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To Reach or Not to Reach? Perception of Body Effectivities by Young Infants

Philippe Rochat[a,*], Nathalie Goubet[b] and Stefan J. Senders[c]
[a] *Department of Psychology, Emory University, Atlanta, GA, USA*
[b] *FAPSE, Université de Genève, Geneva, Switzerland*
[c] *Cornell University, Ithaca, NY, USA*

Two experiments compared 6-month-old infants as they reach for an object. All were proficient reachers but with different levels of sitting ability. The object was presented at various distances, within and beyond reach of the infant. In the first experiment, the scaling of perceived reachability in infants with different postural abilities (i.e. non-sitter, near-sitter, and sitter infants) was explored. The second experiment investigated the role of proprioception in the scaling of perceived reachability by non-sitter and sitter infants. In general, results suggest that perceived reachability is calibrated in relation to the degree of postural control achieved by the infant. Infants demonstrate a sense of their own situation in the environment as well as a sense of their own body effectivities. Both determine the execution, or non-execution, of reaching for a distal object by young infants. Copyright © 1999 John Wiley & Sons, Ltd.

Key words: infant; posture; reaching

Among all the objects that furnish the environment, only a few are physically reachable and eventually graspable, depending on their size as well as their relative distance to an actor. In general, an object's reachability is co-determined by the characteristics of the object and those of the actor in terms of his/her capacity for action and situation in the environment. By analogy to the concept of co-perception introduced by Gibson (1979), according to which perceiving an object is also perceiving oneself, reaching behaviour implies both object- and self-perception. In addition to perceiving an object, the successful execution of a reach requires the combined monitoring by the actor of his/her situation in relation to the object and his/her *own body effectivities* or capacities for action (Turvey and Shaw, 1987; Rochat, 1995a).

Recent evidence demonstrated that young children perceive and anticipate precisely, if not always accurately, the distance at which a graspable object becomes reachable or not reachable for either the self or for another person (Rochat, 1995b). Children from 3 years of age were shown to scale their

* Correspondence to: Department of Psychology, Emory University, Atlanta, GA 30322, USA.

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perception of an object's reachability for themselves and for another adult. Results demonstrated that such scaling was based on the detection of both the actor's physical dimensions and his/her particular postural situation relative to the object (i.e. sitting in front of the object while prevented to lean forward towards it; standing under the object with either the feet flat on the ground or the possibility of standing on tip toes). Based on a precisely scaled perception of body postures and effectivities, participants anticipated the probable outcome of a reach that would have been performed by either themselves or another full-grown person (Rochat, 1995b). If children appear to appreciate their own postural situation and body effectivities to anticipate the outcome of a reach act, when do they begin to do so and what are the determinants of this ability? In the present study, we explore the postural determinants of perceived reachability in infants that have started to reach but are still developing postural control.

Infants start to reach systematically and successfully at around 4 months (Bayley, 1969; Clifton *et al*., 1993), and the question of whether early reaching already includes such anticipation is still an issue. A few studies on infant reaching have suggested that the perceptual ability to anticipate the outcome of a reach might be an intrinsic part of reaching behaviour from its onset in development. Field (1976) reported that in reaching, young infants are sensitive to the distance that separates themselves from an object. Clifton *et al*. (1991a) reported that 6 month old infants tend not to reach for an object sounding in the dark when presented outside of their sphere of prehension. Yonas and Hartman (1993) showed that this early sensitivity to distance in reaching is scaled to the infant's relative propensity to lean forward while reaching, which expands the limits of prehensile space. Such scaling of perceived reachability was also reported with older (12-month-old) infants reaching with or without a long tool that increased their sphere of contact with the object (McKenzie *et al*., 1993). These findings support the idea that, early on, infants demonstrate a sense of their situation in the environment, precisely reaching or not reaching as a function of distance (Field, 1976), their own body effectivities (Yonas and Hartman, 1993), and the opportunity to use tools (McKenzie *et al*., 1993). It appears that when infants start to reach, they detect the affordable distance at which an object is reachable. They might then learn about other affordances of the object once they bring their hand(s) into contact with it, for example whether it is a sounding object when shaken or dropped on the floor. In other words, the detection of affordable distance for reaching and reaching action *per se* appear to co-emerge in early development (Field, 1976; Clifton *et al*., 1991a). However, the general hypothesis guiding the present research is that from the moment infants begin to reach, the detection of affordable distance for reaching varies as a function of postural development, and in particular the infant's relative ability to sit independently.

Beyond these recent facts, questions remain regarding the determinants of perceived reachability in infancy. Based on the existing data, it is yet unclear what kind of information is used by the infant to scale their perceived reachability and to initiate or inhibit a reach towards a desired object. The general rationale guiding the present research was that the unveiling of information used by young infants to scale their perception of what is reachable will give access to the larger issue of what infants perceive of their own body effectivities and, hence, what they perceive about themselves in relation to possibilities for action in the environment (Rochat, 1995a). Furthermore, between 4 and 6 months, when infants start to reach systematically and with increasing precision for objects around them (von Hofsten and Lindhagen, 1979), they go through marked physical growth and achieve landmark progress in the overall control of their own body posture (Amiel-Tison and Grenier, 1986; Rochat and Bullinger, 1994). The general consequence of these developmental changes is that they increase their range and potentials for action on objects. Hence, a fundamental question is the extent to which infants are attuned to these changes as they interact with objects in the environment. The general hypothesis that guided the present research was that from the moment infants reach, they demonstrate scaling of their reaching activity in relation to their relative ability to maintain body balance (i.e. sit independently). In other words, we explore the possibility that, early in reaching development, the perception of the distance at which an object is reachable is scaled to the relative ability to maintain postural balance. Accordingly, we think that from the moment infants start to reach, the development of perceived reachability (i.e. an object's affordance for reaching) depends on the development of postural control (i.e. the ability to sit).

