

Visual-Proprioceptive Intermodal Perception Using Point Light Displays

Mark A. Schmuckler and Jennifer L. Fairhall

Three experiments explored 5- and 7-month-old infants' intermodal coordination of proprioceptive information produced by leg movements, and visual movement information specifying these same motions. The visual information took the form of point light information for leg and feet movements, with visual displays presented in upright, ego-centered on-joint (Experiment 1, $N = 48$); upright, ego-centered off-joint (Experiment 2, $N = 48$); and inverted, observer-centered off-joint (Experiment 3, $N = 48$) orientations. Measures of preferential looking indicated intermodal perception in infants of both ages while seeing on-joint, ego-centered orientations, and for 7-month-olds (and possibly 5-month-olds) while seeing off-joint, ego-centered displays; neither age group demonstrated intermodal perception for off-joint, observer-centered displays. These results suggest that coordination of visual and proprioceptive inputs is constrained by infants' information processing of the displays, and have implications for infants' growing understanding of their self-movement and the development of knowledge of the self.

INTRODUCTION

The past decades have witnessed a growing interest in infants' perceptual capabilities. The issues examined have been numerous, ranging from investigations of basic sensory (e.g., visual and auditory) sensitivities, through the perception of complex objects and events (e.g., object perception, three-dimensional structure from motion), to the cognitive representations of abstract relations and properties (e.g., causality, infants' representations of numbers and mathematical operations). One particularly compelling topic has been understanding infants' coordination of different perceptual inputs into a single, unitary percept. This process, called *intermodal perception*, has generated a great deal of theoretical and empirical interest (Abravanel, 1981; Bushnell, 1981; Bushnell & Boudreau, 1991, 1993; Lewkowicz, 2000; Lewkowicz & Lickliter, 1994; Lickliter & Bahrick, 2000; Rose & Ruff, 1987; Spelke, 1987).

There is evidence that young infants coordinate information from multiple perceptual systems (for reviews, see Lewkowicz, 2000, Lewkowicz & Lickliter, 1994, Rose & Ruff, 1987) with infants, sometimes as young as 1 month, integrating such inputs for knowledge of surfaces, objects, and events (Gibson & Walker, 1984; Kaye & Bower, 1994; Meltzoff & Borton, 1979; but for alternative results, see Brown & Gottfried, 1986; Maurer, Stager, & Mondloch, 1999; Pêcheux, Lepecq, & Salzarulo, 1988). Questions concerning intermodal perception are not restricted to knowing about external sources, however. One can also ask whether infants coordinate inputs for knowledge of their own body position and movement in space (Schmuckler, 1995). In this case, the focus shifts to integrating perceptual (specifically visual) information

specifying body movement with proprioceptive and/or kinesthetic information for such movement.

As they do with intermodal coordination, young infants integrate visual input with kinesthetic and proprioceptive information for body position (see Schmuckler, 1995). For example, infants and children use visual information for maintaining their body position in static (Bertenthal & Bai, 1989; Bertenthal, Rose, & Bai, 1997; Butterworth & Hicks, 1977; Delorme, Frigon, & Lagace, 1989; Jouen, 1984; Lee & Aronson, 1974; Nougier, Bard, Fleury, & Teasdale, 1998; Schmuckler, 1997) and dynamic (Schmuckler & Gibson, 1989; Stofregen, Schmuckler, & Gibson, 1987) postures. Other evidence from research on spatial orientation (Rider & Rieser, 1988; Rieser, Guth, & Hill, 1986; Rieser & Rider, 1991; Schmuckler, 1995; Schmuckler & Tsang-Tong, 2000) and visually guided locomotion (Adolph & Eppler, 1998; Schmuckler, 1996a) suggests that children integrate visual information with proprioceptive and kinesthetic inputs for knowing where they are and how they are moving in space. Unfortunately, this evidence is limited in that the focus has been on aspects such as postural control or spatial orientation, and not on intermodal perception per se.

Other studies have more directly investigated infants' intermodal perception of self-movement. For example, Bahrick and Watson (1985) had 3- and 5-month-old infants perform hidden leg movements while simultaneously watching two video displays, one of which showed an on-line image of the infant's own legs while the other showed a videotape of either the legs of a different child or of the same infant's legs recorded earlier. These authors reasoned that if in-

infants could coordinate the proprioceptive information for movement with the visual consequences of that same movement, they should preferentially fixate either on the on-line display (a *contingent* display) or the videotaped display (a *noncontingent* display). Their results confirmed this prediction, with 5-month-olds (but not 3-month-olds) preferring to watch the noncontingent display. Although the reasons for the direction of preferential looking are speculative, similar directional preferences have been demonstrated by others (Papousek & Papousek, 1974; Rochat & Morgan, 1995; Schmuckler, 1996b) and suggests that infants discriminate the displays on the basis of the matching visual and proprioceptive inputs.

Studies by Rochat and Morgan (1995) and Schmuckler (1996b) extended Bahrnick and Watson's (1985) findings, exploring the information underlying this intermodal perception using leg (Rochat & Morgan, 1995) and hand (Schmuckler, 1996b) movements. Interestingly, both sets of studies found that spatial directionality was critical for discriminating contingent from noncontingent displays, with displays reversing the left-right relations treated as noncontingent. This failure to detect intermodal correspondences occurred despite the temporal contingencies that existed between the two inputs and suggests that intermodal perception is constrained by factors other than temporal information (see Bahrnick & Pickens, 1994). Manipulations of the point of observation, including ego-versus observer-based views (Rochat & Morgan, 1985) and novel limb orientations (Schmuckler, 1996b) did not influence preferential looking, provided that left-right spatial contiguity was retained. Overall, infants' intermodal coordination allows for knowledge of body position in space (Schmuckler, 1995) and may be a precursor to the development of the self (Neisser, 1988, 1991, 1993; Rochat, 1995a).

One assumption in this research is that the critical contingency relation underlying intermodal perception is the correspondence between proprioceptive movement and the actual visual motion observed. Thus, when infants feel their limbs moving in a given direction, the visual image also moves in this direction, with visual and proprioceptive inputs matched in speed, direction, and amplitude of movement. It is also true, however, that the visual motion occurs in a familiar, recognizable framework, such that when infants move their legs they see an image of actual legs moving.

