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Detection of Intermodal Proprioceptive–Visual Contingency as a Potential Basis of Self-Perception in Infancy

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Five-month-old infants can detect the invariant relationship between their own leg motion and a video display of that motion. In three experiments they discriminated between a perfectly contingent live display of their own leg motion and a noncontingent display of self or a peer. They showed this discrimination by preferential fixation of the noncontingent display. This effect was evident even when the infant's direct view of his or her own body was occluded, eliminating video image discrimination on the basis of an intramodal visual comparison between the sight of self-motion and the video display of that motion. These findings suggest that the contingency provided by a live display of one's body motion is perceived by detecting the invariant intermodal relationship between proprioceptive information for motion and the visual display of that motion. The detection of these relations may be fundamental to the development of self-perception in infancy. In addition, though 3-month-olds did not show significant discrimination of the contingent and noncontingent displays, they did show significantly more extreme looking proportions to the two displays than did the 5-month-olds. This may reflect the infant's progression from self to social orientation.

Lewis and Brooks-Gunn (1979) found that by the end of the first year of life, infants are able to discriminate a "live" video image of the self from a recorded image of the self or a peer. The authors propose that this self-recognition is primarily based on the detection of contingent visual stimulation from the live video image. That is, movement of the infant's hand, for example, results in comparable movement of the hand in the video image. Furthermore, they propose that the earliest stages of self-perception are probably based on the infant's detection of some form of response contingent stimulation, such as the contingency between visual and proprioceptive feedback from body motion.

There exists considerable evidence that infants as young as 2 and 3 months are sensitive to experimentally arranged contingencies between behaviors, such as leg kicks, sucking, or vocalization and various forms of visual and auditory stimulation, such as lights, tones, or the movements of an overhead mobile (Rovee & Rovee 1969; Rovee-Collier & Gekoski, 1979; Siqueland & DeLucia, 1969; Watson & Ramey, 1972). There is even some evidence that this sensitivity exists from birth (Sameroff, 1971).

These kinds of contingent relations, however, differ from those provided by a mirror or video image. When the infant turns on a light display by kicking his or her foot (e.g., Watson, 1979) the onset of the light display is contingent upon the onset of the infant's leg motion. When the infant controls the motions of an overhead mobile that is connected to his or her leg by a ribbon (e.g., Rovee & Rovee, 1969), the motions of the mobile are "conjugately" related to the motions of the infant's leg. They

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covary along dimensions of amplitude and temporal pattern. However, the stimulation from such a conjugate display is not perfectly isomorphic with the motions of the infant, like that of a mirror or video image.

The mirror or video reflection of the self provides essentially perfect contingent stimulation. It seems a reasonable possibility that perfect contingency may serve to specify stimulation arising from the self, whereas imperfect contingency may specify stimulation arising from sources other than the self.

If that were so, then one should expect to find that the visual discrimination of self and other, based on contingency perception, would be observable well within the first year of life. There have been a few studies to date that appear to support this expectation. Papousek and Papousek (1974) found that 5-month-olds discriminated a live video image of self from a recorded image of self. Infants showed their discrimination by preferential fixation of the noncontingent, recorded display of self over the contingent, live display of self. A subsequent study by Field (1979) found that 3-month-olds displayed differential responsiveness to a contingent mirror image of the self and a noncontingent presentation of a peer. These infants looked more to the mirror image of the self but smiled and vocalized more in the presence of a peer. However, several procedural confounds inherent in these kinds of studies have made interpretation of their findings difficult. Recording the noncontingent video film of self under experimental conditions that differ from those of the contingent video film of self introduces the possibility that the amount of general body motion displayed by infants in the different conditions may differ and may then serve as a basis of discrimination between the two kinds of displays. Second, the use of facial images as stimuli in these studies creates a confound of differential eye contact and eye motion in contingent and noncontingent displays. The mirror image provides constant eye contact and no visible eye motion for the infant, whereas the recorded image of self or peer provides eye contact and eye motion variability. Papousek and Papousek (1974) attempted to separate eye contact and contingency of the image by using video controls. Though they did find an effect of eye contact, the overall effect of contingency as a basis of discrimination between live and recorded presentations of self was most evident.

These findings would seem to support Lewis and Brooks-Gunn's (1979) assumption that the contingency between visual and proprioceptive information for self-motion could serve as a basis of self-perception in the first months of life. Young infants are constantly presented with visual and proprioceptive information specifying self. Each time the infant reaches, he or she can both see his or her arm reaching and feel it reaching. There is a perfect correspondence between the visual and proprioceptive information for self-motion. The Gibsons (E. J. Gibson, 1969; J. J. Gibson, 1966, 1979) described this kind of information as an invariant, amodal relation that specifies self.

