British Journal of Developmental Psychology (1998), 16, 139–154 *Printed in Great Britain*

Two functional orientations of self-exploration in infancy

Philippe Rochat* and **Rachel Morgan**
Department of Psychology, Emory University, Atlanta, GA 30322, USA

Twenty 3- and 5-month-old infants were presented with either a congruent or incongruent (left/right reversal) on-line views of their own legs on a large TV monitor in two different experimental conditions. In one (no-object) condition, infants viewed their legs which produced a sound each time they moved them. In another (object) condition, they viewed their legs plus an object target which produced a sound each time it was kicked. Results indicate that from 3 months of age infants tend to reverse their pattern of relative visual attention and leg movement depending on the condition. Confirming previous findings, at both ages infants looked significantly longer and were more active while looking at the incongruent view of their own legs in the no-object condition. In contrast, infants looked significantly longer and were more active while looking at the congruent view of their own legs in the object condition. These observations are interpreted as evidence that early in the first year of life, infants express a sense of their own body as a perceptually organized entity which they monitor and control as either an object of exploration or an agent of action in the environment.

Self-exploration is a prominent feature of early development. From approximately 3 months of age, infants engage in systematic and repetitive visual–proprioceptive inspections of their own body, grabbing their feet and bringing them into the field of view for long bouts of exploration (Piaget, 1952). It is only recently that infancy researchers have started to investigate systematically the nature and determinants of early self-exploration. In general, the function of this robust behaviour and the role it may play in early development remain noticeably underspecified. The present research is an attempt to contribute experimentally to this issue.

Investigations have suggested that by the third month, and possibly from birth, infants demonstrate a sense of their own agency (Kalnins & Bruner, 1973; Lewis, Sullivan & Brooks-Gunn, 1985; Siqueland & DeLucia, 1969) and of their own body as an object among other objects (Rochat, 1997). At a theoretical level, these data suggest that infants demonstrate a sense of the *ecological self* (Neisser, 1991) long before the emergence by the second year of the conceptual or identified self that has been commonly documented within the context of the mirror self-recognition task (Lewis & Brooks-Gunn, 1979). In other words, early in development infants appear to detect information that specifies themselves as differentiated and situated entities in the environment. As an example of

* Requests for reprints.

the expression of an early sense of a situated and differentiated (ecological) self, from birth, infants are shown to respond differentially to visual transformations that depend either on movements of their own body or movements of objects in the external environment. Young infants do manifest discrimination between visual and visual-vestibular information (i.e. Jouen & Gapenne, 1995 for evidence with new-borns; Bertenthal & Rose, 1995; Harris, Cassel & Bamborough, 1974; Kellman, Gleitman & Spelke, 1987; for evidence with 4-month-old infants).

Early child psychologists proposed that self-perception originates in the active discovery of the contingency between visual stimuli and proprioception of body movements by young infants (Guillaume, 1926; Wallon 1942/1970). In support of this assertion, Amsterdam (1972) reported that between 3 and 5 months of age infants showed little social behaviour in front of a mirror but spent much time actively exploring the particular visual–proprioceptive correspondence offered by the mirror's reflection (specular image) of their own body. Recently, Van der Meer, Van der Weel & Lee (1995) reported systematic visual–proprioceptive exploration of the spontaneous arm movements by neonates. In this study, small weights pulled on the newborns' wrists towards their toes. Infants were shown to oppose the weight force in order to keep the arm up and in motion, only when they could see their arm either directly or via a video monitor (Van der Meer *et al.*, 1995). This type of early self-exploration can be considered as the perceptual process based on which young infants develop an awareness of the characteristics and effectivities of their own body (Rochat, 1995; Rochat & Morgan, 1995*b*).

Research has demonstrated a sensitivity by young infants to visual–proprioceptive invariants specifying self-produced movement. On the basis of a video technique developed by Papousek & Papousek (1974) to study the onset of facial self-recognition, Bahrick & Watson (1985) investigated the temporal determinants of perceived self-produced leg movements by 3- and 5-month-old infants. In their experiment, Bahrick & Watson placed the infant in front of two TV monitors, one presenting the contingent view of the baby's own legs and the other simultaneously presenting the pre-recorded (non-contingent) view of the baby's own legs, or the legs of another infant. Bahrick & Watson demonstrated that 5-month-olds looked preferentially to the non-contingent view of the legs, detecting the temporal invariants of visual–proprioceptive information that specifies self-produced movement. Using the same basic experimental paradigm, Rochat & Morgan (1995*a*) expanded Bahrick & Watson's findings in a series of experiments that unconfounded spatial determinants in the perception of self-produced movement by 3- to 5-month-old infants. Rochat & Morgan showed that infants discriminated between temporally contingent views of their own legs that were either spatially congruent or incongruent in terms of the visual–proprioceptive information specifying overall movement directionality. In particular, from 3 months of age infants looked preferentially at the on-line view of their own legs displaying incongruent visual information. Interestingly, infants tended to show significantly more leg activity while looking at the image displaying a left–right reversal of their own legs, suggesting increased visual–proprioceptive exploration of the incongruent view.

If young infants demonstrate a visual–proprioceptive calibration of their own body and appear to be sensitive to the intermodal invariants specifying self-produced movement, it is yet unclear what function this ability might serve. In the experiments conducted by Bahrick & Watson (1985), as well as Rochat & Morgan (1995*a*), infants' preferential looking to either the temporally non-contingent or spatially incongruent view of their own legs was interpreted as an index of self-exploration, and in particular as revealing enhanced attention to the view of their own legs that was novel or unfamiliar. The alteration of both temporal contingency and spatial congruence (Bahrick & Watson, 1985; Schmuckler, 1996), or only spatial congruence (Rochat & Morgan, 1995*a*) between vision and proprioception was discriminated by the infant via enhanced attention and active exploration.