The role of familiarity has been addressed in these earlier studies. For example, both Bahrnick and Watson (1985) and Rochat and Morgan (1995) removed distinctive familiar feature information, such as one's toes or recognizable clothing, from the displays by requiring that infants wear unfamiliar socks. To equate

further the two displays featurally, Bahrnick and Watson used a previously recorded videotape of the child currently participating in the experiment as the noncontingent display, whereas Rochat and Morgan used a spatially modified (see previous discussion) on-line display of the child's limbs as the noncontingent stimulus. Despite the removal of these familiar cues, infants demonstrated intermodal perception.

Subsequent research explored visual-proprioceptive intermodal coordination in situations in which movement produced object exploration (Rochat & Morgan, 1998), and, most relevant, when limb recognizability was further reduced (Morgan & Rochat, 1997). Specifically, Morgan and Rochat studied 3- and 5-month-olds' intermodal perception of leg movements while infants wore either fitted leggings that provided information for leg shape or puffy leggings that obscured leg shape. Even though the use of puffy leggings removed characteristic joint-angle information, both groups of infants still recognized their own limb movement and preferentially fixated on the noncontingent display.

Although these studies demonstrate that it is not crucial that infants recognize the familiar characteristics of their own limbs for intermodal perception, they do not indicate if it is the abstract motion of leg movements per se that is intermodally perceived. Thus, although Morgan and Rochat (1997) eliminated limb familiarity, the displays were still recognizable as legs (albeit with a distorted shape), with this familiar context potentially a factor in coordinating visual and proprioceptive inputs. If it truly is the motion that is critical, then intermodal perception should be demonstrated even when the visual object, although largely unrecognizable, retains contingency relations with proprioceptive movement. Demonstrating intermodal perception under these circumstances would provide strong evidence that the motion itself is sufficient for visual-proprioceptive intermodal perception.

The present experiments produced the situation just described by presenting contingent and noncontingent displays of point light limb movement. In his groundbreaking research on biological motion perception, Johansson (1973, 1977) attached small lights to the major joints of actors and filmed these actors in the dark undergoing various movements. This technique produced images for which the only visible information consisted of the movement of spots of light; such displays are called *point light displays*. Johansson (1977) found that observers were quite proficient at identifying the actor's movements, with recognition of actions (e.g., push-ups, jumping jacks) occurring with exposures as short as 200 ms. Subsequent research found that adults recognize their friends, as well as the actor's gender from point light displays (Cutting, 1978;

Kozlowski & Cutting, 1977; McArthur & Baron, 1983), and that such information is relatively impervious to masking by distracter lights (Bertenthal & Pinto, 1994; Cutting, Moore, & Morrison, 1988).

Infants are similarly sensitive to the motion of point light displays. Using a preferential-looking paradigm, Fox and McDaniels (1982) demonstrated that 4- and 6-month-olds, but not 2-month-olds, discriminated between a point light display of a walking adult and either random movements of lights or an inverted point light display. Subsequent research by Bertenthal, Proffitt, and others has thoroughly investigated infants' perception of biological motion displays, examining the importance of spatial relations (Bertenthal, Proffitt, & Cutting, 1984), relative coherence (Bertenthal, Proffitt, Kramer, & Spentner, 1987), occlusion information (Bertenthal, Proffitt, Spentner, & Thomas, 1985), and local rigidity (Bertenthal, Proffitt, & Kramer, 1987) of point light displays.

Although a comprehensive review of this research is beyond the scope of this article (see Bertenthal, 1993), one general finding is that, although sensitive to point light displays, infants undergo considerable developmental change in their response to point light information. As just described, Fox and McDaniels (1982) found that 4- and 6-, but not 2-month-olds, discriminated point light displays. Similarly, Bertenthal and colleagues have observed differences in discrimination of point light information by infants between 3 and 5 months and occasionally between 5 and 9 months (Bertenthal et al., 1985). In a different vein, Soken and Pick (1992) found that by 7 months of age, infants can under some circumstances use point light information for the perception of facial emotional expressions. Although a more complete explanation for these differences is presented in the General Discussion, what is clear—and most relevant to the present research—is that considerable development occurs in the processing of point light motion over the first year.

Thus, point light displays provide a powerful tool for investigating visual-proprioceptive intermodal perception. Point light movement provides unrecognizable, abstract visual information that is nevertheless spatially and temporally contingent with the proprioceptive input. This then allows researchers to examine the use of motion information per se in intermodal integration; exploring some of these issues was the goal of the current studies.

EXPERIMENT 1: INTERMODAL PERCEPTION OF ON-JOINT POINT LIGHT DISPLAYS

Experiment 1 explored visual-proprioceptive intermodal perception of hidden leg movements presented

via point light displays. On the basis of previous research on visual-proprioceptive intermodal perception, this initial study employed displays in which infants' legs assumed a normal, ego-based orientation (see Morgan & Rochat, 1997; Rochat & Morgan, 1995, 1998; Schmuckler, 1996b) with the point lights located on infants' knees, ankles, and toes. Thus, this study provided *on-joint* point light information, which is a compelling situation for infants' perception of biological motion (Bertenthal, Proffitt, Kramer, & Spentner, 1987; Fox & McDaniels, 1982). Moreover, there is some suggestion that point light information might be better recognized by older, relative to younger, infants. Based on prior research on visual-proprioceptive intermodal perception, the most obvious age range for examining this question would be 5 months and older; accordingly, this experiment employed infants 5 and 7 months in age.

Method

Participants. Twenty-four (12 male, 12 female) 5-month-old infants ($M = 21.3$ weeks, $SD = 1.41$) and 24 (10 male, 14 female) 7-month-old infants ($M = 30.3$ weeks, $SD = .57$) participated in this study. Eight of the 5-month-olds, and ten of the 7-month-olds had participated in previous, unrelated research at the laboratory. The data from an additional nine 5-month-old and seven 7-month-old infants were not included due to (1) equipment failure or experimenter error ($n = 5$), (2) the infant not looking toward one or both displays at all ($n = 3$), (3) the infant being born 4 or more weeks premature ($n = 2$), (4) fussiness ($n = 2$), (5) the child's pants accidentally being shown during the study ($n = 2$), (6) parental interference during the study ($n = 1$), and (7) the infant being the wrong age ($n = 1$). Infants were recruited through a local hospital and other available records; parents were contacted by letter and/or phone. All infants lived in or around the Scarborough, Ontario, community, and all received a toy and a certificate (if this was their first visit to the laboratory) for participating. Detailed data concerning racial and ethnic background, as well as socioeconomic status were not gathered.

