INFANT BEHAVIOR AND DEVELOPMENT **18**, 53–68 (1995)

Development of Sitting and Reaching in 5- to 6-Month-Old Infants

PHILIPPE ROCHAT
Emory University
NATHALIE GOUBET
University of Massachusetts

Three studies are reported, investigating changes in body engagement by 5- to 6-month-old infants as they reach for objects in the environment. Infants are distinguished and compared based on their relative ability to maintain a sitting posture without any external body support. The first study demonstrates that manual reaching by sitter infants is coordinated with forward leaning of the trunk, whereas reaching by nonsitters is not. The second study demonstrates that nonsitter infants provided with hip support also show signs of a coordination between reaching of the hand and forward leaning of the trunk. The third study compares nonsitter, nearsitter, and sitter infants as they reach for multiple objects spread across their prehensile space. Results demonstrate expansion in the mapping of infants' prehensile space and hand use as a function of self-sitting ability. The reported results are discussed as expressions of the interaction between the development of postural, perceptual, and action systems in infancy.

posture reaching infancy development

The emergence of self-sitting abilities by 5 months of age is a major milestone of early motor development (Bayley, 1969; Gesell, 1946). It corresponds to marked progress in posture control and the expression of novel muscle synergies (Harbourne, Giuliani, & Mac Neela, 1993). At the level of functional action, the emergence of self-sitting abilities increases dramatically the infant's degrees of behavioral freedom and the possibilities of interacting with objects in the environment. Indeed, self-sitting corresponds to the first conquest of verticality which frees the upper limbs from the encumbrance of maintaining balance in an erect posture (Rochat & Bullinger, 1994). Although it is often recognized that haptic exploration is an important factor of early development (Gibson, 1988; Piaget, 1952), little is known regarding the actual relationship between the emergence of self-sitting and the development of manual action in infancy. Only recently has research started to specify the relationship between motor, perceptual, emotional, and cognitive development. In a series of studies, Bertenthal and Campos (1991) demonstrated that progress in self-produced locomotion manifested by the end of the first year is linked to major changes in domains as diverse as intermodal adaptation, visual attention, social referencing, and the differentiation of emotions. This research is a first attempt to specify the impact of another and earlier milestone of motor development in infancy (i.e., self-sitting) on the expression of a behavior thought to be the basis for major progress in early development (i.e., reaching).

Young infants demonstrate an early propensity to bring their hands in contact with objects in the environment. Reaching has been extensively used as a behavioral paradigm for the study of early cognitive, perceptual, and motor development (Corbetta & Mounoud, 1990; Lockman & Ashmead, 1983). Reaching behavior is among the earliest expressions of an integration between different sensorimotor systems. It combines perceptual discrimination of an object target located in three-dimensional space and a goal-oriented manual action toward this object. In the perspective of development, visually guided reaching is manifested from birth, described as "pre-reaching" (Hofsten, 1982; Trevarthen, 1982), and develops rapidly during the first year (Hofsten & Lindhagen,

The authors wish to acknowledge Mrs. Pearlie Pitts for her help in recruiting participants, all the parents and infants who participated in the experiments, Julie Schweitzer, Michael Tomasello, Irwin Waldman, Paul Scott, and Susan Hespos for their comments on the manuscript and help on data analyses. Research was supported in part by grant no. 11-28725.90 from the Swiss National Science Foundation (FNS) and grant no. MH50385-01 from the National Institute of Mental Health awarded to P.R.

Correspondence and requests for reprints should be sent to Philippe Rochat, Department of Psychology, Emory University, Atlanta, GA 30322.

1979; Piaget, 1952). By 6 months, infants are shown to adjust their reach as a function of perceived spatial and physical properties of the object, such as its size (Bruner & Koslowski, 1972; Hofsten & Ronnqvist, 1988), its orientation (Lockman, Ashmead, & Bushnell, 1984), and whether or not it is reachable (Clifton, Perris, & Bullinger, 1991; Field, 1976; McKenzie, Skouteris, Day, Hartman, & Yonas, 1993; Yonas & Granrud, 1985; Yonas & Hartman, 1993). Although reaching in infancy has been essentially studied as the movement of one hand toward an object, it often corresponds to an engagement of both hands. Six-month-olds tend to engage differentially with either one hand or two hands when reaching for a small or large object (Bruner & Koslowski, 1972; Clifton, Rochat, Litovsky, & Perris, 1991). This differential engagement in relation to the perceived size of the object demonstrates anticipation of haptic consequences, hence planning and preparation in early reaching. Preparatory reaching is not exclusively attached to a visual guidance of the hand, as evidenced when 6-month-olds show preparatory reaching for an object they hear sounding in the dark (Clifton et al., 1991). Altogether, these studies provide evidence that early reaching is not rigidly planned or automatic, nor merely reducible to a reflex response. By 6 months, infant reaching expresses differential manual engagement based on perceived characteristics of the object.

There is good evidence that the development of skilled action in infancy is inseparable from postural development (Reed, 1990). Demonstration of precocious sensorimotor coordinations depends on the postural support provided to the young infant. In a series of clinical observations, Amiel-Tison and Grenier (1986, pp. 102–107) found that visuomotor coordination in neonates is facilitated by holding their heads firmly in the axis of the trunk. According to these authors, the apparent sensorimotor clumsiness and the obligatory responses of the neonate are linked to poor neck control. A reorganization of exploratory activities is observed in prelocomoting infants placed in a "baby walker" device (Gustafson, 1984). Analogous observations are reported in the animal literature, with mouse puppies showing adultlike forelimb behaviors (i.e., grooming) when provided with postural support (Golani & Fentress, 1985). Overall, these observations suggest that important behavioral changes in infancy originate from the interaction between postural and action systems which are developing at different rates.

At around 4 months of age, when infants start to reach systematically and successfully for objects in their environment, they are still unable to maintain a self-supported sitting posture. This explains why early reaching is commonly studied with infants placed in a highly supportive seat, compensating for their lack of postural control. The developmental gap between manual reaching abilities and postural control creates a major challenge for the infant intending to touch and grasp objects. The integrity of the body "as a whole" must be maintained while the reaching act takes place, particularly in situations where losing balance could be potentially harmful (e.g., falling on the ground from an unstable sitting posture). With the achievement of self-sitting posture, the upper limbs of the infant are freed from the encumbrance of maintaining balance. Interestingly, at the time self-sitting abilities emerge in development (around 5 months), infants also start to manifest a coordinated use of the hands in object manipulation and exploration (i.e., "fingering" behavior: Rochat, 1989). Recent observations of 4- to 7-month-olds have shown that the use of either one or two hands in infant reaching depends on the degree of control over self-sitting posture (Rochat, 1992). Nonsitter infants placed in postural conditions that provide good support (i.e., supine, reclined, or prone against a board) tend to reach in majority with both hands toward the object. By contrast, nonsitters in an upright sitting posture reach in majority with one hand, in the same way that sitter infants reach regardless of posture (Rochat, 1992). Besides these observations, little is known about the relation between the emergence of self-sitting abilities and reaching behavior viewed as a whole body engagement, entailing the control of multiple skeletal degrees of freedom, including hands, upper limbs, and torso movements. Indeed, what is the relation between self-sitting as a landmark in the progress of early development and new uses of the body by the infant?

The following three experiments pertain to the relation between the emergence of self-sitting posture and novel use of the body in reaching by 5- to 6-month-old infants. The general aim is to capture further the relation between postural development (self-sitting) and manual action (reaching) in infancy.

EXPERIMENT 1

The aim of this first experiment was to capture in 5- to 6-month-old infants changes in the morphology of reaching, in particular, changes in overall body engagement in reaching. Infants were videotaped while reaching for an object presented in front them. The amount of trunk participation in coordination with upper limbs was assessed in infants who were either able or yet unable to sit on their own (sitter vs. nonsitter infants). Considering that progress in the control of self-sitting posture opens up new degrees of behavioral freedom, the question guiding this experiment was how this progress correlates with changes in the morphology of reaching, viewed as an overall body engagement. The working hypothesis was that progress in the control of upright sitting posture is accompanied by a change in the morphology of infant reaching. In comparison to nonsitter infants, sitter infants were expected to show increased participation of the trunk (i.e., forward leaning) in coordination with upper limb(s) movements.