It seems important at this point to clarify our use of the term *proprioception,* because it has had a variety of connotations in the past. Gibson (1979) maintained that all senses have a proprioceptive as well as an exteroceptive function, and therefore he does not identify proprioception as a separate sensory system. Rather, information about the self is obtained through all the sensory systems. However, for the purposes of this presentation, we need to distinguish among several types of information specifying self. Thus our use of the term *proprioception* will be reserved for that information intrinsic to behavior that arises from the muscles, joints, tendons, vestibular system, and efferent pathways that specify self-motion. This restricted use of the term facilitates an important distinction to be drawn between proprioception in the above sense and the perception of self arising from sources other than those mentioned above (e.g., vision or audition). Thus the distinction between seeing one's hand move and feeling one's hand move (proprioception) can easily be made for our present purposes.

In all the studies described above concerning infants' visual perception of self, infants had direct visual access to the movement of their hands, upper torso, and, to some extent, even facial movement. Therefore, infants' discrimination of a live and recorded image of the upper torso, face, and hands may have been based on the detection of either of two kinds of contingent relations: (a) a visual–visual contingency or (b) a proprioceptive–visual contingency, the theoretically more relevant alternative proposed by Lewis and Brooks-

Gunn (1979). That is, infants may have detected a contingent relation between the visible motions of their own hands and the image of that motion depicted on the video screen. Or, they may have detected a relationship between proprioceptive information for self-motion and the visual display of that motion depicted on the video screen. Research to date has not distinguished between these two possibilities. Distinguishing these two interpretations requires empirical evidence for the capacity of infants to perceive cross-modal contingent relations between vision and proprioception.

The only evidence to date that suggests that young infants detect proprioceptive-visual relations is that on neonatal imitation (Meltzoff & Moore, 1983a, 1983b). The young infant's ability for delayed imitation of facial gestures is interpreted by the authors to demonstrate an ability to monitor proprioceptive information from the facial muscles and joints and to match their gesture with the visually given gesture of the model.

The present research directly investigates the infant's capacity to detect proprioceptive-visual relations uniting self-motion with a visual display of that motion. In order to examine this capabililty, the usual design of mirror or video self-recognition studies was modified in several important ways. Prior confounds of differential eye contact and eye motion between contingent and noncontingent displays were eliminated by presenting nonfacial stimuli. The confound of body motion variability was controlled by using a yoked control design. And finally, the infant's detection of proprioceptive-visual information for self-motion was investigated directly in Experiments 2-4 by occluding the infant's direct view of his or her own body while viewing the video images. This eliminated the possibility of detecting contingency on the basis of visual-visual relations. By incorporating these modifications, three studies investigated 5-month-old infants' sensitivity to invariant intermodal relations uniting proprioceptive and visual information for self-motion. A fourth study extended the investigation to 3-month-olds.

Experiment 1

Because of prior confounds of eye contact, eye motion, and general body motion variability, the basis of infants' discrimination between the contingent image of the self and the noncontingent image of the self or a peer is at present unresolved. In this study, 5-month-old infants were tested for discrimination between a live video image of self and the noncontingent image of a peer. Eye contact and eye motion variability were eliminated by presenting the image of the infant's body from the waist down so that only leg and foot motion were displayed. Body motion variability was controlled across subjects by using a yoked control design. The live image of each infant was recorded and later used as the noncontingent peer film for the next infant. Thus all noncontingent "peer" films were recorded while the peer was also viewing a contingent video image of self along with the noncontingent image of a peer. We were interested in whether infants, in the absence of prior confounds, would discriminate between these nonfacial stimuli on the basis of contingency, and whether they would preferentially fixate the contingent or the noncontingent display.

Method

Subjects. Twenty 5-month-old infants, 10 boys and 10 girls, participated. Their mean age was 148 days (SD = 5 days). Subjects were recruited through the local birth records. Two additional subjects were tested and excluded because of excessive crying and fussiness.

Apparatus and procedures. Infants were seated in an infant seat in a booth enclosed by patterned curtains on two sides, and they faced two television screens approximately 30 inches (76 cm) away. The television screens were positioned side by side, about 18 inches (46 cm) apart (from the inside edge of one screen to the other), and a color video camera was centered between them, directly in line with the infant's legs. The video camera was turned upside down and stood at a height near the infant's head level and at an angle approximating the infant's view of his or her own legs when looking down at them. Because of this, the infant's legs appeared on the video screen with the feet extending in the upper portion of the screen, just as when the infant looks down at his or her feet they extend upward into the infant's visual field. By inverting the camera, the right-left inversions typically produced by video films were altered. In this case, although the feet extended upward, the motion of the infant's right leg, for example, was displayed as motion of the leg on the right side of the screen, in this respect resembling a mirror image.

Figure 1 is a photograph of an infant viewing the display, and it illustrates our apparatus. All infants were fitted with bright yellow booties and were placed in an infant seat that was covered by a bright blue cloth. This was done to maximize visibility of the feet and to equate for color and brightness across subjects.