Stimuli. Two video displays comprised the visual stimuli for the experiment. One display presented an on-line image of the participating infant's legs and feet. Given the contingencies between the visual movement in the display and the proprioceptive input produced by this movement, this display was called the *contingent* display. The other display presented a recorded videotape of a different child's limbs. Because of the absence of spatial or temporal congruence between visual movement and proprioceptive input, this display was called the *noncontingent* display. Similar

to the procedure used by Bahrick and Watson (1985) and Schmuckler (1996b), the noncontingent display for each child consisted of the taped limb movements of the child (within the same age group) who had just previously completed the experiment.

Apparatus. Each infant was tested in an experimental room covered with acoustic paneling, and lit by a pair of overhead lights. During the experiment the infant sat approximately 1 m from a pair of Sony 14-inch CVM-194 color video monitors. Orange curtains were suspended from the ceiling and draped behind the monitors. Either a JVC GF-700 video camera or a Sony Video 8 Handycam camera was positioned between the two monitors, focused on the infant's face. An observer was positioned behind the curtains and was responsible for recording visual fixations using a two-button computer mouse attached to an IBM PC-compatible 286-MHz computer; this observer was unaware of the left–right position of the two displays.

Positioned directly in front of and beneath the monitors, was a wooden box, .91 m tall, .75 m wide, and .44 m deep, that was partially open at its front and back (see Figure 1). The box was covered with a black cloth, with a slit in the front. A JVC GS-CD1U video camera was positioned within the box such that it produced an ego-centered view of the in-

fant's legs on the video monitor (for more details on the camera arrangement, see Schmuckler, 1996b). A blue–black light was placed inside the box to provide illumination.

To produce the point light information, each child wore a pair of long black socks on which patches of black tape had been attached with Velcro; each patch was marked with a circular (1.4-cm diameter) spot of orange florescent paint. Six patches of tape per sock were positioned on the child's knees (one on the top, one on each side), ankles (one on each side), and toes (one in the center of the toes). Illuminating these patches with the blue–black light, with the brightness of the monitor turned down and the contrast of the monitor turned up, caused only the painted circles to appear on the displays, thus producing point light information.

Figure 1 shows a schematic of the experimental setup. Each infant was tested while sitting on a parent's lap. The parent sat in a chair placed at a right angle to the box, facing the side wall (away from the monitors), and the infant sat on the parent's right leg in front of the box, facing the monitors. In this position it was possible to place the infant's legs through the slit in the cloth and into the box. For all infants, the feet and calves, up to the knee, were situated inside the box (sometimes part of the thighs were also included, depending on the size of the infant). The image from the lower video camera (see Figure 1) was displayed to the infant, providing the on-line, contingent display of movement.

Located in an adjacent control room were three video decks controlling the presentation of the noncontingent stimulus videotape, as well as the recording of the infant's face, and leg and feet movements. The image of the infant's legs was recorded using a JVC 550U videocassette recorder (VCR). The previously recorded videotape of a different child's legs (the noncontingent display) was displayed using a JVC 630U VCR, and the infant's face was recorded on a Sharp VCR. A second experimenter in the control room controlled the presentation of the contingent and noncontingent displays, as well as the recording of the child's face and leg movements. Also located in the control room was the 286-MHz computer that kept track of the length of and signaled the end of the experimental trials, as well as monitored the various dependent measures (see "Dependent measures and reliability" section).

Procedure. Prior to the study, a parent removed his or her infant's socks and shoes (if worn), rolled up the child's pant legs (if long pants were worn), and put the black socks on the child's legs. The patches of tape were then attached by an experimenter, who then situated each parent and child in

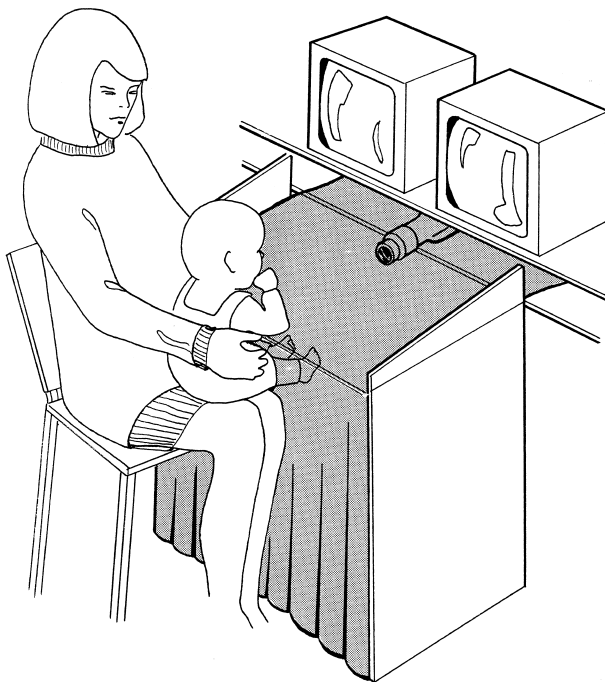


Figure 1 Schematic diagram of the experimental setup for Experiments 1, 2, and 3. Note that the parent is reversed 180° in this figure, relative to the actual position during the study (see text for details).

front of the wooden box. Pilot testing revealed that each infant varied in the amount of spontaneous leg movements produced. Because it was critical that the point light information occur dynamically, the parent was asked to gently move the infant's legs in whatever fashion he or she wished, provided that the motion be roughly continuous and that the parent's hands remained outside of the box.

Once the parent and child were positioned correctly, the experimenter in the control room began the study by turning on the contingent- and noncontingent stimulus displays. The two displays were presented for 1 min, with the infant's fixations toward each monitor recorded. After 1 min, the displays were turned off, parent and child took a short break, and then the procedure was repeated for a second 1-min trial with the left-right position of the displays reversed relative to the first trial. After the second trial, the parent was debriefed as to the purpose of the study. The actual experimental phase was brief (5–10 min), with the entire visit to the laboratory lasting 30 to 45 min. For half of the infants in each age group, the contingent display appeared first on the right and then the left monitor during Trials 1 and 2, respectively; this display placement was reversed for the remaining infants.