Method

Subjects

Sixteen infants were tested. The first group consisted of 8 "nonsitter" infants (see below for criteria), 5 males and 3 females, 150 to 201 days of age (M age = 169.00 days; SD = 16.00 days). The second group consisted of 8 "sitter" infants, 5 males and 3 females, 172 to 236 days of age (M age = 203.00 days; SD = 18.65). Three nonsitter infants were older than 3 sitter infants (age overlap of n = 6). In addition, 7 infants were tested but not included in the final sample (5 nonsitters, 2 sitters) due to failure to reach for the object. 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, and those who could not, as nonsitters. Group attribution was systematically confirmed by the infants' parent(s) in a subsequent interview. There was 100% agreement between two independent observers on group attribution. All infants were healthy on the day of testing. Parents reported a normal course of development following a full-term birth. Infants were recruited from published birth records in the Springfield, MA area.

Procedure

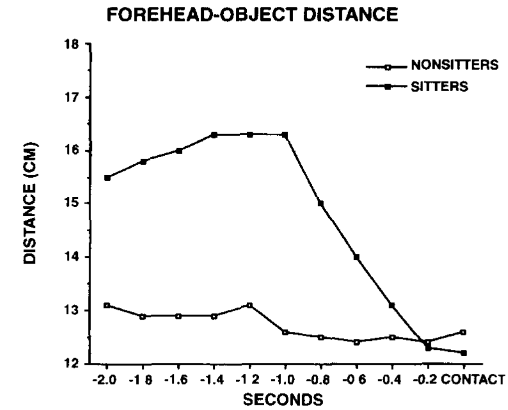
Infants were seated in an upright infant seat with low armrests so as not to constrain arm movements. The back of the infant seat was aligned 80° relative to the floor. During testing, infants were videotaped with a camera affixed to a tripod directly overhead, approximately 2 m away from the top of the infant's head. The video recording provided an overhead view of the infant, including a digital timer with 1/100 s for subsequent frame-by-frame analyses. During testing, the infant was presented in four successive trials with a colorful, hollow, plastic ball, 4 cm in diameter, containing a steel ball bearing, 4 mm in diameter, which produced a compelling sound when agitated. The object was presented in front of the infant by the experimenter who kneeled facing him or her. In a first familiarization trial, the object was directly placed in the infant's right hand for approximately 30 s of free exploration and manipulation. The familiarization trial was meant to trigger the infant's interest in the object. After the familiarization trial, the object was presented in three successive experimental trials. In these trials, the object was first presented out of reach of the infant, approximately 1.5 m away, then the experimenter brought it slowly to within reach, in alignment with the infant's toes (perpendicular to the infant's toes, approximately 40 cm from the infant's torso). At the beginning of each object's presentation, the infant was placed with his/her back perpendicular relative to the ground. The object was centered and in alignment with the infant's shoulders during its approach and was continuously shaken by the experimenter to produce sound and keep the infant engaged. An experimental trial ended when the infant either touched or grasped the object held by the experimenter. Time intervals between object presentations were approximately 30 s. The three trial presentations were meant to increase the probability of obtaining at least one successful reach by the infant (manual contact with the object), in order to be included in the final analysis (see below).

Scoring and Analysis The approach phase of the infant's reach was scored and analyzed in a frame-by-frame analysis with a sampling of 5 images per s. The approach phase included the 2 s prior to the moment of first manual contact with the object (total of 11 images). The frame-by-frame scoring of the video recording was the basis for the coanalyses of trunk movements and movements of the upper limbs during the approach phase of the infant's reach. In particular, scoring was aimed at assessing the relative coordination between reaching of the upper limb(s) and leaning of the trunk, in terms of simultaneous trunk movements accompanying the approach of arm(s) and hand(s) toward the object. Two measures were performed on each analyzed frame: (a) hand-to-object distance, and (b) forehead-to-object distance. These measures were done on the image of the overhead view of the infant, using a computerized analysis of frozen video images. For this analysis, the video monitor and a computer monitor were positioned at a 90° angle with a piece of Plexiglas bisecting the angle. This arrangement allowed the reflection of the video image to fall on the screen of the computer monitor (Page, Figuet, & Bullinger, 1989). While looking at this reflected video image in a frozen frame, the scorer moved a cursor by activating a "mouse" to particular locations. For measure (a), these locations were a fixed point on the infant's reaching hand (between thumb and index finger of the hand contacting the object first in case of a bimanual reach) and a fixed point on the object. For measure (b), these locations were a fixed point on the infant's forehead corresponding to a small piece of white tape placed prior to testing on the anterior portion of the infant's head, and a fixed point on the object. The X and Y coordinates of these points were recorded and stored by a computer. For each scored frame, a program calculated the distance between these recorded positions in computer units (approximately 8 units = 1 cm). Note that this technique of analysis is limited to two dimensions and does not allow recording of movement and distance changes in three dimensions. All analyses are relative to the overhead bidimensional view provided by the camera placed above the infant. Two independent observers scored 40% of the video recordings (n = 10 successful reaches, 5 from randomly picked sitter infants and 5 from nonsitter infants). There was a 100% agreement regarding which trial presentation ended with the infant either contacting the object or not contacting the object. Reliabilities were further assessed with Pearson product-moment correlation coefficients (r) for determination of the moment of contact and the values of measures (a) and (b). Coefficients were 1.00 for moment of contact and above .92 for the two measures

Results

Considering all of the trial presentations, the overall frequency of successful reaches was 22 out of 24 (92%) for the group of nonsitter infants and 24 out of 24 (100%) for the group of sitters. All infants performed at least one reach ending with a manual contact with the object (successful reach). Out of the three trial presentations, the first trial ending with a successful reach was included in subsequent analyses (n = 16, i.e., one reach per infant).

Figure 1 presents group results regarding forehead–object distance (1A) and hand–object distance (1B) in relation to each scored frame of the 2-s approach phase (n = 11 frames of the approach phase with a 200-ms sampling). As shown in Figure 1A, forehead–object distance remained relatively stable up to the moment of contact with the object for the group of nonsitters. In contrast, sitter infants showed a decrease in forehead–object distance corresponding to forward leaning of the trunk as the hand was approaching the object. This leaning of the trunk emerges by frame 6, during the last second of the approach phase of the reach. Figure 1B shows the corresponding decrease in hand–object distance for each group of infants during the 2 s preceding contact. To test statistically the trend illustrated in Figures 1A and 1B, analyses were first performed comparing the value of each measure at Frame 1 (2 s prior to contact) and its value at Frame 11 (moment of contact). A 2 (group) × 2 (frame) ANOVA was performed regarding each of the two measures. Regarding the forehead–object distance, ANOVA yielded a significant group by frame interaction, $F(1, 14) = 7.16$, $p < .02$. Simple effects analyses revealed a significant frame effect for the group of sitter infants, $F(1, 14) = 21.56$, $p < .0001$, but not for the nonsitters, $F(1, 14) = 0.74$, $p < 4$. Regarding hand–object distance, although sitters showed a steeper decrease, the amplitude of hand movement during the approach phase of the reach was comparable for both groups: ANOVA yielded a significant main effect of frame, $F(1, 14) = 17.57$, $p < .0001$, and no significant group by frame interaction for hand–object distance. This result is important because it shows that although the video technique used in this experiment is limited to an overhead (two-dimensional) view of



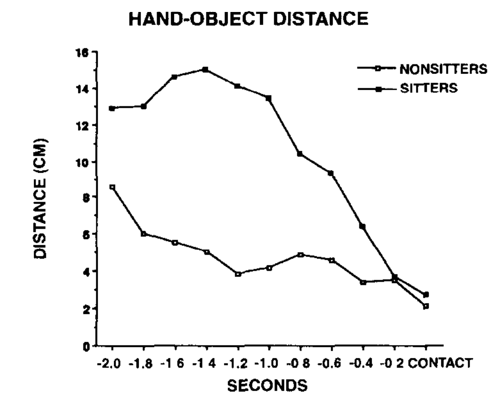


Figure 1. Mean forehead–object distance (1A) and hand–object distance (1B) in centimeters for the group of nonsitter and sitter infants in relation to each scored frame of the 2 s prior to manual contact with the object (200-ms sampling).

the infant, for both groups of infants, a significant movement of the reaching hand in the horizontal plane is captured.