In general, the correspondence between the proprioception of the infant's own movements and the novel visual feedback provided by the TV was associated with increased exploration. This response indicated both discrimination and enhanced exploration of the novel (i.e. spatially incongruent and temporally non-contingent) visual–proprioceptive feedback of the limbs. The infant's behaviour also indexed the expression of an intermodal calibration of the body in space as well as in time.

The present research was aimed at further investigating what determines young infants' attention to their own movement. The aim was to capture the determinants of increased self-exploration and in particular to further test the novelty explanation proposed by Bahrick & Watson (1985) and Rochat & Morgan (1995*a*) to account for their findings. The general hypothesis guiding this research was that the behavioural phenomenon reported by both Bahrick & Watson, and Rochat & Morgan, although systematic, is opportunistic in nature, depending on the context of the task. The rationale was that infants visually prefer the incongruent view of their own body when placed in a context in which they merely have to explore their own limbs in action. In contrast, we predicted an opposite behavioural response in a context in which infants would have to guide and control their limb movements in relation to a fixed target in space. In such a situation, the prediction was that infants would prefer to look at the congruent (familiar) view of their own body in order to guide and control their limb movements in relation to a fixed target in space. To test this hypothesis, 3- and 5-month-old infants were successively presented with congruent or incongruent (left/right reversal) on-line views of their own legs on a large TV monitor. Infants were presented with one of these views in two different experimental conditions. In a self-exploratory or 'contemplative' condition, infants viewed their legs which produced a sound each time they moved them. In another object-oriented condition, they viewed their legs plus an object target that produced a sound each time it was contacted by the infant's leg. Confirming our hypothesis, the results indicate that from 3 months of age infants tend to reverse their relative pattern of visual attention to either view of their own legs and act differently depending on the two task conditions.

Method

Participants

Twenty healthy full-term infants (10 girls and 10 boys) were tested. Ten were 3-month-olds (*M* age = 3 months 15 days; range = 3 months 0 days to 3 months 30 days, SD = 11 days), and 10 were 4–6 month-olds (*M* age = 5 months 3 days; range = 4 months 2 days to 6 months 8 days; SD = 24 days). The infants were recruited from a participant pool consisting of over 500 infants born in the Atlanta area. Parents were contacted by phone and were invited to participate with their infant. Overall, a total of 36 infants were tested. Of the 16 who were not included in the final sample, eight fussed, and eight looked less than 15 per cent of the test period, which was the minimum attention requirement for inclusion in the final sample.

Apparatus

The display and recording apparatus was basically identical to the one used in Rochat & Morgan (1995*a*). Infants were placed in front of a large TV screen (25-inch video monitor Panasonic CT25824) projecting one of two possible on-line views of their own legs from the waist down. These views originated from two different cameras (Panasonic black and white CCTV HWV-BL294). The infants were seated in a 60° reclined infant seat looking up towards the TV, which was inclined 30° at a distance of 2 meters from the infant's eyes (see Fig. 1). The reclined posture of the infants prevented them from seeing their own legs

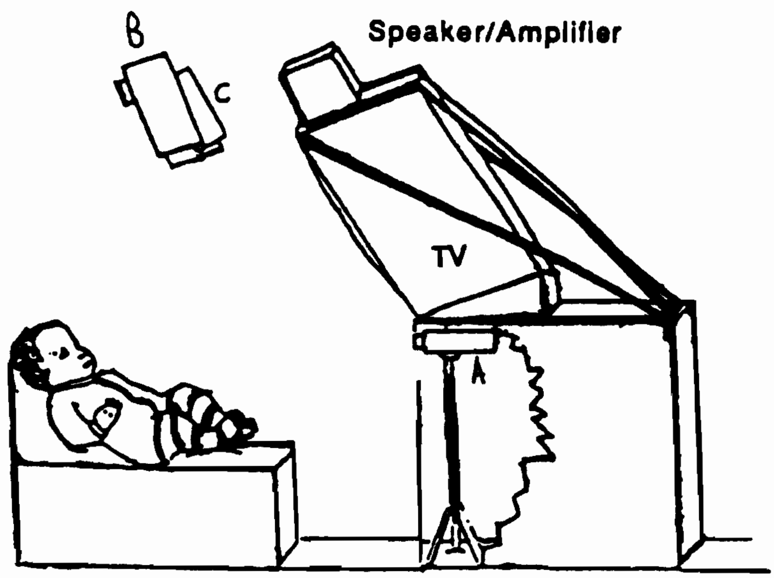

Figure 1. Apparatus and experimental set up of the infant wearing black and white socks while reclined in front of the large TV monitor projecting an online view of the legs from the waist down. Camera A provided a close-up of the infant's face for the analysis of gazing at the display as Camera B and C each provided a particular view of the legs (i.e. ego vs. reversed ego view).

directly, unless they lifted up their heads and looked down. Both cameras were situated 1 meter directly above the infant, providing a view corresponding to what the infant would see when looking down at his/her own legs. In other words, both cameras provided an ego perspective of the legs. However, as one (regular) camera provided a spatially congruent *ego view*, the other (modified) camera provided a *reversed ego view* of the infant's legs. The reversed ego view was obtained by using a modified CCTV camera with a horizontal scan reversal, providing a reversed image of the infant's legs from left to right (see Rochat & Morgan, 1995*a* for further details). In other words, proprioception and vision of self-produced leg movements were spatially congruent in relation to the ego view, and spatially *incongruent* in the reversed ego view. In relation to the latter, when infants felt their leg moving to the right, for example, they simultaneously experienced commensurate but reversed visual feedback of their own leg movement (i.e. leg movement to the left on the TV monitor). Note that either views of the legs were on-line, hence temporally contingent, varying only in their relative spatial congruence with regard to the infant's proprioception of his or her own leg movements.