Dependent measures and reliability. Multiple measures can be analyzed in a preferential-looking paradigm (Dannemiller & Freedland, 1991a, 1991b). The most common measure is the duration of the total fixation toward each display, with preferential looking indicated by greater fixation toward one of the two displays. A second measure (Dannemiller & Freedland, 1991a, 1991b; Kaye & Bower, 1994; Lewis, Kagan, & Kalafat, 1966; Spelke, 1979) is the duration of the initial fixation toward each display, with preferential looking indicated by greater initial fixation toward one of the two. A final measure is the number of fixations directed toward each display, with preferential looking indicated by more fixations toward one of the two. Dannemiller and Freedland (1991a, 1991b) have suggested that all the measures are interrelated and potentially provide insight into preferential looking beyond that offered by the more traditional total fixation measure; accordingly, Experiment 1 employed all three measures.

Because the experimental sessions were videotaped, it was possible to perform reliability coding for these measures. To that end, a second observer, naïve to the purposes of the experiment and to the left-right position of the displays, also coded visual fixations. Following Schmuckler (1996b), coding was considered unreliable if the difference between original and subsequent observations was large (i.e., more than 25–

30% of the larger value), or, more important, if the pattern of preferential looking changed (e.g., more looking toward the contingent display in the original observations, but the reverse pattern for the subsequent observations). Reliability was calculated for 39 of the 48 infants (nineteen 5- and twenty 7-month-olds). All measures proved highly reliable. Aggregating across trial and left-right displays, the codings were strongly correlated, with $r_s(154) = .98, .81, \text{ and } .88$, all $ps < .001$, for total fixation, initial fixation, and number of fixations, respectively.

Results and Discussion

For all three measures, proportion scores were calculated by dividing the time spent looking (total or initial) and the number of fixations toward each display by the time spent looking (total or initial) and the number of fixations toward both displays. These proportions were converted to difference scores by subtracting the proportion measure for the contingent display from the proportion measure for the noncontingent display.

Given that this study provided three dependent measures, it was possible to examine preferential fixation by considering each dependent measure on its own, as well as combining the separate scores into a single, composite measure. Of the two, clearly the more powerful procedure is to examine preferential fixation based on all three measures simultaneously, as this composite measure reflects multiple aspects of infants' looking behavior, as opposed to just a single parameter of looking. The most obvious technique for producing such a composite score is to average the three dependent measures. Although straightforward, this procedure weights all of these scores equally and thus assumes that each contributes comparably to preferential looking and is an equivalent index of the underlying preference. A somewhat more elegant approach that does not make such assumptions is to actually determine the relative weights of the variables and then combine these scores using the more individualized weights. This procedure is, in essence, what a multivariate test accomplishes when it creates a linear combination of the dependent variables. The easiest way to determine these weights is to factor analyze the various dependent measures (Tabachnick & Fidell, 1996) and then use their respective component loadings (normalized such that they add to 1.0) as weights in creating the composite score. This was the procedure employed with the current data.

The difference scores for all three variables (averaged across each participant's two trials) were factor analyzed, with separate analyses conducted for 5- and 7-

month-olds. The normalized component loadings for total duration, initial duration, and number of looks were .388, .291, and .321, for 5-month-olds, and .386, .244, and .370, for 7-month-olds, respectively. These normalized component loadings were then used to create a composite difference score.

The composite difference scores were then explored in a series of analyses. Initial analyses examined this score using a two-way analysis of variance (ANOVA) with the between-subjects factors of age (5 versus 7 months) and order (contingent on the left in Trial 1, versus contingent on the right in Trial 1). This analysis revealed no main effect for age, $F(1, 44) = .20$, $MSE = .01$, *ns*, or order, $F(1, 44) = 1.34$, $MSE = .01$, *ns*, nor any interaction between the two, $F(1, 44) = 1.68$, $MSE = .01$, *ns*, and thus demonstrated that the pattern of preferential looking did not vary as a function of age or order variables. What this test did not reveal, however, was whether there actually was preferential fixation toward one of the displays, and if so, which one. Because these were difference scores, the critical test of this question was to compare the difference score relative to chance (zero difference), with significant positive versus negative differences indicating preferential fixation toward the noncontingent versus contingent displays, respectively.¹ Along these lines, a test of the composite difference score (aggregating across age) revealed a significant preference toward the noncontingent display, $t(47) = 2.80$, $p < .01$. (This, and all subsequent t tests, were two-tailed.) Figure 2 presents the composite preferences for the 5- and 7-month-olds individually, and reveals greater fixation toward the noncontingent displays for both 5-month-olds ($M = 55.1\%$, $SD = 12.4\%$), $t(23) = 2.03$, $p = .05$, as well as 7-month-olds ($M = 53.7\%$, $SD = 9.5\%$), $t(23) = 1.92$, $p < .07$. It should be noted that this final result would have been significant using a one-tailed test. Although overused and often employed to generate significance from weak findings, a one-tailed test would be appropriate given the a priori prediction of preferential looking toward the noncontingent display, based on earlier work (Bahrick & Watson, 1985; Morgan & Rochat, 1997; Rochat & Morgan, 1995, 1998; Schmuckler, 1996b).

¹ Actually, the preceding analysis did technically explore this effect in that some ANOVA programs provide a test of the grand mean of the dependent measure, averaged across all factors, relative to zero. The primary difference between the F ratio provided by the ANOVA and the more stand-alone t test of this effect involves some slight variation in the sum-of-squares error term and a decrease in the df from 47 (t test) to 44 (two-way ANOVA). Because the t test was actually slightly more conservative in this case and was more familiar to readers (although the F ratio produced by the ANOVA is arguably more appropriate), this article reports the results of the t test.