To assess further the results illustrated in Figures 1A and 1B, trend analyses were performed. Regarding forehead–object distance, tests of linear and quadratic trends yielded a significant to marginally significant group by frame interaction, $F(1, 14) = 5.70$, $p < .03$, for linear, $F(1, 14) = 4.18$, $p < .06$, for quadratic. These results confirm the trends described above. The marginally significant interaction for the quadratic trend supports what is depicted in Figure 1A, namely the tendency in sitter infants to lean by Frame 6, 1 s prior to contact. Whereas the statistical significance of this result is marginal, it represents an effect that is substantial in magnitude given the reduced power of tests of interactions (Wahlsten, 1991), as well as the small sample size (Rosnow & Rosenthal, 1989). Regarding hand–object distance, tests of linear and quadratic trends also yielded a significant group by frame interaction, $F(1, 14) = 4.36$, $p < .05$, for linear; $F(1, 14) = 5.63$, $p < .03$, for quadratic. Based on what is depicted in Figure 1B, the significant interaction for the quadratic trend corresponds to the tendency by sitter infants to increase the hand–object distance during the first four frames, the actual approach of the hand taking place during the last seven frames. This observation is analogous to what was observed in the head–object distance analysis. By contrast to nonsitters, leaning of the trunk and reaching of the hand by sitter infants were manifested during the 1 s preceding contact. Trend analyses confirm that the two groups of infants manifested differential leaning of the trunk. In addition, this differential leaning appears to be combined with a different approach of the hand towards the object. To further assess this combination, an analysis was performed on the correlation ratio between forehead–object and hand–object distance variations between frames found for each individual infant during the 2-s approach phase. This average correlation is an index of the relation between the amount of reaching and leaning movements towards the object (velocities). The mean r values were .06 for the nonsitters and .79 for the sitters. A one-factor ANOVA yielded a significant effect of group, $F(1, 14) = 15.62$, $p < .001$. This result indicates that there is a significantly higher correlation between reaching and leaning velocities for the sitter infants compared to the nonsitters.

The results regarding forehead–object distance (Figure 1A) indicate that at the onset of the 2-s approach phase, the forehead of nonsitter infants is on average closer to the object. Following the procedure, at the beginning of the object's presentation, each infant had his/her back placed perpendicular to the ground. Thus, nonsitters tended to lean forward prior to the approach phase of the hand. By contrast, sitter infants showed a marked leaning of the trunk during the 2 s preceding contact, in conjunction with the final movements of the reaching hand towards the object. If nonsitters leaned forward, it was prior, hence not in tandem with the reaching hand. There is a marked difference in the timing of trunk movement by nonsitters. Figure 2 illustrates further some individual differences among nonsitter and sitter infants which were masked by group results. Figure 2 shows typical variations in the timing of coordinated reaching and leaning movements by sitter infants and the absence of such coordination by nonsitters.

EXPERIMENT 2

In Experiment 2, a new group of nonsitter infants was videotaped while reaching in different conditions of varying hip support. The idea was to provide nonsitter infants with the postural support and control they will eventually generate on their own in a few weeks of developmental time. This manipulation was meant to control for the possible age confound of the first Experiment. In particular, the question guiding the second experiment was whether adequate postural support alone could cause nonsitter infants to resemble the group of sitter infants analyzed in the first experiment. Overall body engagement in reaching was compared relative to different postural conditions varying in the amount of hip support provided to the nonsitter infant. The working hypothesis was that the degree of hip support provided to nonsitter infants controls for the coordination between reaching action and leaning of the trunk during the approach phase of the reach. Moreover, results obtained with this new group of nonsitter infants were compared to the results obtained with the group of sitter infants from the first experiment.

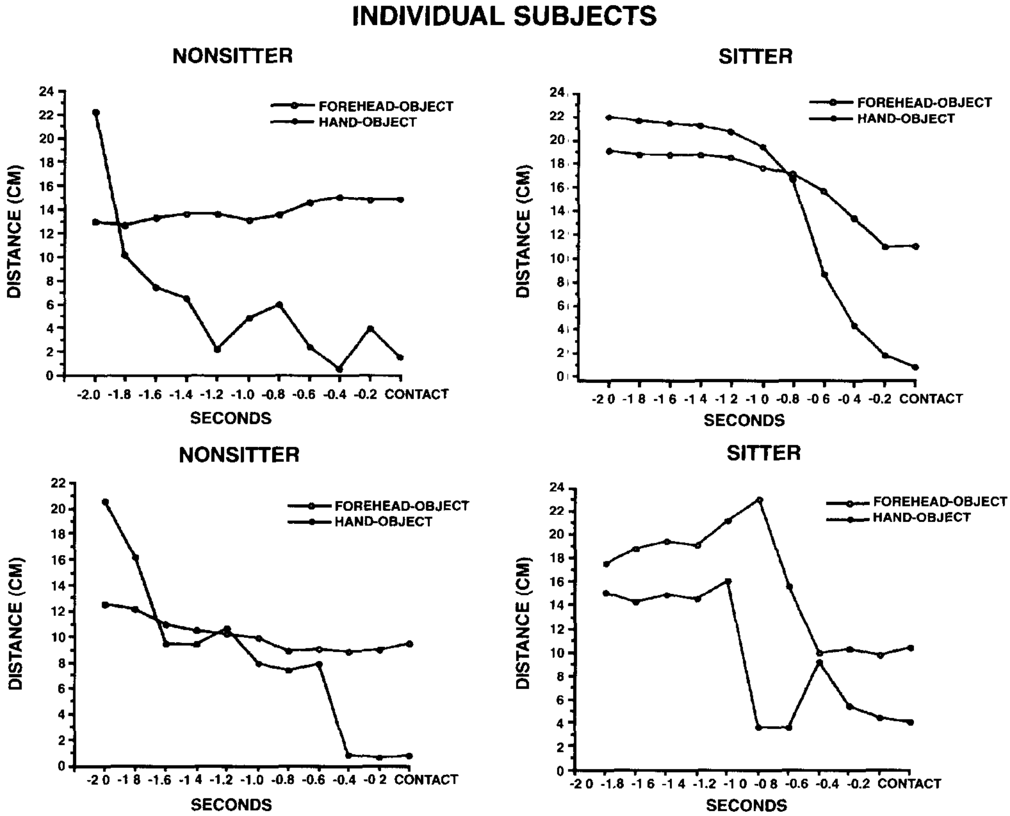


Figure 2. Individual results by two nonsitter and two sitter infants of combined forehead–object and hand–object distance in centimeters during the 2 s prior to manual contact with the object (200-ms sampling).

Method

Subjects

Eight nonsitter infants were tested, 4 males and 4 females, 155 to 172 days of age (*M* age = 163.00 days, *SD* = 7.00). Two additional infants were tested but not included in the final sample due to failure to reach for the object. All infants were unable to maintain self-sitting posture with hands above the ground for at least 30 s. The same videotaped pretest examination employed in Experiment 1 was performed. Nonsitting status of the infant was confirmed by the parent(s) in a subsequent interview, and there was 100% agreement between two independent observers looking at the videotaped pretest. All infants were healthy on the day of testing, and parents reported a normal course of development following a full-term birth. Infants were recruited from published birth records in the Springfield, MA area.

Procedure

The technique, procedure, and object of Experiment 1 were used again in Experiment 2. Infants were placed in an upright infant seat with a video camera providing an overhead view of the infant. After an initial familiarization trial, the infant was tested successively in three different postural conditions in which varying amounts of hip support were provided. In each of these conditions, the infant was presented in three trials with the object in the frontal plane (see procedure of Experiment 1 for details). The procedure was repeated without familiarization in the three different postural conditions. Two inflated cushions were placed at hip level on each side of the infant, between the infant and the inside wall of the seat. A blood pressure measuring device (Lumiscope Inc., Model#100-019NP) was embedded in each cushion and was connected to both a manometer and a hand pump. This device gave fine control over the amount of constant pressure. Opening the pump's valve reduced the pressure applied to the infant's hip region, whereas closing the valve and pumping in air increased the amount of pressure. The rationale for this kind of hip pressure was to simulate the support commonly provided by caretakers holding young infants on their lap, with hands at their hips to prevent them from losing balance as they reach forward. The three postural conditions corresponded to (a) 0 mmHg pressure (no pressure applied), (b) 20 mmHg pressure (medium pressure), and (c) 40 mmHg pressure (high pressure) applied to the infant's hips. Each infant was presented with the object in the three postural conditions, in an order that was counterbalanced over the group of infants.