Infants viewed two color video screens side by side for 4 min. One screen displayed a live transmission of the infant's legs and feet (contingent display) and the other

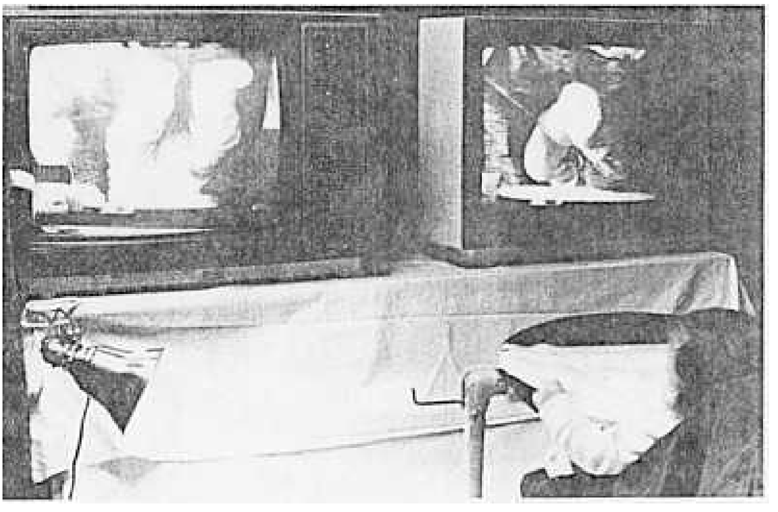

Figure 1. Photograph of the apparatus and stimulus display.

showed the legs and feet of a peer (noncontingent display). The yoked control design controlled for amount of leg motion and visual characteristics of the noncontingent display across subjects. A trained observer, blind to the lateral positions of the displays, monitored the subject's visual fixations to the two screens. She held a set of buttons connected to a Rustrak strip chart recorder and pressed one button while the infant fixated the right-hand screen and another button while the infant fixated the left-hand screen. A second trained observer also monitored fixations for a proportion of the subjects. Interobserver reliability was calculated for the primary and secondary observers on 34 out of 89 subjects across the four experiments reported here, and was .99. This was a correlation between the proportions of total looking time infants spent fixating the noncontingent displays across the two observers.

Lateral positions of the contingent and noncontingent displays were counterbalanced across subjects. Ten infants saw the live display on the right and the peer display on the left, and 10 received the opposite arrangement. The two televisions were connected to cable splitters and a switch that allowed us to present either image to the left- or right-hand screens. Either the infant's parent or a second experimenter operated the switch that turned on both displays and determined to which side the live and peer displays would be presented.

Results and Discussion

Looking proportions were derived by dividing the time infants spent looking to the noncontingent peer image by the time they spent looking to both films, across the 4-min period. Subjects spent an average of .65 of their total looking time viewing the noncontingent image of the peer. This proportion is significantly different from the chance value of .50 according to a t test, $t(19) = 3.30$, $p < .005$. At the individual subject level, 16 out of 20 subjects spent a majority of their total looking time viewing the noncontingent peer film. There were no significant side preferences, $t(18) = .637$, $p > .05$, nor were there any significant sex differences in looking to the two displays, $t(18) = 0.147$, $p > .05$. Looking proportions were also derived for each infant for each of the four 1-min periods separately to test for trends over time in looking to the noncontingent films. A one-way repeated-measures analysis of variance (ANOVA) revealed no significant differences in looking across the four 1-min periods, $F(3, 57) = 1.4$, $p > .05$. In fact, looking proportions to the noncontingent peer film during the first minute (.66) were comparable to those of the last minute (.68).

Five-month-old infants can differentiate between a contingent display of their own leg motion and a noncontingent display of a peer's legs. They showed this discrimination by looking preferentially to the noncontingent display. This discrimination was evident with nonfacial stimuli and under conditions in which prior confounds of eye contact, eye motion, and body motion variability were eliminated. These findings support the interpretation that 5-month-old infants discriminate between video displays of self and peer on the basis of the contingent relations between their own body motion and that displayed in the live video image. How might infants have detected this contingency? What kind of information might they have used as a basis of discrimination? There are at least two possibilities. Infants might have (a) made a visual comparison between the motions of their own legs and those pictured on the video display, and/or they may have (b) used proprioceptive information from their muscles and joints and detected an intermodal relation between this proprioceptive information from self-motion and the visual information displayed on the video screen. Experiment 2 was designed to distinguish between these two alternatives.

Experiment 2

Little direct evidence exists bearing on whether young infants make use of proprioceptive information for determining how their body is moving through space—that is, information from the muscles, joints, and vestibular system. Some findings, however, are consistent with this interpretation, including those of visually guided reaching (e.g., Bower, Broughton, & Moore, 1970; Hofsten, 1979, 1983; McDonnel, 1975) and contingency learning in infancy (e.g., Rovee & Rovee, 1969; Watson & Ramey, 1972), though they could as well be explained on the basis of vision alone. Another area of research bearing on this question is that concerning the infant's use of visual information for monitoring posture and motor behavior. These studies of "visual proprioception" (in the Gibsonian sense; Butterworth & Cicchetti, 1978; Butterworth & Hicks, 1977; Lee & Aronson, 1974) found that the posture of infants who could sit or stand unsupported was disrupted by visual information for body sway, even in the absence of vestibular or proprioceptive information for body sway. Also, research by Jouen (1984) indicated that the infant's head righting response subsequent to a body tilt varies according to the orientation of visual stimulation. This research suggests an early link between vision and proprioception, and it establishes the function of vision for guiding motor behavior in infancy. Although these findings suggest that infants made use of both visual and proprioceptive information for posture control, they may also be interpreted as evidence for the primacy of vision in guiding motor behavior.