Each infant was successively tested in two different experimental conditions: a no-object condition and an object condition. The no-object condition was identical to the one used in the second experiment of Rochat & Morgan (1995*a*). A small tie pin microphone (Realistic 33-1063) was taped to the underside of a sheet of paper placed under the infant's feet. The microphone was connected to an amplifier/speaker centrally affixed to the top of the TV monitor. The sheet of paper acted to spread out the sounds that the infants produced while kicking their legs. Contingent to any leg movement, this device provided a commensurate rustling and scratching sound originating from the speaker on the TV. This auditory feedback provided the infant with contingent sound accompanying the legs' movements, enticing them to move their legs and to orient visually towards the video monitor. In order to further visually engage the infant, black- and white-striped socks were placed on the infant's feet and legs. These socks provided high visual contrast relative to the white background of the seat on which the infant's feet rested.

In the object condition, infants were presented with an object placed in front of either their right or left leg. The object consisted of a 2 ½ in cardboard disc placed on the top of a 3 in long ½ in diameter spring vertically attached to a 4 in × 6 in piece of cardboard covered with a white cloth to match the cloth covering of the infant seat (see Fig. 2). The cardboard sheet containing the object was clipped onto the

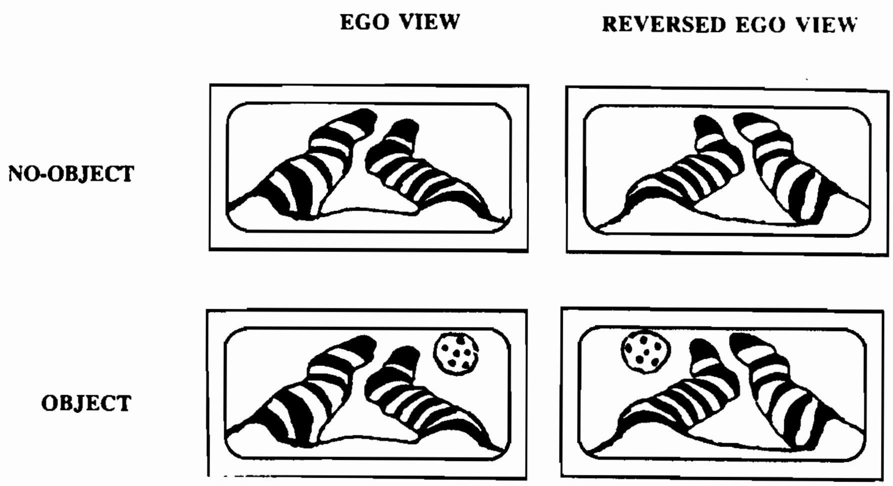

Figure 2. Illustrations of the two possible views of the legs by the infant on the TV monitor (ego vs. reversed ego view) in the two different experimental conditions (object vs. no-object condition).

infant seat. In this condition, the tie pin microphone connected to the speaker/amplifier centrally located on top of the TV monitor (see description above) was placed inside the spring supporting the object so that a commensurate rustling sound was produced *only* when the object was contacted by a foot and kicked by the infant. The microphone under the infant's legs used in the no-object condition was turned off in the object condition. The kickable and soundable object was placed at a location where the infant could kick it with the extended ipsilateral leg. Such placement of the object ensured that the infant would only contact the object with an extended movement of one of his/her legs, breaking away from a resting posture in which the legs are usually bent at the knees.

Procedure

The two camera views of the infant's legs (ego and reversed ego) were presented successively in two separate trials of two minutes within one condition. There was a total of four 2-minute trial presentations (2 conditions × 2 views, see Fig. 2). Within one condition, the order of presentation of the ego and reversed ego view was counterbalanced among infants of each age group. Figure 2 illustrates the general design of the experiment and the corresponding four experimental situations in which each infant was successively tested.

The first two successive test trials occurred in the no-object condition and the last two in the object condition. The rationale for presenting the no-object condition first was based on pilot observations yielding a high participant attrition rate when first tested in the object condition. When the two successive trials within the object condition were presented first, infants appeared to engage significantly less in the display. Overall, the trials in the no-object condition entailed a higher occurrence of auditory feedback, each leg movement causing a noise therefore facilitating the infant's first acquaintance with the display. In the object condition, the side of the object was counterbalanced between participants of each age group, half presented with the object to the left and half to the right for both trials.

The test started immediately after a calibration phase in which an attractive toy was agitated at different locations immediately in front of an opaque curtain covering the TV screen. Recording of the infant's visual tracking of the toy was used to calibrate the infant's gaze towards the screen for later scoring of preferential looking (see scoring below). In between each two-minute trial presentation a sign was held up to indicate the trial change in the video recording of both the infant's face and in the video recording of the infant's legs in the display (see scoring below). At the beginning of each trial, the microphone below the infant's legs or in the object was turned on. At the beginning of the object condition, a curtain was placed over the TV screen and the microphone turned off so that the object could be installed without any visual or auditory feedback provided to the infant. The inter-condition interval was approximately 15 seconds. One experimenter sat behind the infant, signalling trial changes with the sign and controlling for the quality of the visual feedback provided to the infant. Another experimenter kneeled behind a black curtain in the back of the display, operating the video equipment and changing the view of the legs on the screen, at the signal of the first experimenter by flipping a switch on a video mixer (Pelco US 100DT) into which both camera views were fed via the TV monitor. During the whole testing session, parent(s) had the opportunity to observe their infant from an adjacent room via a one-way mirror.

Scoring technique

Scoring of infant behaviour was based on the coding of the audio and visual recording provided by a third camera (Panasonic AG-450 with a zoom lens) placed under the TV monitor and providing a close-up view of the infant's face (see Rochat & Morgan, 1995*a*). The video- and audio-recording of this camera was used for further analyses of both the infant's looking of the legs on the TV and the amount of self-produced leg activity. This was accomplished by the use of a computerized event recorder with multiple input channels running on the computer's clock. One channel was used to score infant looking at the TV monitor. This channel was controlled by a predetermined on/off key on the computer's keyboard. While a coder made a pass through the video-recording of the infant's looking, the sound generated by the infant's leg movements via the microphone placed under his or her feet (no-object condition) or in the object (object condition) was simultaneously digitized via a sound digitizer device (Ceder Technology) and recorded onto a second channel of the event recorder program. The digitized sound corresponding to leg or object movements was first recorded as a sound spectrogram (volume over time) then transformed onto a third channel of the event recorder as successive periods of activity or no activity. The transformation was based on a set threshold corresponding to one third of the maximum input recorded on the sound spectrogram. When the sound which was picked up exceeded the one-third threshold, the program recorded this threshold crossing as an episode of leg activity of two seconds in duration. On the basis of pilot observations, the unit of two seconds was chosen to approximate the characteristics of a typical bout of the infant's leg movements. In summary, this technique allowed the co-analysis of the infant looking at the TV monitor and his/her simultaneous leg activity while looking at the TV (see also Rochat & Morgan, 1995*a*).