Scoring and Analysis In each postural condition, the approach phase of the infant's first successful reach was scored and analyzed in a frame-by-frame analysis with a sampling of five images per s. The same scoring technique, procedure, and analysis were used as in Experiment 1 (see details above). Again, two independent observers scored the video recordings. There was 100% agreement regarding which trial presentation ended with the infant contacting the object. Pearson product-moment correlation coefficients (r) for determination of the moment of contact, hand–object distance, and forehead–object distance measures were all above .90 (see also reliabilities in Experiment 1, using the same scoring technique).

Results

All infants reached successfully three times in each postural condition, indicating an equal propensity to reach across conditions. Out of the 72 reaches performed, 54 were one handed, 36 involving the right hand. In relation to the three postural conditions, the frequency of one-handed reaches was respectively $n = 16$ in the 0-mmHg condition, $n = 19$ in the 20-mmHg, and $n = 19$ in the 40-mmHg condition. First successful reaches in a particular postural condition were further analyzed ($n = 3$ reaches per infant).

The results obtained in the three postural conditions were first compared relative to the value of forehead–object and hand–object distance at Frame 1 (2 s prior to contact) and Frame 11 (moment of contact). Regarding the forehead–object distance measure, a 3 (condition) × 2 (frame) ANOVA with repeated measures yielded a significant main effect of frame, $F(1, 7) = 13.94$, $p < .01$, and no significant effect of condition, $F(2, 14) = 1.98$, nor any significant condition by frame interaction, $F(2, 14) = 0.86$. The same analysis performed on the hand–object value yielded a significant main effect of frame, $F(1, 7) = 38.38$, $p < .001$, and no significant effect of condition, $F(2, 14) = 0.07$, nor any significant condition by frame interaction, $F(2, 14) = 0.30$. Results obtained in the three postural conditions were further analyzed in a series of trend analyses within a 3 (condition) × 11 (frame) design with repeated measures. Regarding forehead–object distance, test of linear trend yielded no significant effect of condition, a significant effect of frame, $F(1, 7) = 8.17$, $p < .03$, and a marginally significant condition by frame interaction, $F(1, 7) = 4.54$, $p < .07$. Considering the reduced power of tests of interactions (Wahlsten, 1991), and the small sample size (Rosnow & Rosenthal, 1989), this effect can be considered as substantial in magnitude. Figure 3A illustrates this interaction, which is due to a steeper decrease of forehead–object distance prior to contact in the 40-mmHg condition (high hip support), compared to the 20-mmHg and 0-mmHg conditions (medium and low hip support). Trend analyses performed on hand–object distance yielded significant linear and quadratic trends for frame only, $F(1, 7) = 50.43$, $p < .0001$ and $F(1, 7) = 7.26$, $p < .04$, respectively, with no significant condition by frame interaction. As shown in Figure 3B, in all three postural conditions, nonsitter infants showed a comparable trend in the decrease of hand–object distance prior to contact.

In a second analysis, sitter infants of Experiment 1 were compared to the group of nonsitters in each of the three postural conditions sep-

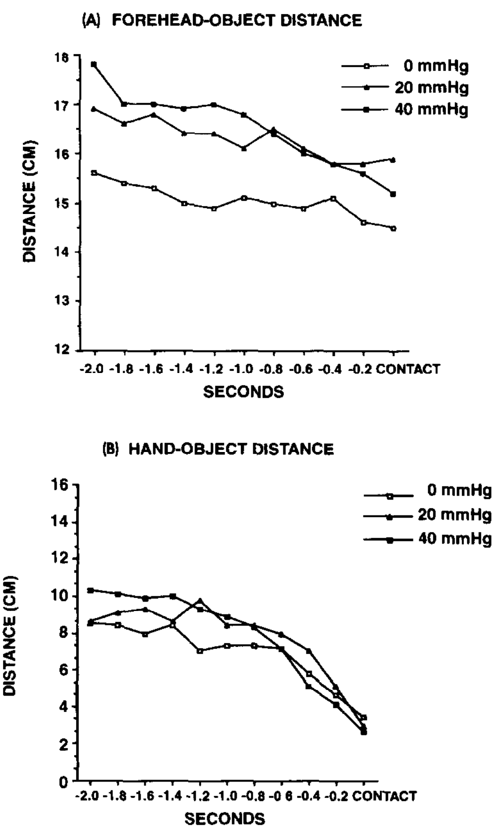


Figure 3. Mean forehead–object distance (3A) and hand–object distance (3B) in centimeters during the 2 s preceding manual contact with the object (200-ms sampling) in each of the three postural conditions: 0 mmHg (low hip support), 20 mmHg (medium hip support), and 40 mmHg (high hip support).

support, reaching in a condition identical to the 0-mmHg condition. The aim of this second analysis was to deal directly with the question guiding this second experiment, namely whether hip-supported nonsitter infants would resemble the sitter infants by expressing similar overall body engagement in reaching. As in Experiment 1, statistical analyses were first performed comparing the value of forehead–object distance at Frame 1 (2 s prior to contact) with its value at Frame 11 (moment of contact). A 2 (group) × 2 (frame) ANOVA was performed regarding this measure and comparing sitters with nonsitters separately in each of the three conditions. An ANOVA comparing sitters with nonsitters in the 0-mmHg condition yielded no significant main effect of group, $F(1, 14) = 0.46$, a significant main effect of frame, $F(1, 14) = 21.56$, $p < .001$, and a significant group by frame interaction, $F(1, 14) = 5.63$, $p < .03$. Comparison of the sitters with the nonsitters in the 20-mmHg condition yielded no significant main effect of group, $F(1, 14) = 1.85$, a significant main effect of frame, $F(1, 14) = 22.94$, $p < .001$, and a marginally significant group by frame interaction, $F(1, 14) = 3.36$, $p < .09$. Comparison of the sitters with the nonsitters in the 40-mmHg condition yielded no significant main effect of group, $F(1, 14) = 1.65$, a significant main effect of frame, $F(1, 14) = 24.86$, $p < .001$, and no significant group by frame interaction, $F(1, 14) = 0.61$. Statistical analyses pertaining to the value of hand–object distance at Frames 1 and 11 comparing the group of sitter infants with the nonsitters showed significant main effects of frame in all conditions: $F(1, 14) = 21.89$, $p < .0004$, in the 0-mmHg condition; $F(1, 14) = 22.40$, $p < .0001$, in the 20-mmHg condition; and $F(1, 14) = 32.24$, $p < .0001$, in the 40-mmHg condition. Unlike the forehead–object distance measure, the hand–object distance measure yielded no significant group by frame interaction in all three comparisons. This result indicates that sitters and nonsitters manifest comparable amplitude of hand movement during the approach phase of the reach.

Sitters of the first experiment and nonsitters in each of the postural conditions were further compared in trend analyses. Regarding forehead–object distance, tests of a linear and quadratic trend comparing the group of sitters with the group of nonsitters in either the 0-mmHg or the 20-mmHg conditions yielded significant group by frame interactions, respectively, $F(1, 14) = 10.99$, $p < .005$, and $F(1, 14) = 13.94$, $p < .002$, for the linear trend; $F(1, 14) = 5.29$, $p < .037$, and $F(1, 14) = 4.30$, $p < .057$, for the quadratic trend. By contrast, comparing sitters and nonsitters in the 40-mmHg condition, only the test of a quadratic trend yielded a marginally significant interaction, $F(1, 14) = 4.09$, $p < .062$. This latter result indicates that although nonsitters provided with high hip support tend to resemble sitter infants by leaning forward as they reach, differences in the timing of the coordination between reaching and leaning persist. Regarding hand–object distance, analyses of a linear trend yielded a significant group by frame interaction when comparing the group of sitters with the group of nonsitters in either the 0-mmHg or the 20-mmHg conditions, but not in the 40-mmHg condition, respectively, $F(1, 14) = 4.58$, $p < .05$, $F(1, 14) = 4.80$, $p < .04$, and $F(1, 14) = 2.28$, $p < .15$. Although manifesting a comparable amplitude of hand movement, it is only when nonsitters are provided with high hip support that they appear comparable to sitter infants in terms of a linear decrease of hand–object distance during the approach phase of the reach.