The strongest evidence to date suggesting that infants make use of proprioceptive information is that demonstrating imitation behavior in neonates (Meltzoff & Moore, 1983a, 1983b). Because these infants had minimal visual access to their own facial expressions, these findings are difficult to account for on the basis of vision alone. It seems likely, therefore, that even very young infants make use of proprioceptive information from the muscles, joints, skin, and/or efferent pathways to control and determine the nature (e.g., direction, intensity and form) of their physical motion.

Experiment 2 directly tests this possibility. Infants were again shown a live video display of their own legs side by side with those of a peer. In this replication of Experiment 1, however, the infant's direct view of his own body was occluded. By occluding infants' views of their body, they no longer have access to visual information for their leg motion and must rely on proprioception for detecting the contingency between their leg motion and the video display of it. We were interested in whether infants would visually discriminate between the contingent and noncontingent displays without visual access to their own leg motion, demonstrating that they could rely on proprioceptive information for specifying self-motion.

Method

Twenty 5-month-old infants, 10 boys and 10 girls, participated. Their mean age was 150 days (*SD* = 5 days). Two additional subjects were tested and excluded from the study for excessive crying and fussiness. The apparatus and procedures were identical to those used in Experiment 1, except that the infant's direct view of his or her own body from the waist down was occluded. This was accomplished by mounting a wooden tray in front of the infant seat and securing the bottom of a large bib to the tray and the top of the bib around the infant's neck. The infant's arms were placed above the bib so that they could move about freely and, as in Experiment 1, were not visible in the video display. The infant's legs and torso extended underneath the tray and bib so that no direct visual access to that portion of their body was possible. As in Experiment 1, subjects viewed a contingent video display of their own legs side by side with a noncontingent display of a peer's legs for 4 min. In this study, 12 infants saw the display of the peer's legs on the right and their own legs on the left, whereas 8 received the opposite arrangement. This unequal distribution occurred by chance as a result of our procedure for controlling observer bias. The infant's parent manipulated the switch controlling the lateral positions of the video displays.

Results and Discussion

Results of the study replicated those of Experiment 1. Subjects spent .66 of the total looking time viewing the noncontingent peer image. This proportion is significantly different from the chance value of .50 according to a t test, $t(19) = 4.39$, $p < .001$. At the individual subject level, 17 of the 20 subjects spent a majority of their total fixation time watching the display of the peer. There was no significant side preference, $t(18) = 0.298$, $p > .05$, nor were there any sex differences in looking to the noncontingent display, $t(18) = 2.03$, $p > .05$. An ANOVA was performed on looking preferences for each minute of the 4-min viewing period to determine whether there were any trends over time in looking to the peer display. Results indicated no differences over the four 1-min periods, $F(3, 57) = 2.38$, $p > .05$.

Five-month-olds show visual discrimination of a contingent display of their own leg motion and a noncontingent display of a peer's leg motion, even when their view of their own body is occluded. Their performance was similar to that of Experiment 1 where they had visual access to their own bodies. These results suggest that young infants need not rely on visual information for determining how their bodies are moving about in space. They need not detect the contingency of the live video display by making a visual comparison of their leg motion and that displayed on the screen. Rather, they may be able to use proprioceptive information from the muscles and joints to determine the nature of their physical motion. As a consequence, infants could have discriminated between the contingent and noncontingent images by detecting the intermodal relationship between the nonvisual proprioceptive information for motion and the visual display of that motion.

However, before this conclusion can be accepted, another interpretation of the results must be considered. It is possible that infants did not detect a contingent relation at all. Rather, they may have recognized features of their own legs and feet and discriminated between their own image and that of the peer on this basis. Though this interpretation seemed rather unlikely for such young infants, it nevertheless remained a possibility. Despite the fact that individual features of the infant's legs and feet were partially controlled by fitting all infants with yellow booties, there was some distinctive visual information. The subject's clothes were visible above the booties and might have been recognized by the infant. Also, the shape of the infant's legs and idiosyncratic patterns of leg motion might conceivably have served to distinguish among subjects. Although studies of self-recognition (Lewis & Brooks-Gunn, 1979) report that infants do not recognize features of their own body until approximately 1½ years of age, this interpretation could not be conclusively ruled out in the present studies. The possibility that infants recognized features of their own body was thus tested in Experiment 3 by eliminating the distinguishing features altogether.

Experiment 3

In this study, features that distinguished among infants' legs and feet were eliminated by presenting the contingent video image of self along with a noncontingent, recorded image of self, rather than the image of a peer. The noncontingent, recorded film was made just prior to testing, and infants wore the same clothes in both video displays. No visual characteristics differentiated the live from the recorded video displays. Only the contingent relation between the infant's leg motion and the live image of that motion could be used as a basis of discrimination. This contingency could be detected only through use of the proprioceptive information because the occluding bib was again used.