Dependent measures

Gazing and leg activity were analysed both separately and in combination. The rationale for this analysis was to assess the eventual preference for either view of the legs in the no-object or object condition, as well as to determine whether they generated different patterns of leg activity in relation to these different experimental contexts. For each test trial, looking and leg activity were analysed in relation to the following parameters: (1) duration (s) of looking at the particular view of the legs on the video display; (2) proportion (per cent) of leg activity while looking at the particular view of the legs on the display ((duration of leg activity while looking at a particular view) $\div$ (overall duration of looking at the display) $\times$ 100); (3) proportion (per cent) of leg activity while looking away from the display ((duration of leg activity while looking away from the display)÷(overall duration of looking away from the display) × 100); (4) onset in seconds or latency to the first thresholded bout of leg activity while looking at the display (see scoring technique above); (5) proportion (per cent) of total trial time the infant engaged in symmetrical leg movements or bilateral forward extension of the legs ((bilateral extension duration)÷(total trial time)×100)); (6) proportion (per cent) of total trial time the infant engaged in asymmetrical leg movements or unilateral forward extension of either the right or left leg ((unilateral extension duration)÷(total trial time)×100); (7) frequency of single (unilateral) leg extensions as a proportion of total frequency of leg extensions (bilateral + unilateral).

The video-recording of the legs as they appeared to the infant was used to score the different types of leg movements (dependent measures 5–7). Using the computerized event recorder, two independent coders pressed a key to enter the discrete forward extensions of one individual leg. A leg extension was operationally defined as a full extension of the infant's leg such that there was no bend at the knee. Prior to coding a videotape of the infant's leg movements, a transparency with a horizontal line across its top was placed on the video monitor. This line indicated the full extension boundary for the particular infant. This line was determined on the basis of a preliminary inspection of the recording and adjusted for each infant. At the beginning of a particular trial, one coder was assigned one computer key corresponding to one channel of the event recorder and another coder was assigned a different channel. As the videotape progressed, coders pressed their assigned keys and held it down at the crossing of the horizontal line on the transparency (indicating a leg extension). When the infant recoiled the leg, the coder released the key, indicating to the program that no extension was occurring for that leg. At the end of coding each trial, the event recorder provided a printout of all the leg extensions for both legs on two channels of the event recorder in terms of frequency and overall duration. From the calculation program of the event recorder it was possible to derive (*a*) the total frequency and duration of bilateral (simultaneous) leg extensions in seconds as a function of total trial time and (*b*) the total frequency and duration of unilateral leg extensions as a function of total trial time.

In order to test for reliability, two independent observers coded one third of the video-recordings of the camera providing the close-up of the infant's face as well as of the camera providing the view of the legs. In particular, six randomly chosen infants were analysed by both observers in all four experimental situations ($N = 24$ two-minute trial presentations). The observers were blind as to what particular experimental situation infants were in. For the measures of looking duration, as well as the duration and frequency of right or left leg extensions, Pearson r moment correlations comparing the scores of the independent coders for each of the six infants in all four experimental situations were greater than .96. Note that this analysis was performed for these three measures only, as the other dependent measures were derived from them (see computerized event recording technique described above).

Results

Table 1 summarizes the results obtained in relation to the two views of the legs in each condition for all dependent measures pertaining to gazing as well as joint gazing and leg activity (dependent measures 1–4).

A 2(age group) × 2(no-object vs. object condition) × 2(ego vs. reversed ego view) mixed design analyses of variance (ANOVA) was performed on the measure of duration (s) of looking at the video display. This analysis yielded a significant condition-by-view interaction ($F(1,18) = 16.55$, $p < .0008$) and no significant main effect of either age ($p < .23$), condition ($p < .44$), or view ($p < .51$), nor any other significant interactions ($p > .65$ for all other interactions). As shown in Fig. 3, infants looked significantly more at the reversed ego view in the no-object condition, and looked significantly more at the ego view in the object condition. Analysis of the simple main effects as well as *post hoc* Duncan tests indicated significant effects of view in both no-object and object condition ($p < .05$).

A same mixed design ANOVA regarding the proportion (per cent) of leg activity while looking at a particular view on display yielded a significant condition-by-view interaction

Table 1. Means and standard deviations for each of the dependent measures (DVs) for both conditions: no-object and object, and for both successive views presented to the infants, ego and reversed ego: (1) looking duration in seconds (LDU), (2) per cent leg activity while looking at the display (LAL), (3) per cent leg activity while looking away from the display (LAW), (4) onset in seconds to the first bout of leg activity (OLA), (5) per cent forward, bilateral leg extensions as a function of total trial time (BIL), (6) per cent forward, unilateral leg extensions as a function of total trial time (UNI), and (7) frequency of single leg extensions as a function of the total number of leg extensions (bilateral + unilateral) (SIN)