Sitters and nonsitters in the three conditions of postural support were compared based on the average correlation ratio between forehead–object and hand–object distance variations during the 2-s approach phase. This average correlation is an index of the relation between reaching and leaning velocities (see Experiment 1). Mean r values were .79 for the sitters of Experiment 1, .39 for the nonsitters in the 40-mmHg condition, .39 in the 20-mmHg condition, and .40 in the 0-mmHg condition. Interestingly, the mean r values for nonsitters in the 0-mmHg condition was .17, when this condition was tested first ($n = 5$ infants), and .79 when it was tested immediately after the 40-mmHg condition ($n = 3$ infants). This observation suggests a strong order effect and possibly a rapid learning of coordinated reaching and leaning movements in the condition of high hip support. One-factor ANOVAs yielded a marginally significant group effect when comparing the sitters with the nonsitters in either the 0-mmHg or 40-mmHg conditions, respectively, $F(1, 14) = 3.53$, $p < .08$, and $F(1, 14) = 3.18$, $p < .09$; and a significant group effect when compared with the nonsitters in the 20-mmHg condition, $F(1, 14) = 6.17$, $p < .02$. These results indicate a higher correlation between reaching and leaning movements associated with the sitter infants compared to the nonsitters in all conditions of postural support, particularly the 20-mmHg condition.

Sitter infants of Experiment 1 were further compared to the nonsitters in the three postural conditions regarding the frequency of coordinated movements between trunk and hand toward the object from one analyzed frame to the next. In particular, frequency of coordinated movements was calculated as the number of instances of simultaneous decrease in hand–object and forehead–object distance from one frame to the next during the 2-s approach phase of the reach (maximum of 10 instances of coordinated movements between Frame 1 and Frame 11). A simultaneous decrease in the two measures was defined independently of its amount by opposition to a simultaneous increase in the two measures, an opposite change, or no change at all from one frame to the next. Figure 4 presents the results regarding the mean frequency of coordinated movements for the group of nonsitters in the different hip support conditions (0 mmHg, 20 mmHg, and 40 mmHg), together with the results obtained with the group of sitter infants of Experiment 1 when performing the same analysis. As indicated in Figure 4, nonsitter infants showed a marked increase in the mean frequency of coordinated movements in the 40-mmHg hip support condition compared with the 0-mmHg and 20-mmHg conditions. In the 40-mmHg condition, nonsitters appeared to express the same mean frequency of coordinated movements between trunk and upper limb(s) compared with the sitter infants of the first experiment. Simple t tests reveal a significant difference between sitters and nonsitters in the 0-mmHg condition, $t(1, 14) = 2.26$, $p < .04$, a marginally significant difference between sitters and nonsitters in the 20-mmHg condition, $t(1, 14) = 1.93$, $p < .07$, and no significant difference between sitters and nonsitters in the 40-mmHg condition, $t(1, 14) = 0.24$, $p < .81$. Overall, the results of this second experiment show that when provided with adequate hip support, nonsitter infants demonstrate increased coordination between trunk and upper limbs in reaching. Provided with the kind of postural support they will eventually self-generate and control in a few weeks developmental time, nonsitter infants resemble sitter infants in their overall body engagement during the approach phase of the reach.

EXPERIMENT 3

Experiments 1 and 2 looked at the morphology of infant reaching during the approach phase of the reach, the analysis ending at the moment of first manual contact with the object.

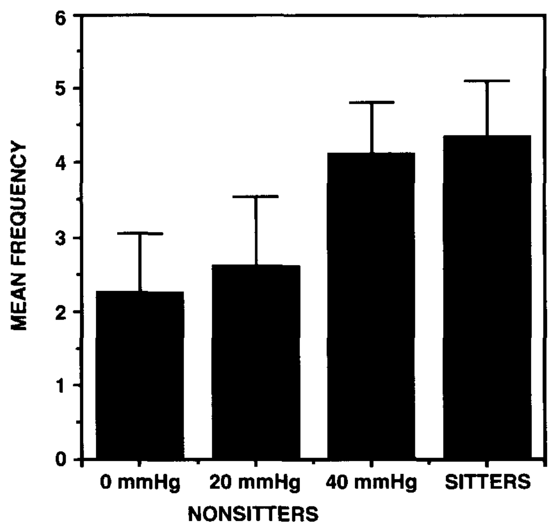


Figure 4. Mean frequency of coordinated trunk and hand movements during the approach phase of the reach for the group of nonsitter infants in the different hip support conditions (0 mmHg, 20 mmHg, and 40 mmHg) and the group of sitter infants of Experiment 1 (no hip support).

Experiment 3 provides an analysis beyond first contact. Object manipulation and exploration during the 2 min following first successful reach was compared in three groups of infants that varied in their ability to control self-sitting (nonsitters, nearsitters, and sitter infants). The question guiding the third experiment was whether the degree of self-sitting ability in 5- to 7-month-old infants correlates with different uses of the hands and apparent changes in the mapping of the infant's prehensile space. Nonsitter, nearsitter, and sitter infants were presented frontally with a large board displaying 15 balls spread across their prehensile space. The working hypothesis was that use of the hands and zones of manual action on the display depends on the infant's degree of self-sitting ability.

Method

Subjects

Thirty infants were tested. The first group consisted of 10 nonsitter infants, 3 females and 7 males, 149 to 175 days of age (*M* age = 162.00 days, *SD* = 7.11). The second group consisted of 10 "nearsitter" infants (see below for criteria), 5 females and 5 males, 137 to 215 days of age (*M* age = 181.00 days, *SD* = 21.12). The third group consisted of 10 sitter infants, 7 females and 3 males, 154 to 256 days of age (*M* age = 210.00 days, *SD* = 30.61). Ten additional infants were tested but not included in the final sample, all nonsitters who failed to engage and reach for the display. As in Experiment 1, group attribution was based on a videotaped pretest examination (see method of Experiment 1 for details). The category of nearsitters was added to include infants who were able to maintain a self-sitting posture for 30 s but with hands leaning against the ground and/or the trunk folding forward on the infant's lap. This category was viewed as intermediary between the inability to sit alone and the ability to maintain upright sitting with hands above the ground. The introduction of this new category was intended to refine the group distinction made in Experiments 1 and 2. Group attribution was systematically confirmed by the infants' parent(s) in a subsequent interview, and there was 100% agreement between two independent observers looking at the videotaped pretest examination. All infants were healthy on the day of testing, and parents reported a normal course of development following a full-term birth. Infants were recruited in the Springfield, MA area

Procedure

Infants were seated in an upright infant seat with low armrests as in the former two experiments. The seat was resting on the floor with a video camera 2.5 m above the infant's head to provide an overhead view. As shown in Figure 5, a display was presented in the frontal plane of the infant and centered at shoulder height. It consisted of a 30-cm high and 15-cm wide white cardboard sheet affixed to a wooden structure supported by an adjustable tripod. The wooden structure gave a slight bend to the cardboard, to provide the infant with equal reachability to all zones of the display's surface. The surface of the display was covered with equally distributed pieces of white Velcro which could support colorful balls, identical to the one used in Experiment 1 and 2. In a first trial presentation (familiarization), the display was presented out of reach of the infant, 2 m away, with one ball attached to the center of the board. The experimenter was kneeling behind the display. When the infant was visually engaged, the experimenter slowly approached the display to within reach of the infant (30 cm away from his/her torso). The familiarization trial ended when the infant touched and detached the ball from the display. If the infant only contacted the ball, the experimenter detached it and handed it to the infant for further exploration. After the familiarization trial, each infant was presented with the display on which 15 balls were attached. The balls were arranged in five columns and three rows, spread across the whole surface of the display (one column of three balls in the center, with two columns on the right hemifield, and two on the left hemifield of prehensile space). The balls were equally spaced horizontally and vertically by 5 cm. In this second presentation, the display was covered with a white sheet and brought to within reach of the infant. The trial started with the sheet being removed by the experimenter, and the display was maintained there for 2 min. The infant was free to interact with the display, touching and eventually detaching the balls. During the presentation, the experimenter gently shook the display which caused the balls attached to it to make a compelling sound. This was intended to maintain the infant's engagement and to invite reaching, touching, and grasping.