Method

Twenty 5-month-olds were tested, 11 boys and 9 girls. Their mean age was 143 days ($SD = 10$ days). The apparatus and procedures were the same as those used in Experiment 2, including the use of the occluding bib, except that a 4-min period preceded the usual testing session in which the infant's legs were recorded. During this period, the infant was seated in the infant seat facing the television screens and wore the occluding bib. Subjects were shown a 4-min live video display of their own legs in two orientations (180° vs. 90°). This was done so that subjects would not become bored or fussy during the recording period as well as to roughly approximate the viewing conditions of the test session in the event that the infants' general amount of leg motion was influenced by viewing displays of infant legs. After the subject's legs were recorded, the infant was taken out of the seat and was entertained in the testing room for approximately a 5-min period. Next, the test session began and was identical to that of Experiment 2

Table 1
Experiments 1, 2, and 3: Proportion of Total Looking Time Spent Fixating the Noncontingent Display

Statistic	Experiment 1: Noncontingent peer display	Experiment 2: Noncontingent peer display	Experiment 3: Noncontingent display of self
P	0.65	0.66	0.69
SD	0.207	0.163	0.196
t	3.30*	4.39**	4.34**

* $p < .005$. ** $p < .001$.

except that the recorded video display of self was shown along with the live display of self. Half the subjects viewed the noncontingent recorded film on the right and the live one on the left, whereas half received the opposite arrangement. An observer, blind to the lateral positions of the displays, monitored the subject's fixations.

Results and Discussion

Results of the study, along with those of Experiments 1 and 2, are depicted in Table 1. These results paralleled those of Experiments 1 and 2 exactly. The proportion of total fixation time spent viewing the noncontingent, recorded film was .69. This is significantly different from the chance value of .50 according to a *t* test, $t(19) = 4.34$, $p < .001$. Eighteen of the 20 subjects spent a majority of their total fixation time viewing the noncontingent display. There were no significant side preferences, $t(18) = 1.56$, $p > .05$, or sex differences, $t(18) = 0.988$, $p > .05$, in looking to the noncontingent display. An ANOVA revealed no significant differences among the proportions of looking time to the noncontingent display across the four 1-min periods, $F(3, 57) = 0.09$, $p > .05$.

Infants spent a majority of their total fixation time viewing the recorded, noncontingent display, just as they had in Experiments 1 and 2. The elimination of featural differences between the contingent and noncontingent displays in this study had no decremental effect on viewing time for the recorded film. These results cast doubt on the possibility that infants relied exclusively on recognition of visual features as a basis of discriminating between the displays of self and peer leg motion in Experiment 2. Rather, this study provides direct evidence for an infant's detection of intermodal contingency between proprioceptive and visual information for motion.

Several alternate interpretations of this study are also possible, though taken together with the results of the other studies, they do not provide serious problems. First, though precautions were taken to elicit similar amounts of leg motion in the recorded and live displays by placing infants in similar viewing conditions during both, amount of leg motion may nevertheless have varied systematically across the two displays. Infants may have become habituated to the testing situation more rapidly because of the additional 4-min recording period and thus displayed less leg motion on the live screen during testing. On the other hand, they may have become less wary of the experimental situation, and by the testing session felt more free to explore and move about. Casual observation, however, revealed no systematic differences in amount of leg motion displayed on the live and recorded screens. Another possible interpretation is that infants may have habituated to the live displays during the recording session and thus looked more to the recorded display during testing than they might otherwise. However, this interpretation requires that infants nevertheless discriminate between the two kinds of displays during the test session on the basis of contingency. Taken together with Experiments 1 and 2, these results provide strong evidence for the interpretation that infants detect invariant relations between proprioceptive and visual information for motion. They also are consistent with Lewis and Brooks-Gunn's (1979) proposal that early self-perception may be based on the detection of contingent relations between vision and proprioception.

Another interesting question remained unanswered, however. Why did infants show their discrimination of the contingent and noncontingent displays in all three experiments by looking preferentially to the noncontingent one? One possibility is that infants found the live image aversive because the image of their leg motion was displaced in space and pictured on a television screen. On the other hand, the information provided by the contingent display was completely redundant with the proprioceptive information available to the infant. Thus the live display, without eye contact provided by facial stimuli, may seem boring and lack novelty for the infant. If infants did indeed find the contingent image redundant and boring, it seemed likely that prior to 5 months of age, there ought to be an age when infants begin learning about the nature of contingency, and find these relations interesting to observe. During this earlier period, they might spend a greater amount of time viewing the contingent display of self and testing out the contingent properties of the image. Thus a fourth experiment was conducted to determine whether younger infants would spend more time looking to a live display of their own leg motion than to a noncontingent peer display.

Experiment 4

In this study, we chose to replicate Experiment 2 with 3-month-old infants. Research on contingency learning has estimated that this capability appears by the age of 3 months or earlier (e.g., Rovee-Collier & Gekoski, 1979; Watson & Ramey, 1972). Also, using facial stimuli, Field (1979) found that 3-month-olds showed greater visual fixation to their mirror image but more reaching and vocalizing in the presence of a peer. We thought that infants of this age might also discriminate our nonfacial stimuli, and because at this age they may be learning about the nature of contingency, they may spend a greater amount of time fixating the contingent image of self than the noncontingent image of the peer.

