INFANCY, *11*(3), 305–320

The Effect of Simulated Self Versus Object Movement in a Nonsearch Task

Mark A. Schmuckler and Stephanie Jewell
Department of Psychology
University of Toronto

This study examined 6-month-old infants' abilities to use the visual information provided by simulated self-movement through the world, and movement of an object through the world, for spatial orientation. Infants were habituated to a visual display in which they saw a toy hidden, followed by either rotation of the point of observation through the world (simulated self-movement) or movement of the object itself through the world (object movement). Following habituation, infants saw test displays in which the hidden toy reappeared at the correct or incorrect location, relative to the earlier movements. Infants habituated to simulated self-movement looked longer at the recovery of the toy from an incorrect, relative to correct location. In contrast, infants habituated to object movement showed no differential looking to either correct or incorrect test displays. These findings are discussed within a theoretical framework of spatial orientation emphasizing the availability and use of spatial information.

One recurrent focus of developmental research investigates how children understand the spatial layout of their environment and their own location within that environment. Traditionally, the primary theoretical issue of such work has explored the child's spatial representation (e.g., Acredolo, 1978, 1979, 1990; Acredolo & Evans, 1980; Bremner, 1978a, 1978b; Bremner & Bryant, 1977; Campos et al., 2000; Clearfield, 2004; Crowther, Lew, & Whitaker, 2000; Hermer & Spelke, 1994, 1996; Lew, Bremner, & Lefkovitch, 2000; Lew, Foster, Crowther, & Green, 2004; Newcombe & Huttenlocher, 2000; Newcombe, Huttenlocher, Drummey, & Wiley, 1998; Spencer & Hund, 2003; Wang & Spelke, 2000). Along these lines,

---

Correspondence should be addressed to Mark A. Schmuckler, Department of Psychology, University of Toronto–Scarborough, 1265 Military Trail, Scarborough, ON M1C 1A4, Canada. E-mail: marksch@utsc.utoronto.ca

space could be coded relative to one's body position (egocentric coding), to its geometric structure (geocentric coding), or to the position of important landmarks (allocentric coding). Within this framework, questions have focused on what spatial system is used by children at a young age, how the choice of system might vary with differing situations, and so on. For instance, one suggestion has been that children undergo a developmental progression from using an egocentric spatial coding to allocentric coding with increasing age and experience (Acredolo, 1990; Campos et al., 2000; Newcombe et al., 1998).

The idea that children employ different coding schemes at varying developmental times does have some drawbacks, however. For instance, children's spatial abilities vary with particular environmental contexts or experimental tasks, as demonstrated by Bremner (1978a, 1978b; Bremner & Bryant, 1977), who observed that children were better at recovering a hidden toy following self -movement (180º rotation) around a hiding array relative to object movement. This result implies that children switch reference schemes depending on the experimental context, and thus shifts the focus to describing the contexts that induce one or the other form of spatial coding. Unfortunately, determining which spatial coding system is being used is often done after the fact, not on a priori predictions of factors that promote particular representational systems (but see Wang & Spelke, 2000, for a notable exception).

An alternative explanation focuses on explicating the available spatial information, how this information changes with varying environmental conditions, and children's abilities to use such information (Jewell, 1999; Jewell & Schmuckler, 2000; Presson & Somerville, 1985; Schmuckler & Tsang-Tong, 2000; Sophian & Wellman, 1983). For example, Bremner's results could be explained by noting that self-movement produces a wealth of perception (e.g., visual) and action (e.g., proprioceptive and vestibular) system information specifying how the world changes, whereas object movement produces only visual information for this change. Accordingly, the superior search performance following self-movement is simply a result of this differential information.

