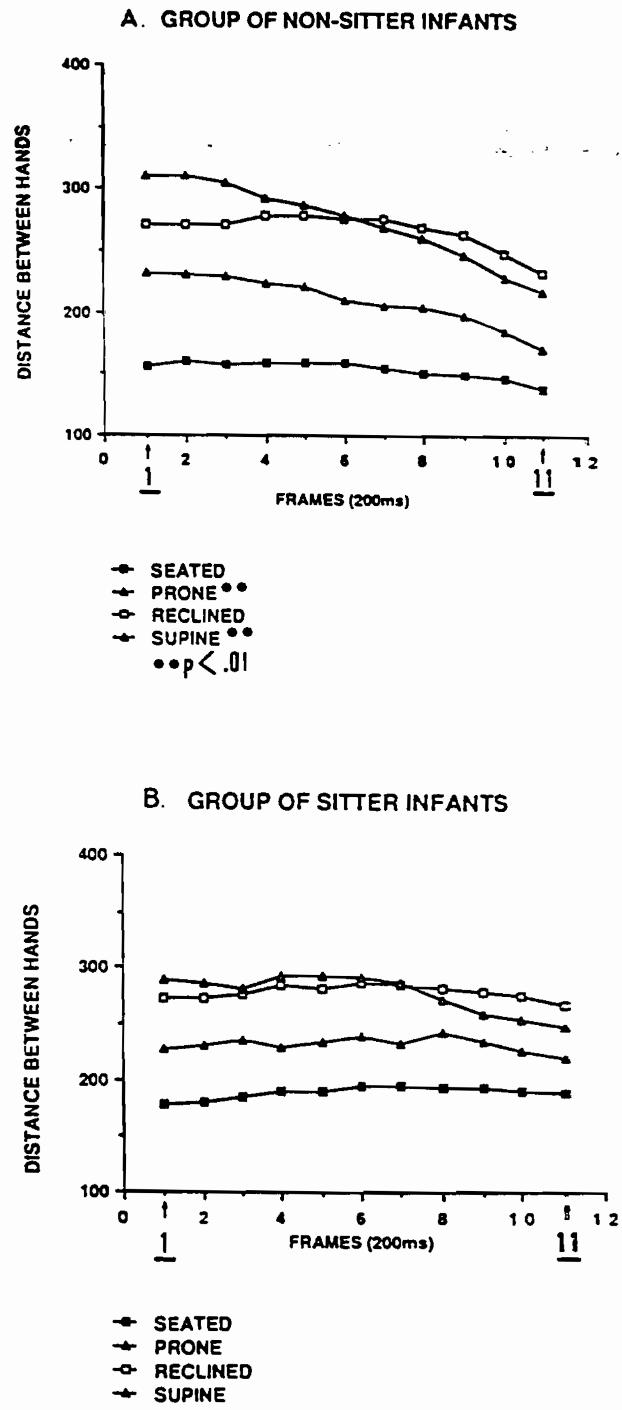

FIGURE 6. Hand-to-hand distance analysis: Mean distance values in computer units between hands during the 2 s preceding first manual contact with the object (11 frames with 200-ms sampling). Figure 6A presents the group data for nonsitter infants, and Figure 6B for sitter infants, in each of the four posture conditions and with values averaged over object-display presentations.

Frame 1 (2 s prior to contact) and its value at Frame 11 (moment of contact), with values averaged over object-display presentations. A 2 × 4 × 2 (Group × Posture Condition × Frame) mixed ANOVA yielded a significant main effect of frame, $F(1, 28) = 21.528$, $p < .0001$, and a significant Group × Frame interaction, $F(1, 28) = 8.554$, $p < .0068$. Simple effects analysis revealed a significant frame effect for the group of nonsitter infants only, $F(1, 28) = 7.664$, $p < .01$. When separate analyses were performed (i.e., each posture condition considered separately), the frame effect for nonsitters was found significant in the prone and supine conditions only, $p < .01$.

In general, analysis of hand-to-hand distance during reaching indicated that, in the prone and supine posture, nonsitter infants demonstrated synergistic movement of the hands toward midline as they reached, significantly reducing distance between hands. Such a trend was not observed for the group of sitter infants in any of the posture conditions.

To assess object effects on hand-to-hand distance during the reach, I compared hand distance values at Frame 1 and Frame 11 for each object display, using a 2 × 6 × 2 (Group × Object Display × Frame), mixed ANOVA design. Again, for this analysis, only infants that reached for all the object displays were included (see hand-alignment analysis). The results of this analysis are presented for each posture condition.