When infants start to reach, they are faced with the major constraint of maintaining the balance of their whole body as they move their hand(s) toward the object. Postural control and adjustment is an integral part of reaching behaviour (Rochat, 1992; Rochat and Bullinger, 1994). Interestingly, at around 4 months, when infants start to reach systematically and successfully, they are still greatly dependent on the external body support provided by caregivers. Typically, early reaching is observed as infants are fastened onto specially designed infant seats (von Hofsten and Lindhagen, 1979; Trevarthen, 1982; Thelen *et al.*, 1993) that compensate for the infants' lack of postural control, and in particular for their lack of independent sitting ability. They provide the external body support infants need to *scaffold* the whole body and free the upperlimbs from the encumbrance of maintaining balance (Rochat, 1992). Seats and other devices compensate for what infants will eventually generate on their own within a few weeks of developmental time. By 6 months, and approximately 8 weeks after the onset of systematic and successful reaching, infants show the first signs of an ability to sit on their own, independently of any external body supports (Bayley, 1969). The developmental lag between the emergence of reaching and sitting abilities provides a unique opportunity to capture what infants perceive of their own body (i.e. their own effectivities or capacity for action) and their own situation in the environment when reaching. In particular, it provides an opportunity to determine whether they are attuned to their current postural constraints (i.e. their relative ability to sit and stretch forward) when reaching towards a distal object (i.e. an object located either within or slightly out of reach).

The two experiments reported here compared 5–6-month-old infants, all proficient reachers but with different levels of sitting ability. Objects were presented to them for reaching, placed at different locations within or outside their own sphere of prehension. In the first experiment, the scaling of perceived reachability in infants with different body effectivities (non-sitters, near-sitters and sitters) was explored. The second experiment investigated the role of proprioception and balance constraints in the scaling of perceived reachability by non-sitter and sitter infants.

EXPERIMENT 1

Experiment 1 investigates the relative scaling of perceived reachability as a function of young infants' ability to sit independently. As infants develop self-sitting abilities, they increase their coordination between trunk and upper-limb movements in reaching (Rochat and Goubet, 1995). Accordingly, such coordination changes their own body effectivities in reaching by expanding their sphere of prehension and substantially increasing their skeletal degrees of freedom. The question guiding the research was then to what extent the infants' decision to reach for distal objects reflected the actual expansion of the limits of prehensile space that accompanies the development of self-sitting abilities. In other words, the specific aim was to document whether perceived reachability by young infants was scaled, determined by postural development, and in particular by the landmark development of independent sitting. Yonas and Hartman (1993) already reported that perceived reachability by 4–5-month-old infants depended on their relative inclination to use their trunk in reaching while sitting on an infant chair. However, it is not clear whether these infants differed with regard to their general ability to sit independently. The present research is an attempt to replicate and expand the original findings of Yonas and Hartman (1993) by inserting them into the larger context of the early interaction between postural, perceptual, and action development.

Reaching was analysed in relation to an object presented at various distances within and outside the infant's sphere of possible prehension. The 5–6-month-old infant participants were screened and compared based on their relative ability to sit on their own. Overall body engagement in reaching by non-sitter, near-sitter, and sitter infants was compared relative to the different distances that the object was presented at. The working hypothesis was that as a function of the development of sitting ability and the parallel emergence of new degrees of behavioural freedom, the infants' perception of the limits of their prehensile space expands. The hypothesis stated a link between the achievement of self-sitting posture and an expansion of the perceived distance at which an object is reachable, or not reachable.

Method

Participants

Thirty infants were tested, divided in three groups of ten infants. The first group consisted of ten 'non-sitter' infants, five girls and five boys, 138–201 days old (mean = 157, S.D. = 18.5). The second group consisted of ten 'near-sitter' infants, six girls and four boys, 125–191 days old (mean = 163, S.D. = 19.5). The third group consisted of ten 'sitter' infants, five girls and five boys, 174–221 days old (mean = 192, S.D. = 14.4). Twenty-six additional infants were tested but not included in the final sample, five because they failed to reach, and 21 because they became fussy or too agitated before completing the test. This relatively large attrition rate is due in part to the long testing session required by the procedure (on average 25 min) and its repetitive character.

Group attribution (non-sitter, near-sitter and sitter infants) was based on a videotaped pre-test 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 non-sitters. The group of near-sitters included infants that 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 an intermediary between the inability to sit alone and the ability to maintain upright sitting with hands above the ground. Group attribution was systematically confirmed by the infant's parent(s) in a subsequent interview and there was 100% agreement between two independent observers on group attribution that analysed all the videotaped pre-test examinations.

All 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, MA area. Approximately 90% of the infants were Caucasian from middle-income families.

Apparatus and Procedure

Infants were seated in an upright infant seat with low armrests so as not to constrain arm movements. Infants were strapped at the waist, not preventing them from leaning forward but preventing them from falling off the seat. The back of the infant seat was aligned 80° relative to the floor. As described in Figure 1, the infant seat was resting on a platform supported by a central axle allowing movement in the forward and backward direction relative to the infants. The movement of the platform was constrained by two spring scales (Braun AG kitchen scales type 4243), placed under each end of the platform. After aligning each scale's dial on a zero position with the infant placed in the seat and his/her back contacting the back of the seat (calibration of baseline posture), the device allowed each shift of the subject's centre of pressure in the forward and backward direction to be translated into weight gain or weight loss observable on either the back or the forward scale (range 0–5 lb. in eighths of a pound). The scales were used as one of the co-occurring indices of *reach*

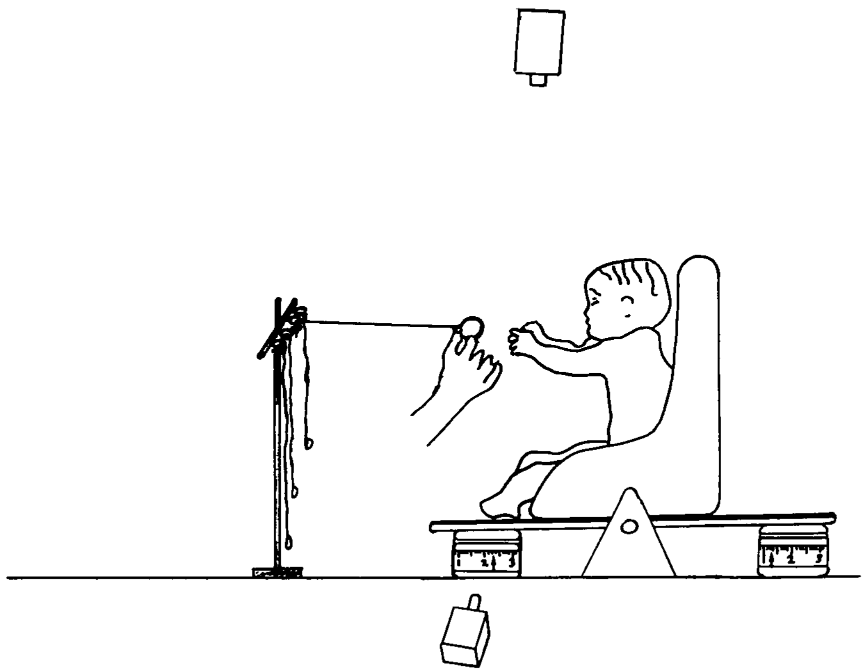

Figure 1. Schematic drawing of the apparatus. The experimenter kneeled beside the measuring distance device that was facing the infant, holding the object between the thumb and index of his right hand.