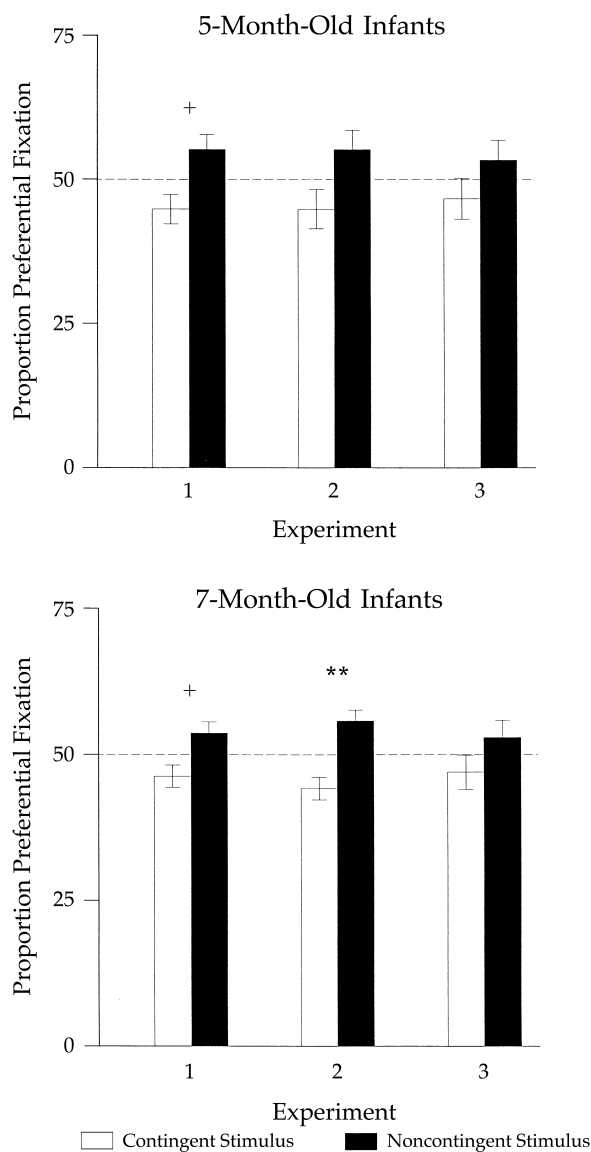


Figure 2 Mean composite looking preference toward contingent and noncontingent displays for 5- and 7-month-old infants in Experiments 1, 2, and 3. Significance relative to chance (50%) is noted: ** $p < .01$; + $p < .10$.

Nevertheless, because it is more conservative, a two-tailed test was employed.

Subsequent analyses assessed preferential fixation for each of the dependent measures individually. For each measure, the proportion difference scores were analyzed in comparable two-way ANOVAs as with the composite measures, using the same factors of age and order. Table 1 presents the proportion scores for all three measures toward the noncontingent display and, for comparison, the raw scores (length and number of fixations.) The analyses of the difference scores

Table 1 Mean Proportion Scores toward the Noncontingent (NC) Display and Raw Scores toward the NC and Contingent (C) Displays for the Three Dependent Variables of Experiments 1, 2, and 3

| | Proportion Scores | | | Raw Scores | | | | | |
|----------------------|-------------------|--------------------------|--------------------------|------------|------|----------|------|---------|------|
| | | | | 5 Months | | 7 Months | | Average | |
| | 5 Months | 7 Months | Average | NC | C | NC | C | NC | C |
| Experiment 1 | | | | | | | | | |
| Total fixation (s) | 55.6 (18.8) | 55.7 (14.2) ^a | 55.6 (16.5)* | 19.0 | 16.3 | 24.1 | 19.2 | 21.6 | 17.7 |
| Initial fixation (s) | 54.9 (15.4) | 53.2 (17.0) | 54.0 (16.1) ^d | 4.3 | 2.5 | 4.9 | 2.8 | 4.6 | 2.7 |
| No. of fixations | 54.8 (10.0)* | 52.0 (6.5) | 53.4 (8.5)** | 6.9 | 6.1 | 8.8 | 8.0 | 7.9 | 7.1 |
| Experiment 2 | | | | | | | | | |
| Total fixation (s) | 53.8 (21.4) | 57.9 (11.6)* | 55.8 (17.2)* | 22.9 | 20.8 | 25.7 | 18.6 | 24.3 | 19.7 |
| Initial fixation (s) | 60.4 (23.3)* | 55.7 (15.3) ^c | 58.7 (19.6)** | 6.2 | 5.0 | 3.0 | 2.6 | 4.6 | 3.8 |
| No. of fixations | 51.9 (12.8) | 53.4 (7.3)* | 52.7 (10.3) ^b | 7.1 | 6.8 | 9.2 | 8.4 | 8.2 | 7.6 |
| Experiment 3 | | | | | | | | | |
| Total fixation (s) | 54.6 (22.0) | 52.7 (17.5) | 53.7 (19.7) | 17.2 | 12.9 | 18.6 | 16.2 | 17.9 | 14.5 |
| Initial fixation (s) | 55.5 (23.7) | 59.5 (19.8)* | 57.5 (21.7)* | 3.5 | 2.0 | 3.8 | 2.4 | 3.6 | 2.2 |
| No. of fixations | 50.0 (13.8) | 47.2 (10.0) | 48.5 (12.0) | 6.3 | 6.4 | 7.3 | 8.1 | 6.8 | 7.2 |

Note: Standard deviations are given in parentheses. All *t* tests are two-tailed. Subscripts indicate different values at the $p < .10$ level.

* $p < .05$; ** $p < .01$; ^a $p < .10$.

revealed results comparable with the composite scores. None of the three measures showed a significant age or order effect, or any interaction between the two. Subsequent *t* tests of these scores relative to chance revealed significant preferential fixation of the noncontingent display for both total duration and number of fixations, and a marginal effect for initial fixation (see Table 1). Table 1 also shows the results of follow-up *t* tests for each measure for the two age groups individually and, although somewhat more mixed, reveals a general preference for the noncontingent display.

Overall, this experiment observed intermodal perception of point light displays of leg movements by 5- and 7-month-old infants, indicated by preferential fixation of the noncontingent display as revealed in the analyses of the composite scores. Although the analyses of the individual measures generally supported this result, it is true that preferential looking in each individual age group was not as uniformly consistent across the three measures as one might have hoped.

Assuming that infants were, in fact, sensitive to the intermodal contingencies in the displays, one explanation for this inconsistency is that the displays were simply not compelling and lacked sufficient information (either visual or proprioceptive) for perceiving self-movement. Relative to earlier research on infants' perceptions of biological motion, the point light information available in this experiment was significantly diminished. In a typical biological motion display (see Bertenthal et al., 1984; Cutting, 1981; Fox & McDaniels, 1982; Johansson, 1973, 1977), point lights appear on the

neck, arms, torso, and legs of the body, producing multiple hierarchically nested limb information from numerous spots of light. In contrast, the displays in the present experiment limited point lights to the infants' knees, ankles, and toes. Unfortunately, the paucity of the number of lights, together with the positioning of these spots and the requirement of presenting an ego-centered view, meant that only a handful of point lights were available for viewing at any one time. (Experimenter observations support this idea, with infants frequently seeing only a few point lights at any one time.) Although there are issues related to the proprioceptive input (discussed subsequently), one partial solution to this problem would be to add more point lights to each limb, thus increasing the available visual information.