	Condition view				Condition-by-view
	No-object		Object		
DVs	Ego	Reversed ego	Ego	Reversed ego	*p* values
LDU					
M	80.5	90.7	87.7	72.3	$p < .0008$
SD	29.8	24.7	21.3	24.9	
LAL					
M	18.1	23.9	21.3	17.6	$p < .0062$
SD	11.7	12.0	12.6	10.1	
LAW					
M	11.0	7.1	6.9	9.0	n.s.
SD	16.1	10.0	7.9	7.6	
OLA					
M	13.4	7.8	6.3	14.0	$p < .02$
SD	13.3	6.6	5.3	16.5	
BIL					
M	24.3	15.5	15.3	13.8	n.s.
SD	26.3	16.9	18.1	14.7	
UNI					
M	38.5	36.4	38.0	31.0	n.s.
SD	22.4	19.2	12.8	19.9	
SIN					
M	50.9	49.3	52.9	44.0	n.s.
SD	18.7	12.9	17.9	17.9	

($F(1,18) = 9.637$, $p < .0062$). No other significant interactions, nor any significant main effect of either age, condition, or view were found. As shown in Fig. 4, infants demonstrated proportionally more leg activity while looking at the reversed ego view in the no-object condition, and more while looking at the ego view in the object condition. Analysis of the simple effects indicated a significant main effect of view in the no-object condition ($p < .03$) and a marginally significant, yet reversed effect of view in the object condition ($p < .10$, see Fig. 4 below).

Regarding the proportion (per cent) of leg activity while looking *away* from the display

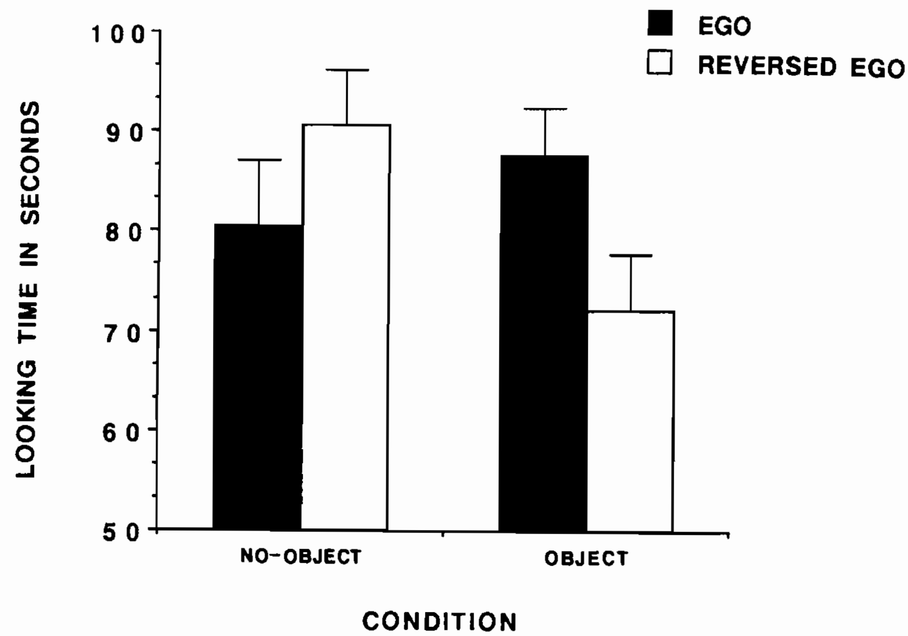

Figure 3. Overall average duration in seconds of looking at either the ego or reversed ego view in either the no-object or object condition.

((duration of leg activity while looking away from the display)÷(overall duration of looking away from the display) × 100), a 2(age) × 2(condition) mixed design ANOVA yielded no significant main effects of age or condition, nor any significant interactions. These negative results indicate that the amount of infant leg activity was comparable when looking away from the display regardless of age or condition. In relation to the preceding data, these latter results confirm that the modulation of leg activity depends on the infant's visual exploration and becomes undetermined when visual attention to the display ceases.

A 2(age) × 2(condition) × 2(view) mixed design ANOVA on the latency in seconds from the beginning of a trial presentation of the first thresholded bout of leg activity while looking at the display yielded a significant condition-by-view interaction ($F(1,18) = 6.663$, $p < .02$). No other significant interactions, nor any significant main effect of either age, condition, or view were found. The significant condition-by-view interaction indicates that there is a shorter latency to kick while the infant is looking at the 'preferred' view of the legs in a particular condition. As shown in Fig. 5, infants demonstrated a *longer* latency to the onset of leg activity while viewing their legs in the ego view of the no-object condition, and a *shorter* latency while viewing their legs in the

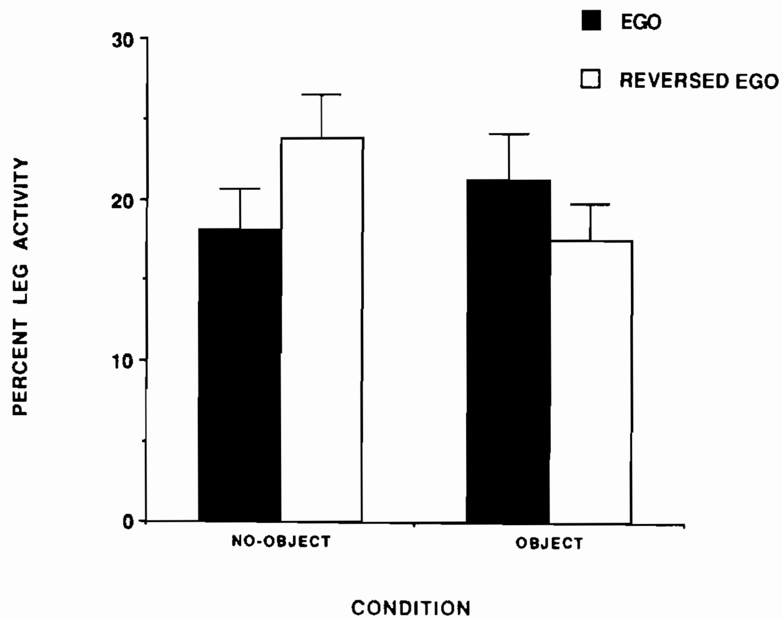

Figure 4. Overall proportion (per cent) of thresholded leg activity while looking at either the ego or reversed ego view in either the no-object or object condition.

ego view of the object condition. Analysis of the simple main effects of leg activity latency indicated significant to marginally significant effects of ego vs. reversed ego view in the no-object and object conditions ($p < .05$ and $p < .08$ respectively).