Based on this framework, Schmuckler and Tsang-Tong (2000) manipulated visual and action system information by presenting 9- to 18-month-old infants with self or object movements (varying action information) that could occur in the light or dark (varying visual information). In this situation, spatial orientation was again better when perceptual and action systems provided information for movement through the world, relative to all other combinations. Along with varying perception and action system information, these studies also examined the use of static cues (i.e., position or color) for object location, and found that a target-specific cue (color) led to better search than an indirect (left vs. right position) cue. This result is also consistent with the idea that the nature of the information available for spatial orientation can succinctly characterize infant spatial behavior. In explaining their results, Schmuckler and Tsang-Tong (2000) noted that not only does self-movement contain action information, it (in contrast to object movement) also produces global optical flow, a very compelling stimulus for movement. As such, even based solely on the visual information, self-movement more powerfully signals changing spatial relations.

Given Schmuckler and Tsang-Tong's (2000) theoretical view, one important implication is that better spatial orientation should occur in response to the visual information arising from self-movement, compared with object movement. Such visual input could be produced by creating a full-scale environment that literally moves around a stationary observer. Unfortunately, such a situation produces some obvious practical difficulties, and thus was not employed in this study.

As an alternative, it is possible to move a recording video camera through the world. This camera would then capture the visual changes associated with self-movement, thus producing a simulation of this optical information. For comparison with this simulated self-movement, a similar object movement sequence could be created, thereby enabling an assessment of spatial abilities based solely on the visual information for self versus object movements. Of course, it is questionable whether such visual displays would actually induce manual search. However, such displays could be used with a visual response measure to index infants' spatial abilities (e.g., Ahmed & Ruffman, 1998; Baillargeon & Graber, 1988; Kaufman & Needham, 1999).

Recently, Kaufman and Needham (1999) compared infant spatial orientation to self and object movements, testing 6.5-month-old infants in a habituation version of Bremner and Bryant (1977). In this work, infants were habituated to an object sitting on the corner of a table. Following habituation, half of the infants were moved to the opposite side of the table, and half stayed in their original position. Half of the infants in each condition were then shown a display in which the object moved to the opposite corner of the table, whereas the remaining infants saw a display in which the object moved to the opposite corner and then returned to its original position. Looking time analyses revealed that infants dishabituated to an actual change of location in the object (i.e., when the object moved to the opposite corner) regardless of whether they themselves moved. Simple changes in location relative to the infant, however, did not induce dishabituation. These results suggest that 6.5-month-olds code space allocentrically and can update this representation based on passive movement. Unfortunately, because Kaufman and Needham (1999) actually moved infants, this work cannot address the efficacy of the visual differences themselves in driving differential spatial orientation. Answering that question was the goal of this research.

METHOD

Participants

Forty 6-month-old infants (*M* age = 26.0 weeks, *SD* = 1.62 weeks) participated in this study. An additional 11 infants were tested but not included due to fussiness (*n* = 5), technical difficulties (*n* = 5), and experimenter error (*n* = 1). All infants were recruited from the ethnically diverse community in and around Scarborough, Ontario, Canada.

Experimental Apparatus

All stimuli were recorded using a Sony Video 8 Handycam camera mounted on a rolling tripod. Videotaped events were played to infants using a JVC BR8600U professional editing VCR, and appeared on a Sony 14-in. CVM-194 monitor, positioned approximately 2 ft from infants. Below this monitor was a JVC GF-700 video camera that provided an image of infants' faces. An experimenter in an adjacent control room noted fixations by toggling the spacebar of an IBM-compatible 286-MHz computer keyboard.

Stimulus Materials

Stimuli consisted of videotaped events. All videotaped segments were recorded in a roughly rectangular space, in which the four backgrounds of the space were visually distinct, with a row of lockers on one side, a wall with an elevator on the second side, a glass door and stairwell on the third side, and a long corridor on the fourth side. For habituation, four sequences, shown schematically in Figure 1, were created. The initial segments of all sequences showed a 51-cm diameter round table containing a blue cup on the left, a red cup on the right, and a colorful cylindrical rattle between the cups. Standing behind this table was an experimenter who lifted the rattle, shook it, and dropped it into one of the cups. The toy was hidden in the left cup or in the right cup in two of the four events, respectively.