attempts (see definition and details below). During testing, infants were videotaped with one camera affixed to a tripod directly overhead, approximately 2 m away from the top of the infant's head. A second video camera filmed the dial of the forward scale under the platform. The image of both cameras (overhead view and forward scale's dial) were synchronized and mixed to appear on a split screen including a digital timer for subsequent frame-by-frame analyses.

A colourful, hollow plastic ball, 4 cm in diameter, containing a steel ball bearing, 4 mm in diameter, that produced a compelling sound when agitated was presented twice to the infant at each of four different distances. At each distance, the object was centred and in alignment with the infant's shoulders. It was continuously shaken by the experimenter to produce sound and keep the infant engaged. The experimenter kneeled beside the measuring distance device (see below) that was facing the infant and held the object between the thumb and index of his right hand (see Figure 1). The distances at which the object was presented were determined relative to the combined alignment of the object with the shoulders and of the *toes* of the seated infant, corresponding to the most outward part of the infant's body in the frontal plane. The experimenter aligned the object perpendicular to the infant's toes. This distance was the nearest and referential distance based on which all others were determined. This nearest distance placed the object about 30 cm from the infant's torso with the back leaning against the back of the seat. The other three distances expanded from this referential distance by *12 cm*: Distance $2 = \text{toes} + 12$ cm; Distance $3 = \text{toes} + 24$ cm and Distance $4 = \text{toes} + 36$ cm. The object presented at Distances 1 and 2 was within reach of the infant. At Distance 3, it was at the limit of prehensile space. The infant could eventually touch it, but only with extreme stretching forward of the trunk and upperlimbs. At Distance 4, the object was out of reach for all infants. In order to accurately present the object at the different distances, a device was used consisting of a piece of wood ($30 \times 5 \times 2.5$ cm) supported at shoulder height in front of the infant by an adjustable metal stand. Four screw eyes were set into the wood, centrally located and at shoulder height of the infant, 2.5 cm apart on the horizontal plane. Through each of these screw eyes was passed a nylon cord with a loop tied in the end, each corresponding to one of the four distances. Beneath each screw eye, the cord passed first through a clothes pin, and then through a locking plastic clamp. The experimenter adjusted the length of each cord by extending it to the desired length (corresponding to the four distances), which was maintained by the clothes pin, and then locked that length into place for the duration of the experiment using the plastic clamp. The experimenter passed the loop at the end of each cord over the middle finger of his presenting hand for each presentation, thereby fixing the distance between the presented object and the infant. At a particular distance, an experimental presentation ended with the infant either touching or grasping the object held by the experimenter or, if no reach occurred, after 30 s. Time intervals between object presentations were approximately 30 s.

Infants were presented with a total of two 5 trial blocks. In each of the two trial blocks, first and last presentations were at the nearest distance as a way to assess the level of infants' motivation to reach all through testing. The order of the three farther distance presentations within a block was counterbalanced over infants of each group.

Scoring and Analysis

Only infants who reached successfully for all four object presentations at the nearest distance were scored and included in the final sample of subjects (see attrition rate in Subjects section above). The videotapes were first scored in a real time analysis to determine whether the infant demonstrated either a successful reach (contact with the object), or an attempt to reach ('reach attempt') for the object at a particular distance. Operational criterion for a reach attempt corresponded to the behavioural co-occurrence of gazing at the object with extension of one or both hands toward the object, together with a forward weight shift as recorded on the scale below the platform (see technique above). Weight shift was indexed by 0.125 lb increments. In other words, a reach attempt corresponded to combined gazing at the object with manual extension and forward weight shift of a minimum of 0.125 lb. These co-occurring measures were scored based on the videotaping.

From a separate scoring of the videotapings, *gazing* at the object by the infant during the presentation was analysed in real time using a multichannel event recorder program written for an Apple Macintosh computer. Based on the recording of the overhead video camera, the computer clock was set on at the beginning of presentation and off at the end by the pressing of a particular key on the computer's keyboard. During presentation, gazing at the object was scored and entered on one channel of the event recorder program by pressing another key. Pressure on the key was interrupted when the infant stopped gazing at the object. Gazing was operationally defined as episodes during presentation when the infant's nose was pointing towards the object with his/her face parallel to the object. The program computed gazing duration in percent of total presentation, as well as frequency of looking at and away from the object.

Finally, based on the overhead view of the infant, a frame-by-frame analysis was performed to measure the infant's forehead-to-object distance in the course of object presentation. This measure was used to assess the mean and range of relative eye-to-object distance during a trial presentation. For this analysis, a computerized analysis of frozen video images technique (Page *et al.*, 1989) was used with a sampling of one image every 2 s over object presentation, until the infant contacted the object or the 30 s presentation elapsed. Using a cursor on the frozen image, the X and Y coordinates of a fixed point on the object and on the infant's forehead (based on a 0.5×0.5 cm piece of white tape placed at midline on the infant's forehead hairline, clearly visible on the overhead camera view) was recorded and stored by the 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 was limited to two dimensions and did not allow recording of movement and distance changes in three dimensions. All analyses were relative to the overhead bidimensional view provided by the camera placed above the infant. Using this technique, and as an index of head mobility in relation to the object, for each presentation (30 s or less) we calculated the average forehead-to-object distance and the range of variation.