Analyses of the results pertaining to types of leg activity in relation to condition and view did not yield any significant results. In particular, the proportion of total trial time infants engaged in symmetrical (bilateral) leg movements, asymmetrical (unilateral) leg movements, and frequency of single (unilateral) leg extensions yielded no significant effect of age, condition, or view, nor any significant interactions. However, these behaviours were measured as a function of total trial presentation time, not as a function of the time the infants were actually gazing at the display. The technique used did not allow for such a distinction. The video-recording of legs was independent, hence not synchronized with the recording of the infant's face. This lack of synchronization did not allow for a co-analysis of gazing and particular *types* of leg activity. Note that such analysis could still reveal differences in relation to conditions and views of the legs, as suggested by all previous results on gazing at the display and global leg activity. In addition, data revealed a large amount of inter-individual variability which might have masked differences between conditions.

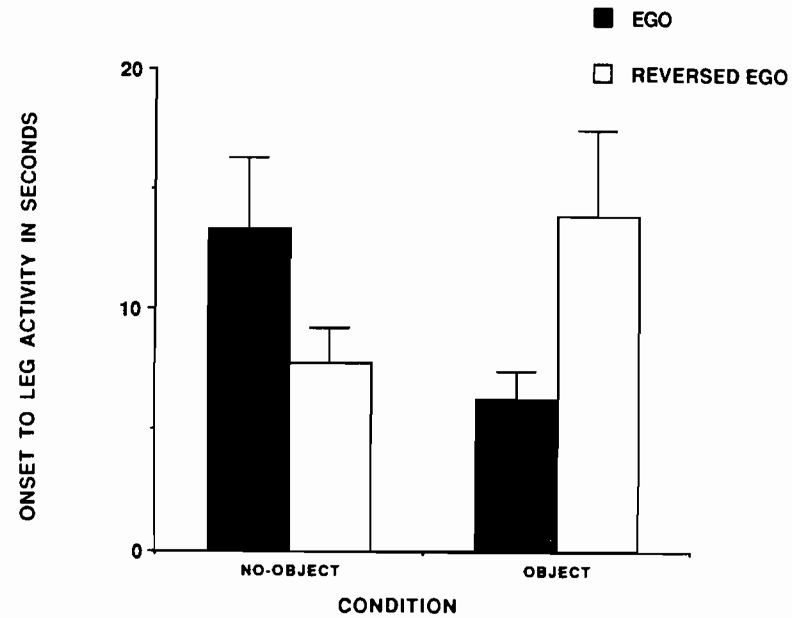

Figure 5. Overall average onset in seconds from the beginning of a trial presentation to the first thresholded bout of leg activity while looking at either the ego or reversed ego view in the no-object or object condition.

Discussion

In general, the results of the present research indicate that visual–proprioceptive exploration of self-produced movement by young infants is context dependent. Infants as young as 3 months of age demonstrated opposite patterns of visual attention to congruent or incongruent views of their own body depending on the context of the task. In particular, visual–proprioceptive exploration of self-produced body movement compared to visual–proprioceptive guidance of the body (i.e. one leg) towards a spatial target produced opposite findings.

The results obtained in the context of mere visual–proprioceptive exploration of self-produced body movement are consistent with those reported in infants younger than 6 months by Bahrick & Watson (1985), Papousek & Papousek (1974), and more recently Rochat & Morgan (1995*a*) as well as Schmuckler (1996). In the context in which young participants merely explore congruent or incongruent visual feedback of their own body movements, infants are reported to devote significantly more attention towards the incongruent feedback. This robust phenomenon is commonly interpreted as the expression of a novelty preference, infants demonstrating an increased engagement in the exploration of the unfamiliar view of their own body movement. In a previous study (Rochat & Morgan, 1995*a*), we demonstrated that this pattern of renewed attention towards the incongruent visual feedback is not purely visual, but rather intermodal in nature based on the fact that self-produced body movement increases significantly as the infant attends visually to the incongruent view. We concluded that infants therefore engage in active visual–proprioceptive exploration of the unfamiliar view of their own body because this view violates an established intermodal calibration of their own body in motion (i.e. violation of perceived movement directionality).

In the present experiment and relative to the no-object condition, the results confirm that infants as young as 3 months engage in renewed active visual–proprioceptive exploration while confronted with a spatially incongruent view of their own legs (i.e reversed ego view that violates the regular calibration of the seen and felt direction of movement). In particular, infants engaged in significantly more visual inspection and more leg activity in the situation in which the seen movements of the legs are reversed. In support of this trend, infants at both ages demonstrated significantly shorter latencies in the production of thresholded bouts of leg activity when presented with the reversed ego view compared to the ego view. This latter result provides further evidence that in the no-object condition, infants showed enhanced visual–proprioceptive exploration when confronted with the incongruent view of the legs.

The major finding of the present study is that in contrast to a no-object condition, the trend is actually *reversed* when the task the infant performs is to aim at an object in space in order to obtain the reinforcing visual, proprioceptive, and in particular the auditory feedback. In the context of the object condition in which the task changes from a free exploration of the legs on the display to the more specific task of a visual–proprioceptive guidance of the body towards a spatial target, infants demonstrated renewed visual attention, leg activity, and shorter latencies to kick when presented with the congruent (ego), as opposed to the incongruent (reversed ego) view.

This reversed trend suggests that the mechanisms underlying infants' attention in these different task contexts are distinct. In the no-object condition, infants' attention to the display appears to depend on the novelty of the visual feedback, and in particular the experience of new visual–proprioceptive information. On the contrary, in the object condition infants' attention to the display depends on the familiarity of the visual feedback that will *facilitate* the visual–proprioceptive guidance of the limb towards the object target in space. In other words, when infants are placed in a situation in which self-generated action is oriented towards an external address in space (i.e. external in relation to the body), they appear to fall back on an already established intermodal calibration of their own body. In a situation where leg movements do not have to be oriented in space in order to obtain the reinforcing auditory feedback, infants appear to be driven by the exploration of what is new in the overall visual–proprioceptive calibration offered by the display.