Scoring and Analysis. Videotapes were analyzed in real time from the moment the display was within reach of the infant. Scoring focused on six different measures: (a) use of right versus left hand in contacting the object during the familiarization trial (one ball presented at center), (b) proportion of right versus left hand contacts during test trial with the 15 balls on display (i.e., percent of the contacts involving either the infant's right or left hand), (c) number of detached balls, (d) location of the first detached ball during test, (e) location of balls detached over the 2-min presentation of the display, (f) frequency of contacts with either the ipsi- or contralateral hand (crossing of midline) during presentation of the display The rationale behind the choice of these measures was to document the infant's upper-limb use in interacting with the display, as a function of independent sitting ability. Although not aimed at documenting handedness and hand preference per se, some of the measures are an index of right- versus left-hand use considered in relation to the various zones of prehensile space. For all six measures, there was over 90% agreement between two independent observers who scored the video recordings.

Results

During the first trial presentation, where one ball was available at the center of the display (familiarization), the majority (74%) of all infants contacted the object with the right hand, $\chi^2(1, N = 30) = 5.55, p < .05$. By group, 78% of the nonsitters, 60% of the nearsitters, and 70% of the sitters contacted the object with the right

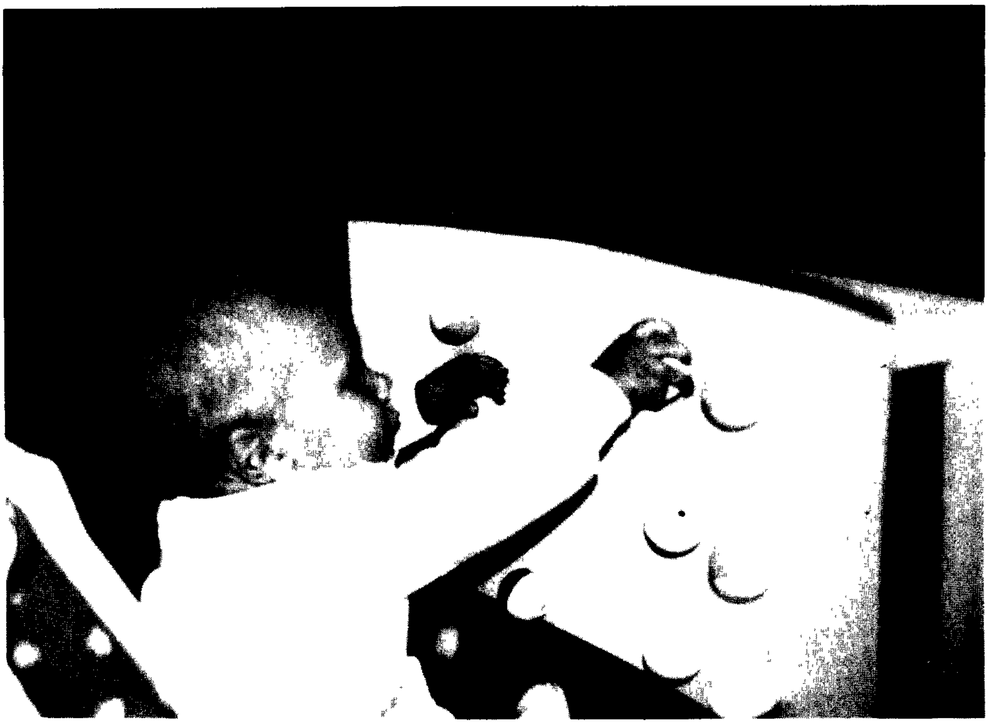


Figure 5. Infant interacting with the 15-ball display of Experiment 3.

hand. In the following presentation, when the display was covered with 15 balls, nonsitter infants continued to show a significant bias toward a right-hand contact with the objects. However, this right-hand bias diminished for the groups of nearsitter and sitter infants. Figure 6 presents for each group of infants the average proportion (%) of right- and left-hand contacts with the balls on the display during presentation. It shows that there is a bias toward right-hand use by nonsitter infants, this bias being reduced for nearsitter and sitter infants who tended to use more equally right and left hands to contact objects on the display. Note that this trend is relative to an upright sitting posture with the multiple-object display presented to the infant. In a well-supported postural condition (i.e., supine, reclined, or prone) and when reaching for a single object presented at midline, nonsitter infants tend to use both hands in reaching (Rochat, 1992). This trend was further analyzed and confirmed with statistical analyses comparing the proportion of right- versus left-hand contacts in each group of infants. A 3 (group) × 2 (hand) ANOVA yielded a significant main effect of hand use, confirming that, overall, infants used their right hands more frequently to contact objects on the display, $F(1, 27) = 5.32, p < .03$. An analysis of the simple effects yielded a significantly higher

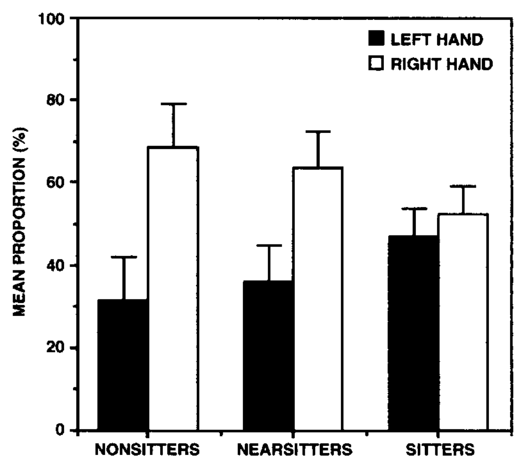


Figure 6. Mean proportion (%) of right- and left-hand contacts with the balls on display during presentation for the group of nonsitter, nearsitter, and sitter infants.

proportion of right-hand contacts for the group of nonsitters, $F(1, 27) = 4.45$, $p < .04$, but no significant differences for the groups of nearsitter and sitter infants. These latter results confirm the trend towards less right-hand bias by nearsitter and sitter infants. This result can be explained by the fact that, typically, nonsitter infants have the left hand encumbered in maintaining balance or stuck under the leaning body as the right hand is busy contacting objects on the display. The lack of postural control appears to constrain the infant in using one hand to contact and detach objects on the display. In other words, the right-hand bias of nonsitters is accentuated due to their lack of postural control and stability. This result documents the link between the achievement of self-sitting posture and the freeing of upper limbs from the encumbrance of maintaining balance. A similar link between the achievement of self-sitting ability and changes in manual engagement was reported by Rochat (1992) within a different experimental context and using a different set of analyses which focused specifically on the relative bimanual engagement of sitter and nonsitter infants as they reached for an object presented at midline. Placed in a posture providing support (supine, prone, or reclined), nonsitters manifest in majority a bimanual engagement as they reach. By contrast, in a seated posture (similar to the condition of the present experiment), the same infants tend to reach in majority with one hand forward, constrained to mobilize the other hand to maintain balance and avoid falling forward as they reach (Rochat, 1992).

In an attempt to analyze what happened after a ball was touched on the display, the frequency of contacts ending with grasping and detaching the ball from the support was scored and compared between the three groups of infants. Results indicate that the frequency of grasping and detaching a ball (maximum 15) during presentation increased significantly with infants' ability to sit (average frequency of 6.8, 7.6, and 10.5 for nonsitter, nearsitter, and sitter infants, respectively). An ANOVA yielded a significant group main effect, $F(2, 27) = 4.81$, $p < .02$. Analysis of the simple effects reveals significant contrasts ($p < .05$) between the group of sitters compared to both the nonsitters and the nearsitters. Note that because of the age confound, other developmental factors might account for this trend.