Two independent observers scored the videotapings. There was 100% agreement on the frequency of successful reaches and reach attempts, as operationally defined. Reliability for the data issued from the event recorder program and the frame-by-frame analysis was assessed on 20% of all trial presentations with Pearson product–moment correlation coefficients (r). Coefficients for all measures were above 0.85.

Results

In general, the frequency of contacts with the object for all trial presentations decreased as a function of distance, this decrease being different for the three groups of infants. For the group of non-sitters, the proportion of infants contacting the object decreased by 50% at Distance 2 where the object was still within reach of the infant. In contrast, for the group of near-sitter and sitter infants, over 80% of the infants contacted the object at Distance 2. A one-way ANOVA comparing mean frequency of contacts at distance 2 (values of 0, 1, or 2 contacts with pooled trial presentations) yielded a significant group effect ($F(2,27) = 5.26$, $p < 0.01$). *Post hoc* Tukey tests indicated significant contrasts ($p < 0.04$) between the group of non-sitters (mean = 1.0, S.D. = 1.05) and the two other groups (mean = 1.8, S.D. = 0.42 for near-sitters; mean = 1.9, S.D. = 0.32 for sitters). For all groups, less than 20% of the infants contacted the object at Distance 3 where the object was still reachable when upper body and arm were fully extended. The small number of contacts at Distance 3 and the absence of contacts at Distance 4 did not allow statistical comparisons. The results indicated that frequency of contacts with the object at Distance 2 depended on the infant's ability to maintain self-sitting. They suggest a relation between the perceived limits of the infant's prehensile space and the infant's developing ability to sit on his/her own.

A 3 (Group) $\times$ 3 (Distance: 2, 3 and 4) mixed design ANOVA[1] on the mean frequency of reach attempts in both trial blocks (values of 0, 1, 2, with pooled trial presentations) yielded a marginally significant main group effect ($F(2,27) = 3.19$, $p < 0.057$). *Post hoc* Tukey tests revealed a significant difference between the group of non-sitter and sitter infants ($p < 0.05$). The ANOVA also yielded a main effect of distance ($F(2,54) = 45.76$, $p < 0.0001$). *Post hoc* Tukey tests indicated significant contrasts between Distances 2 and 3, 2 and 4, 3 and 4 ($p < 0.05$).

Regarding gazing at the object, its proportion over total object presentation decreased as a function of distance for all three groups of infants. In general, infants tended to look proportionally less at the object as a function of distance, this trend being analogous in both trial blocks (overall means of 80%, 75%, 58%, 49%, for Distances 1–4, respectively). A mixed design 3 (Group) $\times$ 2 (Trial block) $\times$ 4 (Distance) ANOVA revealed a highly significant Distance main effect ($F(3,81) = 30.74$, $p < 0.0001$). *Post hoc* Tukey tests indicated significant differences between Distances 1 and 3, 1 and 4, 2 and 3, 2 and 4 ($p < 0.05$).

In contrast, the mean duration of first gaze at the object during presentation increased as a function of distance. First gaze duration doubles on average for presentations at Distance 4 (mean = 6 s) compared to Distance 1 (mean = 2.60 s) and increased steadily in between (mean = 4.8 and 6.23 s for Distances 2 and 3, respectively). Mixed design ANOVA yielded a significant Distance main effect ($F(3,81) = 8.54$, $p < 0.0001$). *Post hoc* Tukey tests showed significant differences between Distance 1 and the three other distances ($p < 0.05$). ANOVA also revealed a significant Group main effect ($F(2,27) = 4.28$, $p < 0.03$), first gaze duration being overall higher for the non-sitters compared to the near-sitter and sitter infants (Tukey test, $p < 0.05$). If we consider first gaze duration as a *potential* index of visual exploration within the context of a preparation to reach, these results would demonstrate a sensitivity to distance and a link between this measure and the degree of postural control achieved by the infant.

Further indication of this phenomenon is the fact that the average number of episodes of looking at the object and away from it (frequency of gazing) during presentation increased steadily with distance for all groups and in both trial

Table 1. Average and range of head–object distance in centimetres during object presentation at Distances 3 and 4 for the three groups of infants

	Distance 3	Distance 4
Non-sitters	27	39
	(18–36)	(29–44)
Near-sitters	28	35
	(20–35)	(19–46)
Sitters	28	36
	(17–35)	(22–43)

blocks (mean = 1.2, 2.3, 4.0 and 4.7, respectively; $F(3,81) = 57.39$, $p < 0.0001$). *Post hoc* Tukey tests indicated significant differences between Distance 1 and all the other distances, as well as Distance 2 with Distances 3 and 4 ($p < 0.05$). Moreover, there was a significant Group-by-Distance interaction ($F(6,81) = 3.58$, $p < 0.003$). Analyses of simple effects revealed that this interaction rests on the fact that non-sitters and near-sitters showed a marked increase in frequency of gazing between Distances 1 and 2, while sitter infants showed a marked increase between Distances 2 and 3 only. Again, this suggests a differentiated sensitivity to distance as a function of postural development.

Finally, results of the frame-by-frame scoring of forehead–object distance during each presentation indicated that although the average of this measure co-varied positively with object distance, there was a wide range of values across infants (see Table 1). We observed numerous instances where the average forehead–object distance co-varied *negatively* with object distance. In particular, for one-third of all infants, the average forehead–object distance during presentation at Distance 4 was equal or smaller compared to presentation of the object at Distance 3. These results suggest that the absolute forehead–object distance (hence the retinal size) did not determine the infant's perception of whether the object was reachable or not.

Results of Experiment 1 showed that infants were sensitive to small differences in distance between themselves and an object (12 cm). Infants use this sensitivity to distance to control whether or not to reach for an object. Furthermore, results showed that the infants' decision to reach for an object combines their sensitivity to the distance separating them from the object and their developing postural control (i.e. their relative ability to sit).

Comparison of age between the group of non-sitters and sitters as well as near-sitters and sitters yielded significant t tests (respectively $t = -4.53$ and 3.62, $p < 0.02$). These significant differences point to the eventuality of an age confound. Interestingly, this eventuality is dismissed when comparing the group of non-sitters and near-sitters. The average age difference between these two groups was only 7 days and t tests comparing them in terms of age in days yielded non-significant results. Despite this age equivalence, we found significant differences in reaching contacts and frequency of gazing between non-sitter and near-sitter infants. This suggests that postural development rather than age *per se* underlie these observations.