Seated Posture

The ANOVA revealed a significant Object × Frame interaction, $F(5, 120) = 3.098$, $p < .0115$. Simple effects analysis revealed significant frame effects only for Object Display 1 in its first presentation, $F(1, 24) = 8.748$, $p < .007$, and for Object Display 2, $F(1, 24) = 5.389$, $p < .029$. Comparison of the means for each of these two object displays showed opposite trends, the distance between hands from Frame 1 to 11 diminishing for Object Display 1 and increasing for Object Display 2. This difference seems to account for the significant Object × Frame interaction.

Reclined Posture

The ANOVA revealed a marginally significant Object × Frame interaction, $F(5, 130) = 1.887$, $p < .10$. Simple effects analysis revealed a significant effect of frame for Object Display 1 in both presentation—$F(1, 26) = 5.103$, $p < .033$, and $F(1, 26) = 4.85$, $p < .037$, respectively—as well as for Object Display 5, $F(1, 26) = 4.516$, $p < .043$. For these object displays, the distance between hands diminished significantly between Frame 1 and Frame 11. Similar results for Object Display 1 in both first and last presentation indicated the stability of infants' responses.

Supine Posture

ANOVA revealed a significant Object × Frame interaction, $F(5, 100) = 2.996$, $p < .014$. Simple effects analysis indicated that for all but Object Display 2, infants showed a trend toward reduction of hand-to-hand distance as they reached for and contacted the object.

Prone Posture

Last, the ANOVA showed a significant Object × Frame interaction, $F(5, 130) = 2.745$, $p < .0216$. Simple effects analysis indicated significant and marginally significant frame effect for all objects but Object Display 2. As in the supine posture, with the exception of Object Display 2, infants tended to reduce hand-to-hand distance as they reached.

In summary, analysis of hand-to-hand distance further indicates the differences between the reaching movements of nonsitter and sitter infants. Nonsitters manifested synergistic and symmetrical movements, as sitter infants showed lateralized, one-handed reaching movements. Results further demonstrated that this difference was dependent both on the postural condition and the object display presented to the infant.

Discussion

The results reported here demonstrate the impact of posture on early eye–hand coordination. They provide a clear demonstration of links between progress in the control of posture and the morphology of infant reaching. In particular, the young infant's ability or inability to maintain a sitting posture appears to be linked to the coordination of both arms and hands in reaching.

As infants develop, the morphology of their reaching behaviors changes qualitatively. As this study shows, most instances of early systematic and successful object-oriented reaches displayed by young infants are characterized by symmetrical and synergistic engagement of both arms and hands in reaches that meet at midline. By contrast, the great majority of reaches displayed by older infants, able to sit on their own, consist in asymmetrical and lateralized reaches. Although one-handed reaches are frequently observed in young infants, the proportion of their occurrences is markedly reduced compared with the older infants. Consistent with the pioneer observations by Bruner (1969), White (1969), and White et al., (1964), our (on-line) analysis of the videotapes clearly suggests a developmental trend from symmetrical and synergistic to manually differentiated reaches.

A closer look at the dynamic organization of hands as they approach the object substantiates the results of the on-line analysis. Frame-by-frame analysis of the reaches of both sitters and nonsitters revealed underlying differences in reach morphology and hand preparation. During the approach phase of the reach, younger, nonsitter infants tended to maintain the alignment of their hands relative to the frontal plane while smoothly decreasing the distance between them. By contrast, infants who were more stable in the sitting posture tended to reach with one hand, showing asymmetric and lateralized hand alignment relative to the frontal plane, and did not show a tendency toward smoothly decreasing distance between hands.

To understand this progression, one should consider early reaching as inseparable from the basic inclination of the young infant to capture objects with the mouth. Recent studies on hand–mouth coordination in neonates suggest that oral capture and the engagement of the sucking system orient, and potentially bring to closure, the manual action of neonates (Blass, Fillion, Rochat, Hoffmeyer, & Metzger, 1989; Butterworth & Hopkins, 1988; Rochat, Blass, & Hoffmeyer, 1988). Of particular relevance, the clasping movement of the hands in early reaching appears to be an integral part of the broader act of transporting objects to the mouth for oral contact and exploration (Bruner, 1969; Rochat & Senders, 1991).

Even before infants are able to reach for and successfully grasp objects they see, they demonstrate competent hand–mouth coordination (Piaget, 1952). When an object is placed in a young infant's palm, she or he will systematically bring the object to the mouth, even though she or he may be yet unable to successfully reach for such an object (Rochat, 1989).