To assess the relative span of prehensile space by nonsitter, nearsitter, and sitter infants, the first ball that was touched and detached among the 15 on display was recorded. In this assessment, two zones of the display were distinguished: center and periphery zones. The center zone comprised the 3 center balls and the 3 balls just below them. The periphery zone comprised the other balls on the top row and the two extreme left and right columns ($n = 9$). The 3 center balls of the bottom row were not included in the periphery zone as most infants, and in particular nonsitter infants, tended to lean forward over them, causing these balls to become close and central in relation to the infant's posture. Figure 7 presents the proportion of infants in each group who first detached a ball either at the center or the periphery zone of the display during presentation. Figure 7 shows that the overall proportion of balls that were first touched and detached at the periphery of the display increases steadily as a function of the infants' sitting ability. This result captures changes in the expansion of prehensile space as a function of progress in the control of self-sitting posture. The first balls detached by nonsitters are in majority within the center and bottom of the display, whereas nearsitter and, in particular, sitter infants expand the range of first detached balls to the top and periphery of the display. This expansion is independent of the infant's particular situation relative to a

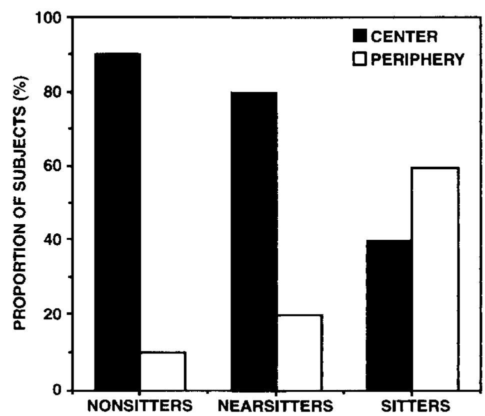


Figure 7. Proportion (%) of nonsitter, nearsitter, and sitter infants who first detached a ball either at the center or periphery zone of the 15-ball display.

fixed height of the display as it is adjusted for each individual infant to be in alignment with the shoulders (see procedure). Similar observations are obtained when looking at the proportion of balls contacted and detached at either the periphery or center zone of the display, over the 2-min presentation. Figure 8 shows again that the overall proportion of balls that were detached at the periphery of the display increases steadily as a function of the infants' sitting ability. Zones of prehensile action appear to be biased toward the center and bottom of the display for the nonsitters, expanding to both the top and the sides of the display for the group of nearsitters and particularly for the group of sitter infants. The number of balls detached from the top was 3 for the nonsitters, 8 for the nearsitters, and 18 for the sitters. The number of balls detached from the sides was 17 for the nonsitters, 19 for the nearsitters, and 26 for the sitters. A 3 (group) × 2 (zone) ANOVA was performed yielding a significant group by zone interaction, $F(2, 27) = 3.54$, $p < .043$. These results suggest that parallel to the development of the ability to sit, there is an expansion of prehensile space. In particular, the zones of manual action are expanding to the top and periphery of the display, reflecting growing control over vertical axis while sitting.

In a final analysis, contacts with balls that were off center on the display (i.e., contacts with either the six balls of the left or the right hemifield relative to the infant) were considered in relation to the ipsilateral or contralateral hand. First, the proportion of "off-center" balls contacted either with the ipsi- or contralateral hand was compared between the group of infants. Results show that on average, nonsitter infants contact off-center balls with the contralateral hand 37% of the time. By contrast, nearsitter and sitter infants show on average only 10% of contacts with the contralateral hand. These results indicate that nonsitters are more inclined to cross midline to contact off-centered objects with the contralateral hand. This trend is confirmed by an ANOVA comparing between groups the proportion of ipsi- versus contralateral contacts with off-center balls, yielding a significant group by laterality interaction, $F(2, 27) = 3.48$, $p < .04$. In subsequent analyses, two types of midline crossing by the contralateral hand were distinguished: midline crossing relative to the display, and midline crossing relative to both the display and the vertical line passing through the infant's nose (nose line). These two types of midline crossing entailed marked differences in trunk and shoulder rotation relative to head orientation. Results show that 43% of midline crossing by nonsitter infants consists of the crossing of both the midline of the display and the infant's nose line. By contrast, only 19% of midline crossing by nearsitters, and 4% by sitter infants, consists of the crossing of both the nose line and the display's midline by the contralateral hand. An ANOVA comparing the three groups of infants relative to the proportion of two crossing types yields a marginally significant group by crossing type interaction, $F(2, 27) = 2.94, p < .07$.

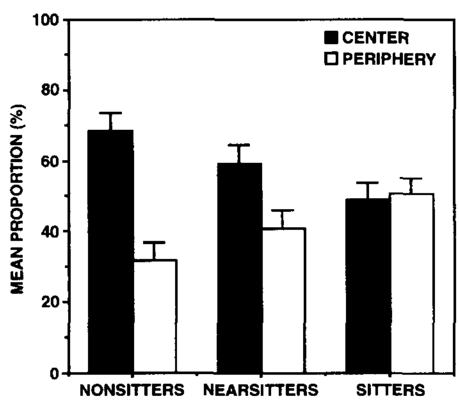


Figure 8. Mean proportion (%) of balls that were detached either at the center or periphery zone of the display, over the 2-min presentation for the group of nonsitter, nearsitter, and sitter infants.

DISCUSSION

In general, results of the three experiments demonstrate that the propensity of young infants to bring their hands in contact with objects in the environment is a whole body engagement. As infants progress towards self-sitting and their first conquest of verticality, reaching behavior is an expression of action control which entails more than eye–hand coordination. The achievement of self-sitting frees the upper limbs from the encumbrance of maintaining balance in an erected posture. This achievement allows coordinated action of the upper limbs and trunk in reaching.

The first experiment demonstrates changes in the morphology of reaching between infants who have achieved control over self-sitting and infants who are in the process of achieving this control yet are unstable when placed in a seated posture with no external body support. Nonsitter infants tend to reach over the 2 s preceding contact, with no simultaneous leaning of the trunk. In contrast, the morphology and control of reaching by sitter infants entails coordinated movements of the upper limbs and trunk. Sitters tend to have a steeper and shorter approach of the hand which takes place over the 1 s preceding contact. This shorter approach phase is combined with a simultaneous and marked forward leaning of the trunk. An important question is whether this new morphology in reaching by sitter infants is triggered by progress in the control of posture, or whether infants learn progressively to use their body differently as they practice reaching and contacting objects in the environment. Rather than mere practice, the second experiment suggests that the morphology of infant reaching and the infant's whole body engagement in reaching is posture dependent. When provided with the adequate scaffolding of external body support, nonsitters are shown to resemble sitter infants, expressing a comparable approach of the hand and a significant increase in coordinated movements of trunk and upper limbs. Yet, trend analyses reveal that differences persist between highly supported nonsitters and unsupported sitter infants. Leaning of the trunk in sitter infants is steeper and occurs during the last second preceding contact. In supported nonsitters, the leaning is more progressive and tends to occur over the 2 s preceding contact. This observation suggests that although there is a resemblance between the supported nonsitters and the sitter infants, they display a different timing in trunk and arm movements. Besides emerging postural control, learning is also an important control variable in the development of coordinated leaning and reaching. Indeed, by comparison to nonsitters, the expression of this coordination in sitter infants becomes clearer and appears to gain in precision as well as in the velocity of its execution.