Method

Twenty-nine 3-month-olds were tested, 16 girls and 13 boys. Their mean age was 99 days (SD = 5 days). Two additional subjects were excluded from the study because of excessive fussiness. The apparatus and procedures were identical to those used in Experiment 2. Subjects viewed the live display of their own legs side by side with those of the peer for a 4-min period and wore the occluding bib.

Results and Discussion

Overall, subjects looked to the noncontingent display of the peer .47 of the time. This proportion was not significantly different from chance.

There was no significant side preference, $t(27) = 0.772$, $p > .05$, nor were there any significant sex differences in looking to the noncontingent display, $t(27) = 1.57$, $p > .05$. An ANOVA revealed no significant trends over the four 1-min periods in looking to the noncontingent peer image, $F(3, 84) = 1.98$, $p >$ .05; however, there was a nonsignificant tendency for infants to spend more time watching the noncontingent film toward the end of the 4-min session (.46 in Min 1 vs. .54 in Min 4).

There was, however, some suggestion of bimodality in the distribution of looking proportions for the 3-month-old subjects, as shown in Figure 2. Looking proportions for only three subjects fell near the mean, between .4 and .6, whereas proportions for 14 subjects fell below .4, and 12 fell above .6. This distribution is reflected in the larger standard deviation for 3-month-olds (.281) than for 5-month-olds in Experiment 2 (.163). A nonparametric test, the Moses test of extreme reactions (Siegel, 1956) was conducted to determine whether these two samples were drawn from populations whose distributions differed significantly, one exhibiting a more centralized distribution, and the other a more dispersed one. Results of the test indicated that the 3-month-olds did indeed show looking proportions that were significantly more extreme than those of the 5-month-olds in Experiment 2 ($p < .005$). These results suggest that some 3-month-olds predominately watched the peer display, whereas others predominately watched the contingent display of self. Although it is possible that this reflects only an alternating pattern of side preference, it may be that 3-month-olds are in the process of making a transition from greater interest in self and the contingency provided by a live video image of self, to greater interest in other and the potential for social interaction.

Although these results, taken together with those of the 5-month-olds, may reflect a developmental trend in infants' ability to detect perfect contingent relations provided by a video image of the self, it is also possible that they reflect a trend in the development of preference for this kind of perfect contingency. Infants' preference for invariant relations specifying self may decline with age as they become more socially oriented. This interpretation is

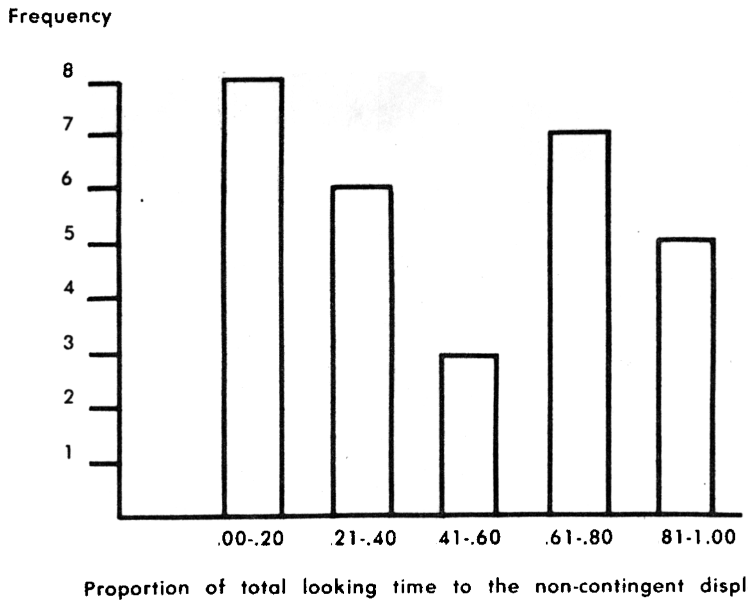

Figure 2. Experiment 4: Distribution of looking proportions for the noncontingent display.

consistent with the finding that 3-month-olds show significantly more extreme looking proportions than do 5-month-olds.

General Discussion

Five-month-old infants show differential visual fixation to a contingent video image of their legs moving and a noncontingent image of a peer's legs moving. They showed this discrimination under conditions in which potential confounds of eye contact, eye motion, and general body motion variability were eliminated. Eye contact and eye motion were eliminated by using nonfacial stimuli, that is, images of an infant's legs moving. Potential discrimination on the basis of general body motion was ruled out by using a yoked control design. Each subject's live image was recorded and later served as the noncontingent image for the next infant, thus controlling for amount of general body motion across subjects.