Discussion

Self-sitting allows the systematic coordination between reaching and forward leaning of the trunk, which in turn expands the limits of the infant's prehensile space (Rochat and Goubet, 1995). This first experiment provides evidence that the perceived limits of the infants' prehensile space matches the level of their relative sitting ability, and hence their relative forward stretchability while maintaining an upright sitting posture. Infants' perceived reachability integrates their relative effectivity in leaning forward without losing balance. The results indicated that reaching or not reaching by young infants is based on an accurate sense of their own body effectivity: a sense of their relative ability to maintain postural balance while reaching forward towards a distal object.

One question is whether infants might have improved their reaching over the ten presentations (two blocks of five presentations) of the object at the various distances. Our observations did not provide any clear evidence of such learning or change in reaching strategy over the presentation time. Infants were all proficient reachers and to be included in the study needed to reach for the object at the proximal distance during the first and last trial presentation. This controlled for fatigue and habituation. Furthermore, because the order of presentation at Distances 2, 3 and 4 was counterbalanced, there was no optimum regularity for distance learning. *Post hoc* analyses did not yield any apparent systematic order effect comparing each repeated distance presentation.

Finally, the great variation observed among infants and across presentations regarding the range and average forehead–object distance suggests that the distance at which an object is perceived as reachable or not reachable is probably not determined in reference to the infant's head, but in relation to a more global and stable (although developing) body schema. This schema is hypothetically construed as an *intermodal sense of the body*, perceived by the infant as a functional whole situated in the environment and endowed with particular capacities for action (effectivities).

To test further the early onset of an intermodal sense of the body in the context of reaching behaviour, we performed a second experiment with infants as close in age as possible (185 days on average or 6 months), but who had different postural control abilities (non-sitter vs. sitter infants). The rationale was to manipulate directly the postural and proprioceptive constraints imposed on the infant while presented with an object to reach. The idea was to analyse the extent to which these constraints determine young infants' perceived reachability, whether they can or cannot yet sit independently.

EXPERIMENT 2

Non-sitter and sitter infants were tested in two conditions, one in which a weight was attached to each hand of the infant and the other with only light bracelets. When reaching, this weight brought forward the infant's centre of mass and, therefore, reduced the actual extent of the infant's maximum reachability (also see Rochat and Wraga, 1997, for a similar technique and rationale used with adult participants). This manipulation allowed the investigation of the eventual scaling of perceived reachability in relation to both the infant's relative ability to sit and the presence or absence of the weight constraint. The rationale was that in addition to the impact of postural development, the manipulation of weight constraint would inform on the ability by young reachers to scale their perceived reachability based on proprioceptive information. The question guiding the research was to what extent young infants perceive reachability in relation to the presence or absence of the additional load that, if not preventing reaching, changes the amount of effort required by them to contact the object. Scaling of perceived reachability in relation to such proprioceptive information would suggest that infants already have a remarkably adjustable sense of their own situation and body effectivities in the environment. It would also indicate that proprioception is actively used by the infant to guide reaching for objects and to detect what they afford for action.

Only two groups of 6-month-old infants were compared depending on their ability or inability to sit independently with their hands above the ground (non-sitter and sitter infants). The reason for comparing only non-sitters and sitters was to achieve a better control for a potential age confound. We compared two groups of infants with different postural abilities but similar ages (see Participants below). Note that to achieve this goal and in contrast with the first experiment, the group of non-sitters included *both* non- and near-sitters.

Method

Participants

Thirty-two infants were tested, divided in two groups—'non-sitter' and 'sitter'. The 'non-sitter' group consisted of 14 infants, six girls and eight boys, 166–203 days old (mean = 182 days, S.D. = 11.9). The 'sitter' group consisted of 18 infants, eight girls and ten boys, 173–216 days old (mean = 195 days, S.D. = 14.52). A t test comparing the two groups by age in days was significant ($p < 0.01$). Fifteen additional infants were tested but not included in the final sample, five because they failed to reach and ten because they became fussy. Again, this relatively large attrition rate is due in part to the long testing session required by the procedure (on average 25 min) and also probably to its repetitive character. As in Experiment 1, group attribution (non-sitter and sitter infants) was based on a videotaped pre-test examination. 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 non-sitters. Again, group attribution was systematically confirmed by the infant's parent(s) in a subsequent interview and there was 100% agreement between two independent observers on group attribution that analysed all the videotaped pre-test examinations. All 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, MA area. Approximately 90% of the infants were Caucasian from middle-income families.

Apparatus and Procedure

The same apparatus and basic procedure used in Experiment 1 was used in the present research (see Method of Experiment 1 for details). As in Experiment 1, infants were seated in an upright infant seat resting on a platform supported by a central axle allowing movement in the forward and backward direction relative to the infants. The same colourful object was presented to the infant successively at four distances in the same counterbalanced order as in Experiment 1. There were two blocks of five test trials—one block with weights (200 g, 'weight' condition) attached to both of the infant's wrists, and the other with a light bracelet (5 g, 'no weight' condition) attached to both wrists. In each of the two conditions, first and last presentations were at the nearest distance. The order of the three farther distance presentations within a condition and the order of condition was counterbalanced over infants of each group. At a particular distance, an experimental presentation ended with the infant either touching or grasping the object held by the experimenter, or if no reach occurred, after 30 s. Time intervals between object presentations were approximately 30 s (see Method of Experiment 1 for further details). At the beginning of testing, a 6 cm bracelet made of a light material weighing 5 g and including a built-in pocket where weight could be added was put on each of the infant's wrists. The bracelet was tightened with Velcro. In the weight condition, 195 g of weight (small bag of lead fishing weights) was slipped into the built-in pocket of each bracelet. With the bracelet on, and prior to each trial block, the infant was familiarized with the ball by placing it in their hand for a 30 s period of free exploration and while the experimenter calibrated the four distances for the particular infant (see Method of Experiment 1 for details). In the weight condition, infants demonstrated no particular effort in lifting their arm and reaching for the object at the nearest distance. The 200 g weight was chosen based on pilot trials which indicated that this weight provided the maximum constraint while still being manageable for the infant in terms of lifting and moving the upperlimbs. Only infants who reached successfully at all presentations of the object at the nearest distance (Distance 1) were included in the study.