The third experiment demonstrates that the freeing of upper limbs caused by the emergence of self-sitting abilities is correlated with different use of the hands in object manipulation and exploration. Interestingly, compared with nearsitter and sitter infants, nonsitters show more "lateralization" in reaching, using more one hand over the other to contact objects, even if located in contralateral regions of prehensile space. This phenomenon is due to the fact that the hands of nonsitters are not equally free to interact with the display, one being commonly encumbered in the maintenance of body balance. This is clear evidence of interaction between posture and action in infancy. Progress towards self-sitting will eventually free both hands from the encumbrance of maintaining balance, allowing further progress in bimanual cooperation such as fingering (Rochat, 1989). Another consequence of the encumbrance of one hand in the maintenance of balance is the fact that nonsitter infants show more instances of prehensile space midline crossing to contact off-centered balls on the display. Furthermore, the midline crossing by nonsitter infants often entails extreme shoulder rotation with crossing of the nose line. Typically, the nonreaching hand, by supporting the whole body, is stuck under the body's weight. This fact is another demonstration of the importance of postural control in the development of hand use and the mapping of haptic space. In general, results show that the preferred zones of action on the display expand as a function of the level of sitting ability. Compared with the group of nonsitter infants, nearsitters and sitters tend to act on more off-centered zones of prehensile space with the ipsilateral hand. This use of the ipsilateral hand allows the infant to expand prehensile space equally to the right and left hemifields, without drastic shifts in the body's center of gravity. This expansion is also the expression of a new cooperation between the hands, in the sense of a new bimanual collaboration. With progress in the control of self-sitting and the freeing of upper limbs from the encumbrance of maintaining balance, there is an accompanying division of labor between the hands, each one oriented towards the ipsilateral portion of prehensile space. This new organization of manual action exploits the symmetry of the body and reduces the effort involved in major shifts in the body's center of mass. It is indeed more economical in terms of energy expenditure or physical effort to move one upper limb compared to moving the whole body and rotating the trunk as in the case of the frequent midline crossing observed in nonsitter infants. The maintenance of an upright sitting posture while exploring the display also enables the infant to contact objects in the upper part of prehensile space, which is done increasingly by nearsitter and sitter infants. In general, Experiment 3 demonstrates that with the achievement of self-sitting, the functional mapping of prehensile and haptic space changes. There is a differential use of the hands and an overall expansion of the zones of haptic interaction between the infant and objects in the environment.

In these studies, infants were compared based on their relative motor ability and, in particular, on their relative ability to sit independently. This comparison, although crucial for the study of the interaction between posture and action in development, renders difficult the control of age as a factor. In Experiments 1 and 3, there were obvious age differences between groups. These differences could theoretically account for the presented results, possibly independent of differences in postural abilities. If age is the factor and in order to provide meaning to chronological age, it is necessary to define what is changing as the infant gets older. This research suggests that the development of self-sitting posture, which occurs within a relatively predictable time frame, is a potential control variable of early action development. Future research is needed to specify other factors which might contribute to this development. Experiment 2 was an attempt to control for the age confound, in which the infants were tested in various postural support conditions. These conditions were meant to simulate self-generated support normally achieved within a few weeks of developmental time. A similar approach has been adopted by Gustafson (1984) who studied spatial exploration in prelocomoting infants placed in walkers. More experimental research of this type is needed to overcome the critical issue of age as a confound inherently attached to the study of the relation between posture and action in infancy (Rochat & Bullinger, 1994).

In conclusion, the three experiments demonstrate that the emergence of self-sitting posture is an important controlling variable in how infants reach and contact objects in the environment. They show that the first conquest of verticality opens up new degrees of behavioral freedom for object manipulation and exploration. Additional research is needed to further investigate the interaction between posture and action in infancy, in particular, its potential impact on early perceptual and cognitive development.

REFERENCES

Amiel-Tison, C., & Grenier, A. (1986). *Neurological assessment during the first year of life*. New York: Oxford University Press.

Bayley, N. (1969). *Bayley Scales of Infant Development*. New York: Psychological Corporation.

Bertenthal, B.I., & Campos, J.J. (1991). A systems approach to the organizing effect of self-produced locomotion during infancy. In C. Rovee-Collier & L.P. Lipsitt (Eds.), *Advances in infancy research, Vol 6*. Norwood, NJ: Ablex.

Bruner, J.S., & Koslowski, B. (1972). Visually preadapted constituents of manipulatory action. *Perception, 1*, 3–14.

Clifton, R.K., Perris, E.E., & Bullinger, A. (1991). Infants' perception of auditory space. *Developmental Psychology, 27*, 187–197.

Clifton, R.K., Rochat, P., Litovsky, R., & Perris, E. (1991). Object representation guides infants' reaching in the dark. *Journal of Experimental Psychology: Human Perception and Performance, 17*, 323–329.

Corbetta, D., & Mounoud, P. (1990). Early development of grasping and manipulation. In C. Bard & L. Hay (Eds.), *Development of eye–hand coordination across the life span*. Columbia: University of South Carolina Press.

Field, J. (1976). Relation of young infants' reaching behavior to stimulus distance and solidity. *Developmental Psychology, 5*, 444–448.

Gesell, A. (1946). The ontogenesis of infant behavior. In L. Carmichael (Ed.), *Manual of child psychology*. New York: Wiley.

Gibson, E.J. (1988). Exploratory behavior in the development of perceiving, acting, and the acquiring of knowledge. *Annual Review of Psychology, 39*, 1–41.

Golani, I., & Fentress, J.C. (1985). Early ontogeny of face grooming in mice. *Developmental Psychobiology, 18*, 529–544.

Gustafson, G. (1984). Effects of the ability to locomote on infants' exploratory behaviors: An experimental study. *Developmental Psychology, 20*, 397–405.

Harbourne, R.T., Giuliani, C., & Mac Neela, J. (1993). A kinematic and electromyographic analysis of the development of sitting posture in infants. *Developmental Psychobiology, 26*, 51–64.

Hofsten, C. von. (1982). Eye–hand coordination in newborns. *Developmental Psychology, 18*, 450–461.

Hofsten, C. von, & Lindhagen, K. (1979). Observations on the development of reaching for moving objects. *Journal of Experimental Child Psychology, 28*, 158–173.

Hofsten, C. von, & Ronnqvist, L. (1988). Preparation for grasping an object: A developmental study. *Journal of Experimental Psychology: Human Perception and Performance, 14*, 610–621.

Lockman, J.J., & Ashmead, D.H. (1983). Asynchronies in the development of manual behavior. In L.P. Lipsitt

& C.K. Rovee-Collier (Eds.), *Advances in infancy research, Vol. 2.* Norwood, NJ: Ablex.

Lockman, J.J., Ashmead, D.H., & Bushnell, E.W. (1984). The development of anticipatory hand orientation during infancy. *Journal of Experimental Child Psychology, 37,* 176–186

McKenzie, B.E., Skouteris, H., Day, R.H., Hartman, B., & Yonas, A. (1993). Effective action by infants to contact objects by reaching or leaning. *Child Development, 64,* 415–429.

Page, D., Figuet, G., & Bullinger, A. (1989). A device for the computer processed analysis of video frames. *Journal of Motor Behavior, 21,* 317–322

Piaget, J. (1952). *The origins of intelligence in children.* New York: International Universities Press.

Reed, E.S. (1990). Changing theories of postural development. In M. Woollacott & A. Shumway-Cook (Eds.), *The development of posture and gait across the lifespan.* University of South Carolina Press.

Rochat, P. (1989). Object manipulation and exploration in 2- to 5-month-old infants. *Developmental Psychology, 25,* 871–884.

Rochat, P. (1992). Self-sitting and reaching in 5–8 month old infants: The impact of posture and its development on early eye–hand coordination. *Journal of Motor Behavior, 24,* 210–220

Rochat, P., & Bullinger, A. (1994). Posture and functional action in infancy. In A. Vyt, H Bloch, & M. Bornstein (Eds.), *Francophone perspectives on structure and process in mental development.* Hillsdale, NJ: Erlbaum (pp 14–37).

Rosnow, R.L., & Rosenthal, R. (1989). Statistical procedures and the justification of knowledge in psychological science. *American Psychologist, 44,* 1276–1284.

Trevarthen, C. (1982). Basic patterns of psychogenetic change in infancy. In T.G. Bever (Ed.), *Regressions in mental development Basic phenomena and theories.* Hillsdale, NJ: Erlbaum.

Wahlsten, D. (1991). Sample size to detect a planned contrast and a one degree-of-freedom interaction effect *Psychological Bulletin, 110,* 587–595.

Yonas, A., & Granrud, C.E. (1985). Reaching as a measure of infants' spatial perception. In G. Gottlieb & N. Krasnegor (Eds.), *The measurement of audition and vision during the first year of postnatal life· A methodological overview.* Norwood, NJ: Ablex.

Yonas, A., & Hartman, B. (1993). Perceiving the affordance of contact in 4- and 5-month-old infants *Child Development, 64,* 298–308.

27 April 1993; Revised 11 February 1994 ■