Purely visual characteristics that might have distinguished the contingent and noncontingent video displays were also controlled. In Experiments 1, 2, and 4, they were partially controlled by fitting all infants with yellow booties. In Experiment 3, they were eliminated altogether by presenting a live image along with a recorded image of self for discrimination. Even in the absence of distinguishing visual characteristics, infants showed a robust discrimination of the contingent and noncontingent displays.

And finally, Experiments 2, 3, and 4 introduced a control procedure to determine the nature of the contingent relations detected by infants. Did infants detect intramodal relations between the sight of their moving legs and the video display of that motion, or did they detect intermodal relations between proprioceptive stimulation from their moving legs and the video display of that motion? To distinguish between these two alternatives, the infants' direct visual access to their own bodies was occluded, eliminating the possibility of an intramodal visual–visual comparison. Discrimination of the contingent and noncontingent displays by 5-month-olds was evident even when infants wore an occluding bib. Therefore, these infants must have detected contingency by perceiving the invariance between the proprioceptive stimulation from their own motion and the visual stimulation from the live video display of that motion. This early detection of proprioceptive–visual invariants is consistent with Lewis and Brooks-Gunn's (1979) proposal that early self-perception may initially develop through the detection of these kinds of intermodal relations. It is also consistent with Meltzoff and Moore's (1983a, 1983b) interpretation that neonatal imitation is based on the detection of proprioceptive–visual relations.

There is a perfect correspondence between the visual and proprioceptive stimulation from one's own body motion. When the infant watches his or her moving body, the visual and proprioceptive information for that motion are united by a common temporal relationship, trajectory or direction of motion, and intensity of motion. Changes within each of these dimensions are invariant over vision and proprioception. For example, the infant can both feel and see the increasing intensity of his or her leg kicking. In the present studies, infants may have detected the contingency between proprioceptive information for motion and the visual display of that motion on the basis of any or all of these kinds of relations.

Research on intermodal perception in infancy has found that infants by 5 months of age are capable of detecting these invariant relations across other modalities. Sensitivity has been shown across vision and audition to various kinds of temporal invariants (e.g., Allen, Walker, Symonds, & Marcell, 1977; Spelke, 1979; Walker, 1982), including the temporal microstructure specifying object substance (Bahrick, 1983). Infants also detect audio–visual invariants between speech sounds and the mouth shape that produces them (Kuhl & Meltzoff, 1984). Across the visual and tactile modalities infants have shown sensitivity to invariants of shape, texture, and substance (e.g., Gibson & Walker, 1984; Meltzoff & Borton, 1979), as well as for trajectory or direction of motion (Aitken, 1983). Given that infants can detect these relations across the visual and acoustic, or visual and tactile modalities, it might well seem reasonable that they would also be capable of detecting these invariants across vision and proprioception. The present research supports this inference.

There are two possible interpretations of the present results demonstrating discrimination of the contingent and noncontingent displays on the basis of proprioceptive–visual invariant detection by 5-month-old infants. One interpretation is that although infants detected invariant proprioceptive–visual information specifying the self, they did not, in fact, perceive this information to specify the self. Rather, they simply responded to the invariant without detecting its affordance. The alternative interpretation, consistent with Gibson's (1969) view, is that detection of this proprioceptive–visual invariant entails perception of the self from the beginning. The present results cannot distinguish between these two alternatives. Obtaining a definitive answer to this question provides a challenge for future research. Nevertheless, the present results indicate that 5-month-old infants possess perceptual capabilities that are fundamental to the perception of self.

Another finding of these studies that deserves further attention is the fact that infants showed their discrimination of the contingent and noncontingent displays by preferential fixation of the noncontingent display. This replicates Papousek and Papousek (1974), who presented facial stimuli to 5-month-olds. This preference for noncontingent stimulation specifying other over perfectly contingent stimulation specifying self may be interpreted as part of the infant's development of increasing responsiveness to social stimulation or to external stimulation in general. In the outside environment and social world, none of our actions produce a perfectly contingent and concomitant set of transformations like those specifying self-motion. When the infant bats a mobile, the mobile moves, but in a pattern and rhythm somewhat different from that infant's own actions. When the infant knocks over a toy, it falls and has a motion of its own. And when the infant smiles, the mother responds in her way, by vocalizing or approaching or engaging in game-like interactions. These kinds of contingent relations are not invariant with the infant's behavior. They are imperfect.

Watson (1972, 1979) proposed that the human infant's concept of a social object is initially formed through experience with this kind of imperfect contingency. This hypothesis provides a theoretical context for the present results. Stimulation that is perfectly contingent or invariant with the infant's behavior may specify self, whereas stimulation that is imperfectly related to the infant's behavior may specify other, quite early in infancy.

Experiment 4 suggests the possibility that the relative preference for the noncontingent display of other over the perfectly contingent display of self may be reversed prior to the age of 3 months. Although 3-month-olds showed no significant preference for the image of self over peer, they did show significantly more extreme looking proportions than did the 5-month-olds. Their looking proportions were bimodally distributed, whereas those of the 5-month-olds were more centrally distributed. These findings, along with those of Field (1979), that 3-month-olds look more to their mirror image than to a peer, suggest the possibility that the age of 3 months may represent a transition period in which attention shifts from perfect contingency specifying self to imperfect contingency specifying other.