Scoring and Analysis

Scoring and analysis were analogous to those used in Experiment 1 (see Method for details). Using the same criteria and scoring technique relative frequency of contacts, reach attempts, percent gazing, first gaze duration during presentation, and frequency of gazing at the object were analysed. These measures were used as dependent variables of perceived reachability as a function of the four distances and the weight/no weight conditions (independent variable).

Again, two independent observers scored the videotapings. There was 100% agreement on the frequency of successful reaches and reach attempts, as operationally defined. Reliability for the data issued from the event recorder program regarding all gazing measures was assessed for 20% of all trial presentations with Pearson product–moment correlation coefficients (r) and all were above 0.90.

Results

Overall, the frequency of contacts with the object decreased as a function of distance for both groups of infants and in both experimental conditions (no weight vs. weight). Frequency of contacts decreased slightly between Distances 1 and 2 (by 30% for the non-sitter infants and 20% for the sitters). However, for all groups, less than 10% of the infants contacted the object at Distance 3 where the object was still reachable when stretching out. The analysis of reach attempts yielded more interesting results.

As indicated in Figure 2A and B, the overall proportion of infants expressing reach attempts decreased as a function of distance, this decrease depending on the group of infants. All sitter infants (Figure 2B) manifested a reach attempt when the object was presented at Distance 2, as only 70% of non-sitters did, regardless of the weight or no weight condition (Figure 2A). In contrast, the proportion of sitter infants expressing reach attempt(s) started to decrease markedly at Distances 3 and 4. At a descriptive level, these results are congruent with those of Experiment 1, suggesting that attempts to reach for the object at farther distances depend on the infant's ability to maintain self-sitting; hence, there is a link between the perceived limits of the infant's prehensile space and the developing ability to sit independently. However, unlike in the preceding experiment, we were unable to provide statistical support for these observations.

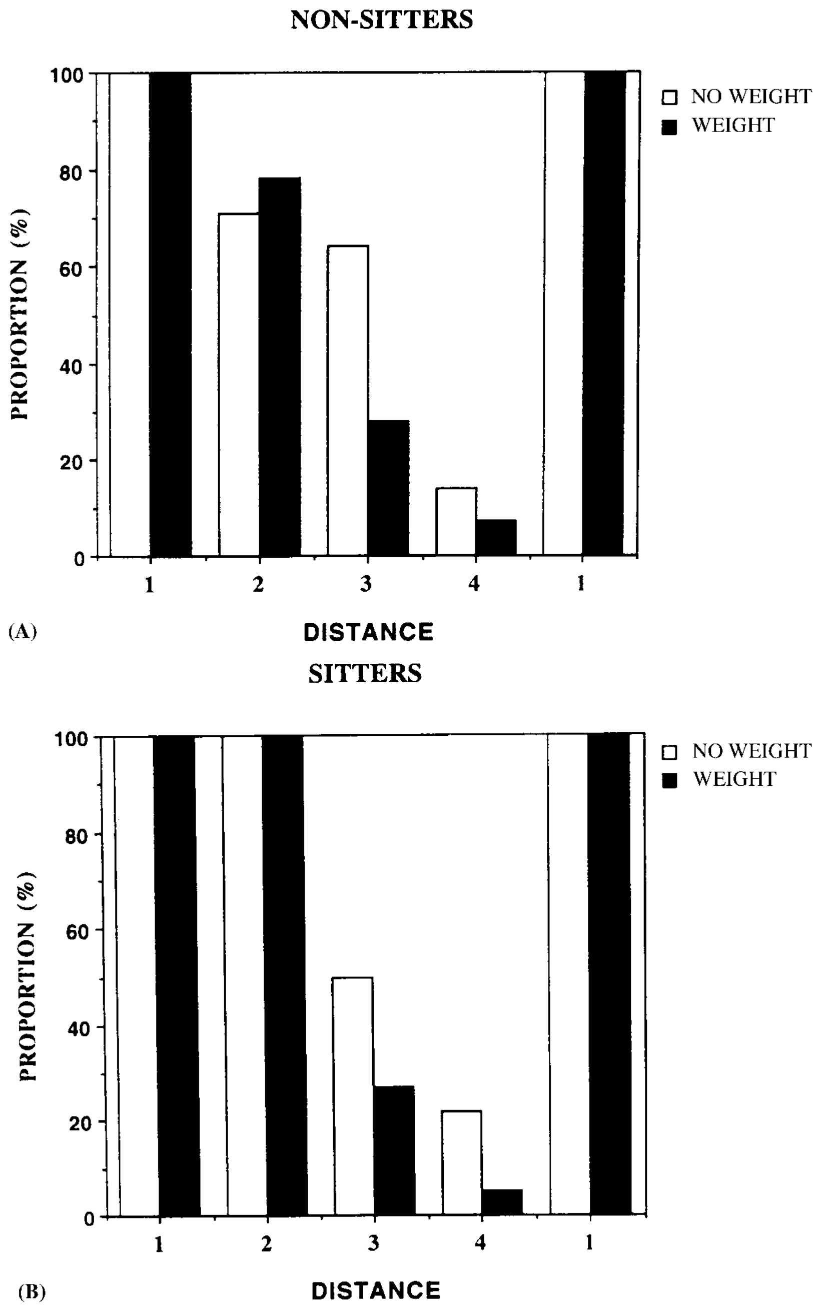

Figure 2. Proportion in percent of (A) non-sitter and (B) sitter infants, in either the No Weight or Weight condition, demonstrating at least one reach attempt at the various distances the object was presented: at the toes (Distances 1 and 5), toes + 12 cm (Distance 2); toes + 24 cm (Distance 3); toes + 36 cm (Distance 4).

In relation to conditions at Distances 3 and 4, the proportion of reach attempts by infants of either group was markedly greater in the no weight compared to the weight condition (respectively mean = 37.5%, S.D. = 38.10 and mean = 17.18%, S.D. = 30.08). By computing values of one or zero for evidence or no evidence of reach attempt, respectively, at Distances 3 and 4 (pooled to enable the ANOVA), a 2 (Group: non-sitters vs. sitters) × 2 (Condition: weight vs. no weight) mixed design AVOVA was performed yielding a significant main effect of condition ($F(1,30) = 5.69$, $p < 0.02$). No significant effect of group or any significant interactions were found. These results confirm that in the no weight condition, infants of both groups manifested significantly more attempts to reach for the object at the limit and beyond their sphere of prehension (i.e. Distances 3 and 4).