Overall, this reversed trend in attention and self-exploration demonstrates the remarkable resourcefulness and flexibility of young infants in the way they distribute their attention depending on the context of the task. It also points to the active role played by the infants while attending the various video displays of their own legs. They showed enhanced engagement to the most informative display for the goal (i.e. kicking of the object when the object was present), defaulting to an interest in visual/proprioceptive novelty when no object was present. In other words, when appropriate, and in particular in the context of a spatially and goal-oriented action (the object condition), infants will actively focus on what is congruent with the regular intermodal experience of their own body in order to accomplish the task. In this condition (object condition) the infants' pattern of attention reflects their engagement in an action mode making use of the congruent information that will most efficiently guide the infant towards the spatial goal of kicking the object target. In the other, no-object condition, the infants' reversed pattern of attention reflects their engagement in an exploratory mode, focusing on novel information that adds to the regular intermodal experience of their own seen and felt body in action. In one case infants' attention appears to be primarily opportunistic or pragmatic, driven by the most efficient way to accomplish a spatially oriented action successfully. In the other, infants' attention appears more gratuitous, driven by the exploration of the novel experience of seen and felt body movements.

In analysing different types of leg movements in the two conditions, our aim was to provide perhaps further evidence of the dual attentional and motivational mode of self-exploration as described above. In addition, evidence of significant differences in the pattern of leg activity while attending to the various displays could have provided, arguably, some support to the view that infants understood that it was their own legs portrayed in the video. Systematic differences in the pattern of leg activity as a function of conditions could be interpreted as a behavioural index of such understanding, in the same way that particular behaviour in front of the mirror is interpreted as an index of self-recognition (Lewis & Brooks-Gunn, 1979). However, the analysis did not yield any positive results. One general reason might be that the categories of leg movements on which the analysis was based were not relevant relative to what babies at this age are motorically capable of controlling and doing with their legs. In conducting this analysis, we assumed but did not control whether the tested infants could generate differentiated patterns of leg movements (i.e. uni- vs. bilateral movements) at will, or could learn to do so within the time frame of the experiment. Another reason might be due to a technical limitation in the recording of the behaviour. The video-recording of the legs was not time locked with the recording of the infant's face from which visual attention to the display was scored. This limitation prevented the co-analysis of visual attention and various *patterns* of leg activity, in addition to the overall leg activity index provided by the microphone (see Method). It is feasible that such analysis might have revealed consistent data regarding the patterns of leg activity, had all instances of leg activity occurring when the infant was not attending to the visual display been eliminated. Such trimming of the recording was not possible based on the recording technique used in this research. We did find, however, a significant link between the overall leg activity as indexed by the microphone and visual attention to the display, the pattern of this link depending on both the condition and the type of visual display (see discussion above).

The fact that 3- and 5-month-old infants did not behave in significantly different ways suggest that the intermodal calibration of the body and the two modes of selective attention guiding self-exploration are well established by the third month. Further research on the intermodal determinants of self-exploration by younger infants would eventually provide developmental data on the emergence of the intermodal calibration of the body. However, existing evidence of neonatal imitation (Meltzoff, 1993), hand–mouth coordination by neonates (Rochat, 1993; Rochat, Blass & Hoffmeyer, 1988), and in particular evidence of anticipatory mouth opening documented in the new-born (Blass, Fillion, Rochat, Hoffmeyer & Metzger, 1989; Butterworth & Hopkins, 1988; Lew & Butterworth, 1995) suggest that his or her calibration might be established well before the third month and eventually from birth.

Neonatal imitation indicates that from birth infants are capable of mapping body parts of others (e.g. tongue of the adult model) onto their own body (e.g. their own tongue). As suggested by Meltzoff & Moore (1995), imitation entails intracorporeal recognition and coordination, as well as intercorporeal mapping: 'By imitating, the infant is showing that a specific body part of the other can be mapped to a specific organ of the self' (Meltzoff & Moore, 1995, p. 76). Accordingly, neonatal imitation is evidence of an intermodal calibration of the body and the expression of an early sense of self that develops in interaction with others (Meltzoff, 1990). Aside from imitation that develops in a social and communicative context, evidence of an early detection of perceptual information that specifies what physical objects afford for action (e.g. relative suckability or graspability of various objects, Rochat, 1987) also points to an early mapping of body parts to particular aspects of physical objects. These observations suggest that the intermodal calibration of the body and an early sense of the ecological self (Neisser, 1991) develop from birth. Our findings provide further demonstration that young infants are actively engaged in exploring, as well as instrumenting their own body to achieve new goals.

In conclusion, the data reported here confirm that infants as young as 3 months are actively involved in exploring a novel intermodal calibration of the body that deviates from what they have previously learned and normally experience when feeling and seeing their own body moving in space. In addition, self-exploration and the distribution of attention while exploring their own body in motion depends on the context of the task. In a contemplative (no-object) context, self-exploration by the infant appears to be enhanced by novelty. Inversely, self-exploration appears to be enhanced by familiarity in a spatially oriented (object) context. These observations demonstrate the importance of considering the context of the task in trying to account for the determinants and underlying mechanisms of self-exploration in infancy. They also indicate that at least from 3 months of age, infants can be guided by different motives and engage in different modes of exploration of their own body (e.g. exploratory vs. goal-oriented modes) depending on the situation.

The dual mode underlying self-exploration indexed in the present research supports the contention that from very early on infants express a sense of their own body as a perceptually organized entity that can be attended to as either an object, or as an agent in the environment.