The results of these studies taken together demonstrate that information provided by a live video image of one's body motion can be perceived through the detection of invariant intermodal relations between visually and proprioceptively specified motion. Five-month-olds prefer to view a noncontingent display of self or peer over a perfectly contingent display of their own motion. The detection of proprioceptive-visual invariants may be fundamental to the infant's perception of self and may underlie the development of visual self-recognition in infancy.

References

Aitken, S. (1983). *Infant response to amodal information on approach.* Paper presented at the biennial meeting of the Society for Research in Child Development, Detroit.

Allen, T. W., Walker, K., Symonds, L., & Marcell, M. (1977). Intrasensory and intersensory perception of temporal sequences during infancy. *Developmental Psychology, 13,* 225–229.

Bahrick, L. E. (1983). Infants' perception of substance and temporal synchrony in multimodal events. *Infant Behavior and Development, 6,* 429–451.

Bower, T. G. R., Broughton, J. M., & Moore, M. K. (1970). Demonstration of intention in the reaching behavior of neonate humans. *Nature, 228,* 679–680.

Butterworth, G., & Cicchetti, D. (1978). Visual calibration of posture in normal and motor retarded Down's syndrome infants. *Perception, 7,* 513–525.

Butterworth, G., & Hicks, L. (1977). Visual proprioception and postural stability in infancy. *Perception, 6,* 255–262.

Field, T. (1979). Differential behavioral and cardiac responses of 3-month-old infants to a mirror and peer. *Infant Behavior and Development, 2,* 179–184.

Gibson, E. J. (1969). *Principles of perceptual learning and development.* New York: Appleton-Century-Crofts.

Gibson, E. J., & Walker, A. S. (1984). Development of knowledge of visual and tactual affordances of substance. *Child Development, 55,* 453–460.

Gibson, J. J. (1966). *The senses considered as perceptual systems.* Boston: Houghton-Mifflin.

Gibson, J. J. (1979). *The ecological approach to visual perception.* Boston: Houghton-Mifflin.

Hofsten, C. von. (1979). Development of visually guided reaching: The approach phase. *Journal of Human Movement Studies, 5,* 160–178.

Hofsten, C. von. (1983). Catching skills in infancy. *Journal of Experimental Psychology: Human Perception and Performance, 9,* 75–85.

Jouen, F. (1984). Visual-vestibular interactions in infancy. *Infant Behavior and Development, 7,* 135–145.

Kuhl, P. K., & Meltzoff, A. N. (1984). The intermodal representation of speech in infants. *Infant Behavior and Development, 7,* 361–381.

Lee, D. N., & Aronson, E. (1974). Visual proprioceptive control of standing in human infants. *Perception and Psychophysics, 15,* 529–532.

Lewis, M., & Brooks-Gunn, J. (1979). *Social cognition and the acquisition of self.* New York: Plenum Press.

McDonnel, P. M. (1975). The development of visually guided reaching. *Perception and Psychophysics, 18,* 181–185.

Meltzoff, A. N., & Borton, R. W. (1979). Intermodal matching by human neonates. *Nature, 282,* 403–404.

Meltzoff, A. N., & Moore, M. K. (1983a). The origins of imitation in infancy: Paradigm, phenomena, and theories. In L. Lipsitt & C. Rovee-Collier (Eds.), *Advances in infancy research* (Vol. 2, pp. 265–301). Norwood, NJ: Ablex.

Meltzoff, A. N., & Moore, M. K. (1983b). Newborn infants imitate adult facial gestures. *Child Development, 54,* 702–709.

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

Rovee-Collier, C., & Gekoski, M. J. (1979). The economics of infancy: A review of conjugate reinforcement. In H. W. Reese & L. P. Lipsitt (Eds.), *Advances in child development and behavior* (Vol. 13 pp. 195–255). New York: Academic Press.

Rovee, C. K., & Rovee, D. T. (1969). Conjugate reinforcement of infant exploratory behavior. *Journal of Experimental Child Psychology, 8,* 33–39.

Sameroff, A. J. (1971). Can conditioned responses be established in the newborn infant? *Developmental Psychology, 5,* 1–12.

Siegel, S. (1956). *Nonparametric statistics for the behavioral sciences.* New York: McGraw-Hill.

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

Spelke, E. S. (1979). Perceiving bimodally specified events in infancy. *Developmental Psychology, 15,* 626–636.

Walker, A. S. (1982). Intermodal perception of expressive behaviors by human infants. *Journal of Experimental Child Psychology, 33,* 514–535.

Watson, J. S. (1972). Smiling, cooing, and "the game." *Merrill-Palmer Quarterly, 18,* 323–339.

Watson, J. S. (1979). Perception of contingency as a determinant of social responsiveness. In E. B. Thoman (Ed.), *The origins of social responsiveness* (pp. 33–64). New York: Erlbaum.

Watson, J. S., & Ramey, C. T. (1972). Reactions to response contingent stimulation in early infancy. *Merrill-Palmer Quarterly, 18,* 219–227.

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