Following hiding, one of two displacements occurred. In simulated self-movement the video camera filming the event was rolled 180° to the opposite side of the table; this movement took about 20 sec. Two self-movement events were created. When the toy was initially hidden in the left (blue) cup, the camera was rotated clockwise, and when the toy was initially hidden in the right (red) cup, the rotation was counterclockwise; both rotations kept the hidden toy in the foreground. Because of the visual distinctiveness of the four background spaces, simulated self-movement was clearly indicated by the global optic flow of one background texture into another, as well as the fact that the experimenter hiding the toy gradually disappeared from view as the camera rotated around the table.

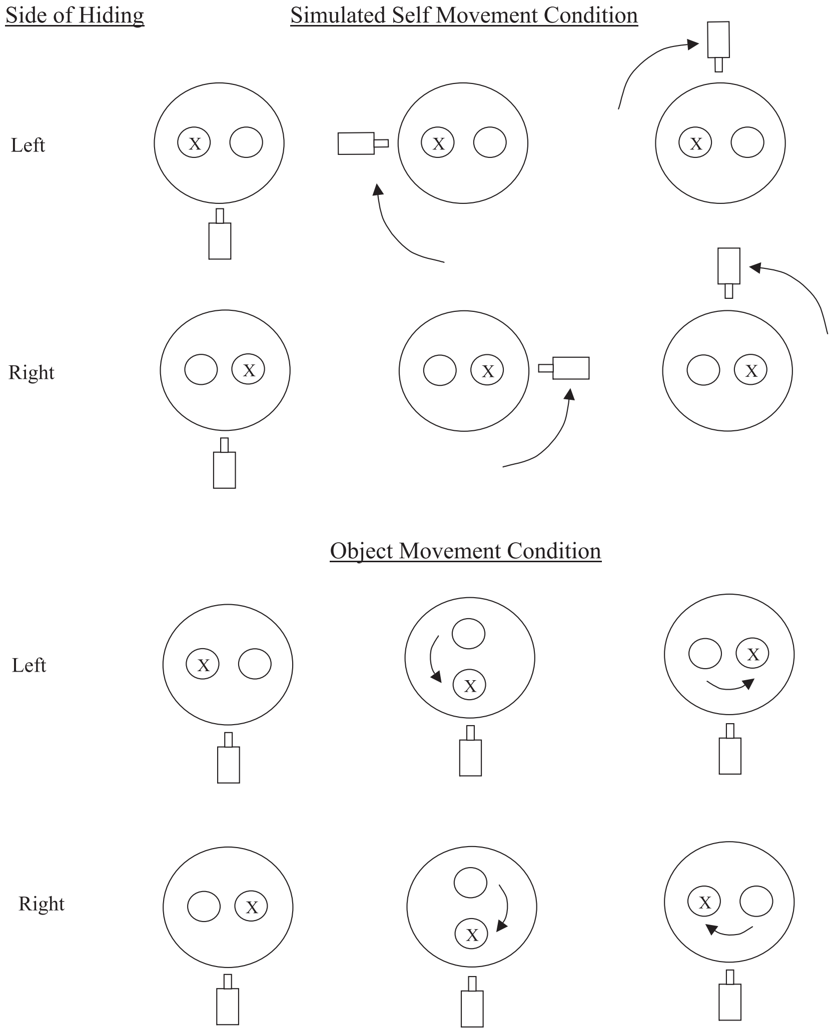

FIGURE 1 Schematic diagram of the movement conditions. X indicates the location of the hidden toy.

For object movement the camera remained stationary while the table was rotated 180°, with this movement lasting about 17 sec. Again, two object movements are possible. When the toy was initially hidden in the left cup, the table was rotated counterclockwise, and when the toy was hidden in the right cup, the table was rotated clockwise. Visually, this condition provided only localized optic flow of the focal objects (the table with the hiding array) relative to the stationary background, and was also indicated by the fact that the experimenter stayed in the camera's view during the entire motion.