Acknowledgments

The authors express their appreciation to all parents and infants who participated in the study as well as to Joy Sichveland and Ross Gould for their help in the testing and scoring of the infant participants. Preliminary results of this research were presented as a poster at the meeting of the Society for Research in Child Development (Indianapolis, April 1995) and at the International Conference on Perception and Action (Marseilles, July 1995). The research was supported in part by grant No. MH50385-01 from the National Institute of Mental Health and grant No. SBR-9507773 from the National Science Foundation, both awarded to Philippe Rochat.

References

Amsterdam, B. (1972). Mirror self-image reactions before age two. *Developmental Psychobiology*, 5, 297–305.

Bahrick, L.E. & Watson, J.S. (1985). Detection of intermodal proprioceptive–visual contingency as a potential basis of self-perception in infancy. *Developmental Psychology*, 21, 963–973.

Bertenthal, B.I. & Rose, J.L. (1995). Two modes of perceiving the self. In P. Rochat (Ed.), *The Self in Infancy: Theory and Research*. Amsterdam: Elsevier Science.

Blass, E.M., Fillion, T., Rochat, P., Hoffmeyer, L.B. & Metzger, M.A. (1989). Sensorimotor and motivational determinants of hand–mouth coordination in 1–3-day-old human infants. *Developmental Psychology*, 25, 963–975.

Butterworth, G. & Hopkins, B. (1988). Hand–mouth coordination in the new-born baby. *British Journal of Developmental Psychology*, 6, 303–314.

Guillaume, P. (1926). *L'imitation Chez L'Enfant*, Paris: Alcan.

Harris, P.L., Cassel, T.Z. & Bamborough, P. (1974). Tracking by young infants. *British Journal of Psychology*, 65, 345–349.

Jouen, F. & Gapenne, O. (1995). Interactions between the vestibular and visual systems in the neonate. In P. Rochat (Ed.), *The Self in Infancy: Theory and Research*, pp. 277–301. Amsterdam: Elsevier Science.

Kalnins, I.V. & Bruner, J.S. (1973). The coordination of visual observation and instrumental behavior in early infancy. *Perception*, 2, 307–314.

Kellman, P.J., Gleitman, H. & Spelke, E. (1987). Object and observer motion in the perception of objects by infants. *Journal of Experimental Psychology: Perception and Performance*, 13(4), 586–593.

Lew, A.R. & Butterworth, G. (1995). The effects of hunger on hand–mouth coordination in newborn infants. *Developmental Psychology*, 31, 456–463.

Lewis, M. & Brooks-Gunn, J. (1979). *Social Cognition and the Acquisition of Self*. New York: Plenum.

Lewis, M., Sullivan, M.W. & Brooks-Gunn, J. (1985). Emotional behaviour during the learning of a contingency in early infancy. *British Journal of Developmental Psychology*, 3, 307–316.

Meltzoff, A.N. (1990). Foundations for developing a concept of self: The role of imitation in relating self to other and the value of social mirroring, social modeling, and self-practice in infancy. In D. Cicchetti & M. Beeghly (Eds), *The Self in Transition: Infancy to Childhood*, pp. 139–164. Chicago: University of Chicago Press.

Meltzoff, A.N. (1993). The centrality of motor coordination and proprioception in social and cognitive development: From shared actions to shared minds. In G.J.P. Savelsbergh (Ed.), *The Development of Coordination in Infancy*, pp. 463–496. Amsterdam: Elsevier Science.

Meltzoff, A.N. & Moore, M.K. (1995). A theory of the role of imitation in the emergence of the self. In P. Rochat (Ed.), *The Self in Infancy: Theory and Research*, pp. 73–93. Amsterdam: Elsevier Science.

Neisser, U. (1991). Two perceptually given aspects of the self and their development. *Developmental Review*, 11, 197–209.

Papousek, H. & Papousek, M. (1974). Mirror-image and self-recognition in young infants: A new method of experimental analysis. *Developmental Psychobiology*, 7, 149–157.

Piaget, J. (1952). *The Origins of Intelligence in Children*. New York: International Universities Press.

Rochat, P. (1987). Mouthing and grasping in neonates: Evidence for the early detection of what hard or soft substances afford for action. *Infant Behavior and Development*, 10, 435–449.

Rochat, P. (1993). Hand–mouth coordination in the newborn: Morphology, determinants and early development of a basic act. In G.J.P. Savelsbergh (Ed.), *The Development of Coordination in Infancy*, pp. 265–288. Amsterdam: Elsevier Science.

Rochat, P. (1995). Early objectification of the self. In P. Rochat (Ed.), *The Self in Infancy: Theory and Research*, pp. 53–72. Amsterdam: Elsevier Science.

Rochat, P. (1997). Early development of the ecological self. In C. Dent-Read & P. Zukow-Goldring, (Eds), *Evolving Explanations of Development*, pp. 91–122. Washington DC: American Psychological Association.

Rochat, P., Blass, E.M. & Hoffmeyer, L.B. (1988). Oropharyngeal control of hand–mouth coordination in newborn infants. *Developmental Psychology*, 24, 459–463.

Rochat, P. & Morgan, R. (1995*a*). Spatial determinants in the perception of self-produced leg movements by 3- to 5-month-old infants. *Developmental Psychology*, 31, 626–636.

Rochat, P. & Morgan, R. (1995*b*). The function and determinants of early self-exploration. In P. Rochat (Ed.), *The Self in Infancy: Theory and Research*, pp. 395–418. Amsterdam: Elsevier Science.

Schmuckler, M.A. (1996). Visual–proprioceptive intermodal perception in infancy. *Infant Behavior and Development*, 19, 221–232.

Siqueland, E.R. & DeLucia, C.A. (1969). Visual reinforcement of non-nutritive sucking in human infants. *Science*, 165, 1144–1146.

Van der Meer, A.L.H., Van der Weel, F.R. & Lee, D.N. (1995). The functional significance of arm movements in neonates. *Science*, 267, 693–695.

Wallon, H. (1942/1970). *De L'Acte à la Pensée: Essai de Psychologie Comparée*. Collection Champs. Paris: Flammarion.

Received 9 July 1996; revised version received 14 March 1997