EXPERIMENT 2: INTERMODAL PERCEPTION OF OFF-JOINT POINT LIGHT DISPLAYS

Experiment 2 increased the amount of available visual information by increasing the number of fluorescent spots on infants' legs. One consequence of this solution was that the point light information was no longer restricted solely to the infants' joints, but instead was found both on, but primarily off, the joints.

A concern in using off-joint point light information is that including such information makes it more difficult for infants to detect variations in the displays (Bertenthal, Proffitt, Kramer, & Spentner, 1987; Fox & McDaniels, 1982). For example, Fox and McDaniels

observed that 6-month-old, but not younger, infants distinguished on- versus off-joint point light displays of hand movements. Similarly, Bertenthal, Proffitt, Kramer, and Spentner (1987) found differences in encoding and discrimination by 3-month-old infants of biological motion displays in which on-joint motion was paired with either a scrambled point light display or a display containing off-joint point light information. Infants viewing the on-joint versus scrambled display showed both differential encoding and subsequent discrimination of the displays, whereas infants viewing the on-joint versus off-joint display failed to discriminate the two. These authors suggested that perceiving off-joint point light information required more sophisticated processing by infants. Thus, the use of off-joint information may have a significant impact on infants' intermodal perception; Fox and McDaniel's results suggests this effect may vary between 5- and 7-month-old infants.

Method

Participants. Participants were 24 (8 male, 16 female) 5-month-old infants ($M = 20.7$ weeks, $SD = .95$) and 24 (10 male, 14 female) 7-month-old infants ($M = 30.2$ weeks, $SD = 1.04$), drawn from the Scarborough, Ontario, community. Twenty of the 5-month-olds, and 23 of the 7-month-olds had participated in previous, unrelated studies at the laboratory. The data from an additional eleven 5-month-olds and four 7-month-olds were not used in this study due to (1) equipment failure or experimenter error ($n = 5$), (2) the infant not looking toward either one or both of the displays at all ($n = 3$), (3) failure to achieve reliability in coding looking ($n = 3$), (4) parental influence on the infant's looking behavior or holding the infant incorrectly ($n = 3$), and (5) fussiness ($n = 1$). Infants were recruited using the same methods as described in Experiment 1, and received comparable remuneration for participation.

Stimuli, apparatus, procedure, and reliability. This experiment differed little from the previous one in detail, employing the same apparatus, procedure, conditions, and counterbalancing as in Experiment 1, although due to experimenter error, 13 of the 7-month-olds received the contingent display on the right monitor on the first trial, whereas only 11 received the reversed order. The most significant deviation in this experiment involved the nature of the point light information. To produce off-joint point lights, 18 spots (1.0 cm in diameter) of orange fluorescent paint were randomly positioned on each sock. Although there were substantially more point lights per leg than in Experiment 1, the point light density for each leg was not especially high; relative to the surface area of the sock, the point

lights covered roughly 4.1%. Similarly, in terms of the absolute number of points, these displays did not include a lot of information. For example, biological displays of human movement typically employ 11 point lights in a display (Bertenthal et al., 1984, 1985; Bertenthal, Proffitt, & Kramer, 1987; Bertenthal, Proffitt, Kramer, & Spentner, 1987), a few points less than displays used in the current experiment. On the other hand, Soken and Pick's (1992) study on emotional expression employed 50 point lights on an actor's face, significantly more than in the current experiment. Point light density is an issue in that if the point lights are dense enough, such displays can provide an impression of surface, and possibly form information. Of course, if provided, such information actually obviates the general goal of these experiments. Fortunately, extensive concern over this issue is unwarranted. Given that the front and back of infants' legs cannot be seen simultaneously, there would typically be only about nine point lights available per leg at any one time; such information is very unlikely to provide reliable form information. Indeed, informal observations by experimenters over the course of conducting these studies (about 2½ years) suggests that although one can discern which point lights lie on the same leg, there is no strong perception of recognizable form.

Reliability assessments from the recorded visual fixations were performed for 45 of the 48 infants (twenty-three 5-month-olds and twenty-two 7-month-olds). Aggregating across left-right position and trial, the two sets of codings were strongly correlated with $r_s(178) = .99, .92$, and $.95$, and $ps < .001$, for total fixation, initial fixation, and number of fixations, respectively.

Results and Discussion

Data were subjected to the same analyses as in Experiment 1. Total fixation, initial fixation, and the number of fixations toward contingent and noncontingent displays were converted to proportions, and difference scores were created by subtracting contingent from noncontingent proportions. These difference scores were combined by factor analyzing the measures (separately for 5- and 7-month-olds) and using the component loadings as weights in creating a composite score; the weights for this study were comparable with those of Experiment 1. Analyses were then performed on the composite scores as well as the individual measures. Again, for both sets of measures, scores differing from zero reflected greater-than-chance preference, with positive scores reflecting preference for the noncontingent display.

As in Experiment 1, initial analyses examined the composite scores in a two-way ANOVA, using the between-subjects factors of age (5 versus 7 months) and order (contingent on the left in Trial 1 versus contingent on the right in Trial 1). This analysis revealed no main effects for age, $F(1, 44) = .04$, $MSE = .02$, *ns*, or order, $F(1, 44) = .89$, $MSE = .02$, *ns*, nor any interaction between the two, $F(1, 44) = .70$, $MSE = .02$, *ns*. As in the previous experiment, the critical test involved comparing the overall difference score, collapsed across age and order, to chance (zero difference). This test revealed significant preferential fixation of the noncontingent display, $t(47) = 2.84$, $p < .01$. Figure 2 displays the composite scores for the 5- and 7-month-olds and reveals that despite the lack of a main effect for age, 7-month-olds preferentially fixated the noncontingent display ($M = 55.8\%$, $SD = 9.2\%$), $t(23) = 3.10$, $p < .01$, whereas 5-month-olds did not ($M = 55.1\%$, $SD = 16.6\%$), $t(23) = 1.50$, *ns*.

Subsequent analyses examined preferential fixation for each of the dependent measures individually; these values, along with the raw scores for 5- and 7-month-olds, appear in Table 1. Each set of difference scores was analyzed in a two-way ANOVA using the same factors of age and order. The only noteworthy effect evidenced from these analyses was a marginally significant main effect for order for the number of looks, $F(1, 44) = 3.52$, $MSE = .01$, $p < .07$, with the infants who viewed the contingent display on the right on the first trial showing less preference overall for the noncontingent display than the infants who viewed the contingent display on the left initially. Table 1 also presents the results of follow-up *t* tests for each measure for the 5- and 7-month-olds individually. The 7-month-old infants demonstrated either significant or marginally significant preferential looking for all three measures. The pattern for the 5-month-olds was more ambiguous; their initial fixations demonstrated a significant preference, whereas the remaining measures did not, although both were in the correct direction. Although suggestive of an age effect, it should be remembered that there was no main effect for age (for either the composite scores or any of the individual measures), and the pattern of preferential looking was generally consistent across measures. Thus, any age effects, although intriguing, must be viewed speculatively.