When object-to-mouth transport in 2- to 5-month-old infants is microanalyzed, results suggest a developmental progression from two- to one-handed engagement similar to that seen in the present study. Early retrievals are marked by movements of both hands toward the mouth after clasping at midline; later retrievals tend toward independent, one-handed movement (Rochat, in press; Rochat & Senders, 1991). It appears, then, that developmental changes in the behavioral expression of early eye–hand coordination reported here recapitulate those observed in the development of object-to-mouth transport (hand–mouth coordination), further supporting the idea of a functional link between early reaching and oral capture. The functional continuity and mechanisms linking hand–mouth and eye–hand coordination in development need further investigation.

Indeed, what controls or motivates this transition? In the present study, results suggest that the infant's ability to maintain an upright seated posture is an important determinant of this transition. We find that nonsitter infants, although showing strong tendencies toward bimanual and synergistic reaching, tend to reach primarily with one hand only when placed in the seated posture. Sitter infants, by contrast, show a majority of manually differentiated reaches when reaching in all posture conditions. Thus, the achievement of postural control appears to participate in the transition from symmetrical to lateralized upper-limb movements in reaching.

Following Bernstein (1967), these behavioral changes can be interpreted as expressions of the infant's varying mastery over biomechanical degrees of freedom (see also Bruner, 1970; Goldfield & Michel, 1986; Kelso, Putnam, & Goodman, 1983; Kelso, Southard, & Goodman, 1979). Symmetrical and synergistic movements of the hands in reaching compress the degrees of freedom of the upper limbs by duplicating in synchrony the action of both hands. For the young infant, the benefits of a clasping or crabbing reach are twofold: Each hand counteracts the momentum of the other, maximizing stability and preventing the reach from crossing midline; and when reaching for objects presented centrally, the precision of the reach is potentially maximized. Despite these benefits, this compression of degrees of freedom also limits the possibilities for differentiated manual action.

As infants gain stability and progress to lateralized and asymmetrical reaches, they gain the possibility of differential functioning of the hands. By the end of the first semester, for example, manual independence in fingering behavior and object manipulation/exploration emerges as a landmark in the development of early motor behavior (Rochat, 1989).

In this study, nonsitter infants were relatively stable in all but the seated posture, and the resultant liberation from postural obligations made bimanual reaches both possible and useful. In the less stable seated upright posture, these infants were apparently obliged and/or liberated to lateralize their reaches to accommodate their precarious position. When nonsitter infants did reach bimanually while seated upright, they often ended up falling forward, coming to rest in a folded posture that effectively prevented them from reaching accurately toward the object target.

Note that it is mainly in this posture condition that the great number of existing studies have documented early eye–hand coordination. Methodological considerations aside, this might be why reaching in infancy has been approached as a predominantly one-limb, one-handed action.

The results presented here suggest that the control of posture, and in particular the control of self-sitting, is an important control variable of early reaching and is potentially relevant to progress in object manipulation and exploration during the infant's first year.

Finally, the type of object display presented to the infant, regardless of his or her self-sitting ability, also contributes to the morphology of the reach. Frame-by-frame analysis showed that Object Display 2, in which two balls were presented simultaneously in the infant's left and right hemifield, was associated with more hand alignment in both age groups and less hand distance reduction. What differentiated this object display from the others is that there was nothing at the center of the plexiglas support. In other words, the infant's reach was solicited simultaneously to the right and to the left, with nothing in between. Results indicated that with this object display, infants tended to mobilize symmetrically both hands to capture simultaneously both balls of the display. This bimanual engagement is not isomorphic to the crabbing movements often observed in nonsitter infants, as it does not entail a hand distance reduction during the approach phase of the reach. These observations suggest that, regardless of their ability or lack of ability to control stable self-sitting, infants are capable of adjusting their bimanual engagement in relation to the particular spatial arrangement of the display. This adjustment appears to depend on the presence or absence of the object at the center of prehensile space and not on the actual separation between objects in the display. Indeed, the morphology of reaching was different for the display where one ball was presented at the middle, in between the left and right one (Object Display 3). Although further research is needed to map more accurately relevant zones of the infant's prehensile space, these observations support existing evidence of sophisticated preparatory reaching based on perceived spatial properties of the object by infants in their second semester (Hofsten & Ronnquist, 1988; Lockman et al., 1984; Rochat, Clifton, Litovsky, & Perris, 1989).

In conclusion, the control of early reaching has multiple determinants that need to be considered to capture the complex interaction underlying its development. This study shows, at minimum, that both posture and perceived spatial configuration of the object are important determinants of early eye–hand coordination.

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