Regarding gazing at the object, its proportion (%) over total object presentation time decreased as a function of distance for both groups of infants (Distance 1 mean = 81.75, S.D. = 8.24; Distance 2 mean = 75.85, S.D. = 15.63; Distance 3 mean = 62.92, S.D. = 19.22; Distance 4 mean = 63.63, S.D. = 17.91). In general, infants tended to look proportionally less at the object as a function of distance, this trend being analogous in both trial blocks. A 2 (Group) × 2 (Condition) × 4 (Distance) ANOVA revealed a highly significant Distance main effect ($F(3,90) = 16.49$, $p < 0.0001$). *Post hoc* Tukey tests yielded significant results in the pair comparison of Distances 1 and 2, 1 and 3, 1 and 4, 2 and 3, and 2 and 4 ($p < 0.04$). These results confirmed that, in general, infants tended to look proportionally less at the object as a function of distance, this trend being similar in both conditions (weight and no weight). Note that for these analyses, and based on the data obtained in the previous experiment, results obtained at the beginning and end baseline distances were collapsed.

In contrast, and as in Experiment 1, the mean duration of first gaze at the object during presentation increases as a function of distance, progressively doubling between Distances 1 and 4. A 2 (Group) × 2 (Condition) × 4 (Distance) ANOVA yielded a significant distance main effect ($F(3,90) = 8.57$, $p < 0.0001$). *Post hoc* Tukey tests yielded significant results in the pair comparison of Distances 1 and 3, 1 and 4, and 2 and 4 ($p < 0.01$). First gaze durations were: at Distance 1 mean = 2.6, S.D. = 1.28; Distance 2 mean = 3.23, S.D. = 2.19; Distance 3 mean = 4.54, S.D. = 3.22; and Distance 4 mean = 5.20, S.D. = 3.55. No significant effect of weight, group, nor any significant interactions were found. Considering first gaze duration as an index of visual exploration within the context of a preparation to reach, these results demonstrate sensitivity to distance. However, and partly in contrast with the results of Experiment 1, they do not suggest any significant dependence to either group or condition variables.

Further indication of this phenomenon is the fact that the average episodes of looking at the object and away from it (frequency of gazing) during presentation increases steadily with distance for all groups and in both trial blocks ($F(3,90) = 36.54$, $p < 0.0001$). Frequency of gazing were: Distance 1 mean = 1.20, S.D. = 0.3; Distance 2 mean = 1.69, S.D. = 0.96; Distance 3 mean = 3.16, S.D. = 1.02; and Distance 4 mean = 2.70, S.D. = 0.95. *Post hoc* Tukey tests yielded significant results in the pair comparison of Distances 1 and 3, 2 and 3, 1 and 4, and 2 and 4 ($p < 0.01$). No significant Group-by-Distance interaction was found.

Discussion

The results of this second experiment replicated in part what was found in the previous study. Measures pertaining to the frequency of contacts, reach attempts and all gazing measures indicated that, overall, infants are perceptually sensitive to small differences in distance between themselves and an object (12 cm). They use this sensitivity to control whether to or not to reach for an object. However, results for this experiment did not provide reliable evidence that the decision to reach depends on the infant's relative self-sitting ability. One possible reason for this contrasted finding is that in this second experiment, non-sitter and near-sitter infants were pooled. This means that the non-sitter group included infants that were probably very close to sitting independently, although not passing our pre-test assessment. This fact might have contributed to the failed replication of the significant effect of sitting ability found in Experiment 1. Furthermore, it is possible that the presence of weights might have overridden differences in sitting ability as a factor of perceived reachability. Accordingly, the infants' decision to reach for the object was based on a sensitivity to the absence or presence of the weights that shifted their centre of mass. This sensitivity did not interact with the infants' relative achievement of self-sitting control. It appears that the varying weights attached to the wrists determined the infants' decision to reach or not to reach for the object when the object is at critical distances (i.e. Distances 3 and 4). At these distances, both groups of infants took into consideration the postural and gravitational constraints of the weight in reaching for the object. Results for Experiment 2 indicated that for these critical distances, perceived reachability depends on the infants' sense of their own body effectivities calibrated in relation the constraints imposed by the weights. Such visual (object distance) and proprioceptive (weight) calibration occurred quasi immediately considering the remarkably small amount of experience infants had with the weights attached to their wrists.

GENERAL DISCUSSION

The rationale for the present research was based on the fact that there is a developmental lag between the emergence of reaching and sitting abilities. As mentioned at the beginning of this paper, this fact provides a unique opportunity to capture what infants perceive of their own body effectivities or capacity for action. By 6 months, and approximately 8 weeks after the onset of proficient reaching behaviour, infants show the first signs of an ability to sit independently (Bayley, 1969). The emergence of independent sitting expands the infant's limits of prehensile space as it also corresponds to the developing ability to coordinate trunk and upperlimbs in reaching (Rochat and Goubet, 1995). The general aim of the research was to document some of the determinants of young infants' perceptions of what is reachable: whether this perception depends on their relative ability to sit; and whether it is calibrated as a function of their progressive capacity to stretch out and expand the limits of their prehensile space as well as a proprioceptive sense of their own body effectivities. The question was not merely whether infants actually do reach farther as a function of postural development, which they do (Rochat and Goubet, 1995), but whether they calibrate their decision to reach as a function of their developing sitting ability (i.e. outward stretching ability without losing balance, Experiment 1) and novel bodily constraints that entail a shift in the body's centre of mass (weights attached to the wrists, Experiment 2).