If, in fact, the age difference in this study was real, what might underlie this variation? Unfortunately, it is unclear whether the difference was due to better recognition of the intermodal correspondences by 7-month-olds, brought about through the availability of more visual information, or weaker intermodal perception by 5-month-olds, produced in response to off-

joint point light information. Regardless of whether there was truly a developmental difference in this experiment, this latter possibility does raise the idea that intermodal perception might be constrained by information processing of the display. One way of testing this implication would be to present point light displays to young infants that are even more difficult to process than the off-joint displays; such displays should then lead to a failure of intermodal perception. This hypothesis was tested in the next experiment.

EXPERIMENT 3: INTERMODAL PERCEPTION OF INVERTED OFF-JOINT POINT LIGHT DISPLAYS

Experiment 3 examined intermodal perception using point light displays that remained spatially and temporally congruent with proprioceptive inputs, but were nevertheless difficult for infants to process visually. Such a situation was created by inverting the displays, a manipulation known to significantly limit recognition of point light information by affecting infants' information processing of such displays (Fox & McDaniels, 1982; Sumi, 1984). Thus, if infants intermodally matched such inverted displays, this would provide dramatic evidence that such matching was based on motion correspondences between visual and proprioceptive inputs devoid of any sense of object recognition. Failure to intermodally match, on the other hand, would imply that information processing in the form of object recognition constrained intermodal perception.

Method

Participants. This experiment employed 24 (14 male, 10 female) 5-month-old infants ($M = 21.5$ weeks, $SD = .67$) and 24 (14 male, 10 female) 7-month-old infants ($M = 30.1$ weeks, $SD = .79$), drawn from the Scarborough, Ontario, community. Five of the 7-month-olds (but none of the 5-month-olds) had participated in previous, unrelated studies in the laboratory. The data from an additional thirteen 5-month-olds and ten 7-month-olds were not used in this study due to (1) equipment failure or experimenter error ($n = 7$), (2) fussiness ($n = 6$), (3) the infant not looking toward one or both displays at all ($n = 5$), (4) the infant's pant legs showing on the contingent display ($n = 2$), (5) failure to achieve reliability in coding visual fixations ($n = 2$), and (6) prematurity ($n = 1$). Infants were recruited using the same methods described in Experiments 1 and 2, and received comparable remuneration for participation.

Stimuli, apparatus, procedure, and reliability. The most important deviation in this experiment was that rather than providing upright, ego-centered point light in-

formation for infants' legs and feet, this experiment presented inverted, observer-centered point light displays, produced by modifying the top-bottom raster of the video monitor. This inversion, however, retained the left-right spatial contiguity of the displays, which is critical for such intermodal perception (Rochat & Morgan, 1995; Schmuckler, 1996b). To maximize the motion information, infants wore the same socks as in Experiment 2, which provided the off-joint point light information. The rest of the apparatus, procedure, conditions, and counterbalancing were the same as in the previous two experiments. Reliability coding on 47 of the 48 infants (twenty-three 5-month-olds and twenty-four 7-month-olds) revealed high reliability, with $r_s(186) = .97, .77, \text{ and } .87, ps < .001$, for total fixations, initial fixations, and number of fixations, respectively.

Results and Discussion

Data were analyzed as in Experiments 1 and 2, with proportion difference scores calculated for the total fixation, initial fixation, and number of fixation variables; from these, composite difference scores were created. These composite scores were analyzed in a two-way ANOVA, using the same age and order factors as before. Once again there was no effect for age, $F(1, 44) = .0, MSE = .03, ns$, or order, $F(1, 44) = .03, MSE = .03, ns$, nor any interaction between the two, $F(1, 44) = .34, MSE = .03, ns$. Most important, the comparison of the overall difference score relative to chance revealed no preferential fixation of either display, $t(47) = 1.40, ns$. Figure 2 presents the mean composite scores and reveals a lack of preferential fixation for both 5- and 7-month-olds ($M_s = 53.3\% \text{ and } 53.0\%$, $SD_s = 17.2\% \text{ and } 14.3\%$), $t_s(23) = .94 \text{ and } 1.03, ns$, respectively.

Finally, a series of two-way ANOVAs employing age and order as factors examined preferential looking for each dependent measure individually. As with the previous studies, these analyses failed to reveal any main effects or any interactions for the three measures. Most important (see Table 1), infants did not exhibit preferential fixation for either total fixation or the number of fixations, although they did exhibit preferential looking for initial fixations. Table 1 also gives the results for the 5- and 7-month-olds individually. There was no evidence of preferential fixation for the 5-month-olds, and only one of the three measures (initial fixation) was significant for the 7-month-olds (see Table 1).

Given that the averaged and individual composite scores and virtually all of the individual measures failed to reveal significant preferential fixation, the

most conservative summary of these results is that neither age group recognized the intermodal relation between visual and proprioceptive information. Thus, this experiment suggests that intermodal recognition was constrained by familiar object perception.

GENERAL DISCUSSION

Overall, these three experiments demonstrated that infants can, in some situations, use the motion information produced by point light displays for recognizing their own movements. Both Experiments 1 and 2 found that infants preferentially watched a noncontingent display containing point light information of the moving legs of another infant, compared with a contingent display containing point light information of their own movement. Experiment 3 qualified this result, revealing that when these displays provided an observer-centered view, infants failed to intermodally perceive their own movement.

Before discussing the implications of these findings, one methodological issue that requires consideration is the rather pragmatic concern over the response magnitude in these studies. Preference for the noncontingent display in these studies was indicated by preferential fixation of 55% to 60% (see Table 1). Although statistically significant, such amounts are not overwhelming on an absolute or intuitive basis, and do raise concerns. It is important to realize, however, that similar preferential-looking levels have been found in previous research. For example, Schmuckler (1996b) observed significant preferential fixation (based on total fixation duration) of 55% to 60%. Similarly, Bahrick, and Watson (1985) and Rochat and Morgan (1995) observed comparable (albeit slightly higher) levels of preferential looking of 60 to 65%. Thus, although not large, 55 to 60% is not out of the norm.