The results of the first experiment provide further evidence that 6-month-old infants are highly sensitive to small distance changes (12 cm) in attempting to reach for a distal object. These data confirm the findings of Field (1976), Clifton *et al*. (1991a) and Yonas and Hartman (1993), suggesting that young infants detect the affordance for reaching of an object placed at various distances. As proposed at the beginning of the paper, it appears that when infants start to reach, they detect the affordable distance at which an object is reachable. In addition, early reachers demonstrate that as a function of their developing sitting ability and the correlated emergence of new degrees of behavioural freedom expanding the limits of their prehensile space (i.e. trunk and upper-limbs coordination; Rochat and Goubet, 1995), they calibrate their decision to reach or not to reach. Analysis of the average forehead–object distance during presentation of the object either at the limit of their prehensile space or 12 cm beyond indicated that this decision is not performed in reference to the eyes–object relative distance, but rather in relation to a sense of the body as a *functional whole*, situated and endowed with particular effectivities for action. This sense appears to be re-calibrated as a function of postural development and in particular the development of independent sitting. Future research is needed to assess further the interaction between sitting status, previous sitting and reaching experience. Longitudinal data would help to clarify this interaction.

The second experiment provides further evidence of a proprioceptive awareness of the body by young infants. Regardless of their relative ability to sit, infants detect additional postural and balance constraints in reaching when weights are attached to their wrists. These weights moved forward the infant's centre of mass and reduced the limits of their reachability while maintaining balance. Infants able or not yet able to sit show signs of an appropriate adjustment to the weights, deciding differentially to reach or not to reach towards the object. In general, they tended to reach for farther objects without the weights and for closer objects with the weights. These results suggest indeed that the infants had a proprioceptive sense of their own body effectivities, in addition to a precise sense of the distance that separates them from objects in the environment. Note that analogous interpretation can be made at later stages of development in relation to locomotion (Adolph, 1997). Adolph showed that infants recalibrate their perception of obstacles in the environment as they learn bipedal locomotion.

What is remarkable in the results of the two experiments is that infants' sensitivity to the object's reachability and the apparent calibration of this sensitivity as a function of their sitting ability (Experiment 1) or novel weight constraints (Experiment 2) were observed in a highly supportive postural situation. The seat on which infants were placed and to which they were strapped, prevented them from falling forward, regardless of their stretch towards the object. In fact, infants probably used this support to increase their reachability. However, they did not just reach towards the object at any of the distances. In most instances, infants did not try to reach for an object that they *might* have been able to contact in the full stretch afforded by the seat and its support. This suggests again that infants discriminated their own situation relative to the object and of their own effectivities in reaching. They did not merely rely 'blindly' on the fact the they were secured on the seat and that they did not risk losing balance and falling onto the ground. Future research should investigate further what underlies this apparent restraint of the infant.

In the two experiments we tried to minimize the potential confound between the manipulated group variable (i.e. the relative ability to maintain an independent sitting posture) and the postnatal age of the infants. Such confound could be problematic to the extent that age is associated with other cognitive or perceptual factors that might be invoked as an alternative account of the observed behaviours. However, it is unlikely that the group differences we observed in Experiment 1 are principally due to factors others than those we manipulated. In this experiment, the maximum average age span between groups was 35 days. In addition, all infants included in both experiments were selected on the basis of comparable reaching skills within our general procedure. All were proficient reachers, equally inclined to reach for the kind of objects we presented to them. They showed a differential reaching response in relation to distance, suggesting that at the time of testing they had all developed a comparable capacity to discriminate the variable distances at which we presented the object. If age was a factor, it was in relation to the amount of experience infants had in interacting with objects in the environment and, hence, in reaching. This amount of experience must probably play an important role, but it is yet unclear what this role might be and how it might have determined the reported findings. What is certain is that infants varied systematically in their relative ability to sit and that this postural factor clearly contributes to what they perceive as reachable or not reachable in Experiment 1. Finally, it is important to note that results indicated significant differences among groups with average age differences of less than 7 days (e.g. significant differences in reaching contacts and frequency of gazing between non-sitter and near-sitter infants in Experiment 1).

The present findings can be construed within the larger theoretical framework of the early sense self-manifested by infants. They add to recent research findings suggesting that long before the emergence by the second year of self-awareness commonly documented within the context of the mirror self-recognition task (Lewis and Brooks-Gunn, 1979), young infants demonstrate a sense of the *ecological self* (Neisser, 1991; Rochat, 1997). Accordingly, the ecological self corresponds to a sense of self as a differentiated entity, situated and agent in the environment. This sense of self is perceptually based and preconceptual, manifest at the onset of development (Rochat, 1995a) and not specifically human, expressed across species (Cenami Spada *et al.*, 1995). Research demonstrated that by the third month, and possibly from birth, infants have a sense of their own agency (Siqueland and DeLucia, 1969; Kalnins and Bruner, 1973; Lewis *et al.*, 1985), and of their own body as an object among others. In support of such precocious differentiation, neonates have been reported to respond differentially to actual movements of their own body and to movements of external objects that are not accompanied by contingent vestibular stimulation (Jouen and Gapenne, 1995; see also Harris *et al.*, 1974, Kellman *et al.*, 1987 and Bertenthal and Rose, 1995 for similar evidence with 4-month-old infants). Consistent with such findings in support of an early sense of the own body as a differentiated entity, Rochat and Hespos (1997) found that neonates and 4-week-old infants were rooting differentially to self- vs. external cutaneous stimulation of the perioral region.

The present research demonstrates that young infants have a sense of their own body effectivities in reference to which they execute, or do not execute, actions. These findings emphasize the role of postural development as a major determinant of action in infancy. They also provide evidence of a proprioceptive–visual sense of self by young infants. We suggest that an early sense of the own body effectivities forms the perceptual origins of the conceptual self emerging within a few months of developmental time, in particular by the end of the first year when infants manifest a sense of self as a permanent object (Butterworth, 1995). Future research should investigate further the nature of the preconceptual self-manifested by young infants, in particular the functional link between the early manifestation of perceived body effectivities and later self-recognition.

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Notes

1. Note that the use of analysis of covariance (ANCOVA) with age as a covariate was not a viable option because the design and data violate assumptions for such analysis. Our groups were not randomly selected, group attribution determined on the basis of the pre-test establishing relative independent sitting ability. Infants were grouped according to a pre-existing difference. Moreover, the assumption for the ANCOVA is that the regression slopes are homogeneous, in particular that the effects of the dependent variable are the same for each value of the covariate. In the present case, the slopes were not identical in each of the groups (see Myers and Wells, 1995 for further details).

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