There are two fundamentally intriguing results arising from these studies. First, and on a basic level, it was remarkable that infants showed evidence of intermodal recognition in these studies at all. Put simply, these experiments (or, at least Experiments 1 and 2) demonstrated that infants could match the temporal and spatial contingencies between visual and proprioceptive inputs when the visual source bore no familiar context information for infants. That is, infants did not need to see a pair of legs moving to recognize that the movement on the screen matched their proprioceptive movement. This finding once again highlights the central role of temporal and spatial contingencies in intermodal perception research (Rochat & Morgan, 1995; Schmuckler, 1996b), and also fits well with Morgan and Rochat's (1997) finding

that limb familiarity is not necessary for intermodal coordination.

The second interesting result was that intermodal recognition, despite not needing a familiar context, was nevertheless constrained by infants' information processing of these displays. One way of characterizing these experiments is that they represented increasing levels of difficulty in the processing of point light information. As previously discussed, Bertenthal, Proffitt, Kramer, and Spentner (1987) suggest that processing off-joint point light information is more difficult than processing on-joint information, although any difficulties posed by point light placement are clearly resolved with increasing processing capabilities. Adults, for example, are at worst only mildly influenced by this factor (Dittrich, 1993; but see Cutting, 1981), and some (Bertenthal & Davis, 1988; Bertenthal & Pinto, 1993) have suggested that strict on-joint point light information is not necessary for perceiving biological motion.

In contrast to the mild influence of location, orientation (canonical upright versus inverted) significantly affected intermodal perception. This result is in keeping with the general finding that inversion influences the perception of biological motion for both infants (Bertenthal et al., 1984, 1985; Bertenthal, Proffitt, & Kramer, 1987; Fox & McDaniels, 1982) and adults (Dittrich, 1993; Sumi, 1984). For example, adults more quickly and accurately recognize point light locomotor activities when they are presented in an upright, as opposed to inverted, orientation (Dittrich, 1993).

One explanation as to why orientation has such an impact on the processing of point light displays involves the importance of knowledge-based constraints in perceiving biological motion. Bertenthal and colleagues (Bertenthal, 1993; Bertenthal & Davis, 1988; Bertenthal & Pinto, 1993) have speculated that for older infants an important factor in perceiving point light displays is whether such displays can be understood with reference to a stored, conceptual category (e.g., animate object, human gait). Changes in the display that then violate this conceptual category (e.g., inappropriate occlusion information or inappropriate phase relations) lead to discrimination. When the display is inverted, however, older infants cannot use this stored knowledge, and as a result, the same display changes (occlusion, phase) do not violate a conceptual category; hence, such changes are not discriminated. In contrast, younger infants do not use such conceptual knowledge, but instead respond purely on the basis of the amount and salience of differences in motion. This distinction between perceptual and conceptual processing has been proposed by others (Mandler, 1988, 1990, 1992; Spelke 1988, 1994),

although the applications of this idea differ substantially across authors. Although this hypothesis cannot explain why older infants do not respond to changes in perceptual input when faced with nonconceptual processing (inverted displays), it is nevertheless an intriguing idea and may be part of the constraints on intermodal perception investigated in the current studies.

One aspect of the present research that has been implicit is that the upright orientation of the displays was, in fact, reversed relative to the orientation generally used in point light displays. Beginning with Johansson's (1973, 1977) research, the typical orientation of biological motion was an observer-based one, with the actor's head at the top of the display and the legs and feet at the bottom. As already described, however, the ego-centered orientation employed in Experiments 1 and 2 was one in which the limbs were seen as if looking down on one's own body. When presented on a vertical monitor, this placed the upper parts of the body (in this case, the thighs) at the bottom of the display, and the lower extremities (the feet and ankles) at the top. Thus, from the framework of biological motion research, infants recognized their own movements from inverted (ego-based) point light displays, and failed to recognize their own movements in upright (observer-based) point light displays.

One implication of this finding is that what constitutes the normal or "canonical" orientation for biological motion is experience based. In perceiving self-movement, one typically has an ego view, whereas in perceiving the movement of objects or others one generally has an observer view. This distinction is reminiscent of Bertenthal's (1993) idea of knowledge-based constraints in perceiving point light information, and also fits with the idea that there are two modes of perceiving the self: one for controlling actions and another for recognizing objects (Bertenthal, 1996; Bertenthal & Rose, 1995). Along these lines, perceiving-for-action might (at an early age) be essentially tied to ego-centered information, with recognition of self-movement—arguably a prerequisite for perceiving-for-action—also constrained by such information.

The first goal of the present experiments was to examine infants' use of motion information devoid of recognizable featural or form information for perceiving self-movement. The findings showed that such movement was sufficient for intermodal perception, provided that it occurred in terms of coherent object perception. As an aside, one might wonder whether failures to detect intermodal correspondences could be explained by limitations in proprioceptive processing, particularly given that the proprioceptive input was produced passively. Although a logical possibility, it should be remembered that infants' leg movements

were passively produced in all of these studies. Given the results of both Experiments 1 and 2, it seems unlikely that by itself, a limitation in proprioceptive processing caused by passive movement can fully account for failures in intermodal matching; at the least, this explanation requires an interaction between visual and proprioceptive processing. Nevertheless, this does raise the intriguing question of what might happen to intermodal matching in more difficult visual processing situations if infants received stronger proprioceptive inputs, produced through active leg movements. Such a question could be investigated in future research.

In sum, these experiments further explored infants' abilities to intermodally match a visual display of their own movement with the proprioceptive information produced by that movement. Within a larger context, these experiments speak to the general issue of infants' self-recognition, and potentially the precursors to infants' development of a self-concept (Bahrick, 1995; Butterworth, 1992; Schmuckler, 1995; for multiple discussions of this theme, see Rochat, 1995b). Accordingly, investigating the nature of the constraints on such intermodal perception and self-recognition has implications for understanding children's perceptual and cognitive development, as well as the growth of their social understanding.

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ADDRESSES AND AFFILIATIONS

Corresponding author: Mark A. Schmuckler, Division of Life Sciences, University of Toronto at Scarborough, 1265 Military Trail, Scarborough, ON M1C 1A4, Canada; e-mail: marksch@banks.scar.utoronto.ca. Jennifer L. Fairhall was also at the University of Toronto at the time of this study.

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