Finally, two test events were created in which an experimenter lifted both cups off of the table and tilted them forward. In one of these events the toy emerged from the blue cup (now on the right side), and in the other the toy emerged from the red cup. Both events were short, lasting about 7 to 8 sec, with each event showing the reappearance of the toy in the correct or incorrect location, depending on the original side of hiding. For all habituation and test events, the viewing angle of the camera remained constant, with the camera position approximately 5 ft above the floor, looking down slightly onto the hiding array.

Experimental Design and Paradigm

Crossing movement type (simulated self-movement vs. object movement) and side of hiding (hidden to the left vs. hidden to the right) produced four conditions: simulated self-movement left, simulated self-movement right, object movement left, and object movement right. Ten infants were assigned to each condition.

All infants were tested using an infant control habituation procedure (Horowitz, Paden, Bhana, & Self, 1972; see Rosenblum, Schmuckler, & Johnson, 1997, for details of this procedure). Once begun, a habituation trial continued for as long as infants maintained fixation, up to a maximum of 120 sec. Trials ended when infants either looked away for 2 sec, or the maximum looking time had been reached. Infants were considered habituated once their fixation time on two consecutive trials dropped to 50% of their initial interest on the first two habituation trials totaling more than 12 sec. With this procedure, the minimum number of habituation trials is 4 and the maximum is 20. Following habituation, infants saw the two test events twice each, in alternating order (i.e., correct–incorrect–correct–incorrect or incorrect–correct–incorrect–correct). Test trials ended when infants looked away for 2 sec or fixated for 120 sec.

Procedure

Each parent sat on a chair positioned 90° (facing the side wall) relative to the stimulus monitor, with the infant seated on the parent's right leg facing the monitor. Each parent was asked to not look at the monitor during the study; by and large, parents cooperated with this request. Once the parent and infant were situated, the experiment was begun. If the infant failed to fixate the habituation stimulus, an experimenter attempted to attract the infant's attention. Overall, the procedure lasted about 10 min, with the entire visit to the laboratory lasting about 45 min.

Reliability

Reliability codings of visual fixations for a majority of infants ($n = 38$) were conducted by a second naive observer using the videotapes of infants' fixations. Reliability coding for the remaining 2 infants was not calculated due to a loss of the videotaped visual fixations. Amalgamating across infants, the average absolute difference between original and reliability for the habituation trials was 2.1 sec ($SD = 4.4$), and for test trials it was 1.4 sec ($SD = 2.4$). The original and reliability codings for the habituation sequences were strongly correlated, $r(288) = 0.98$, $p < .001$, as were test trials, $r(150) = .94$, $p < .001$.

RESULTS

Initial analyses focused on the habituation data, looking at the number of trials to habituate, the total habituation looking time, the average habituation looking time per trial, and the criterion looking time, using two-way analyses of variance (ANOVAs), with the between-subjects factors of movement condition (simulated self vs. object movement) and side of hiding (initially hidden to the left vs. to the right). The means and standard deviations for these measures and the results of these ANOVAs appear in Table 1, and reveal no differences as a function of either factor.

Having determined that habituation did not differ between the various conditions, subsequent analyses examined the test trial looking times, using a four-way ANOVA, with the within-subjects factors of test display (correct vs. incorrect) and trial (Trial 1 vs. Trial 2), and the between-subjects factors of movement condition and test trial order (correct–incorrect vs. incorrect–correct). Of

TABLE 1
Comparison of Parameters of the Habituation Phase, as a Function of Simulated Self Versus Object Movement and the Direction of Movement

Movement Condition	*Number of Habituation Trials*		*Criterion (sec)*		*Total Habituation Time (sec)*		*Average Habituation Time (sec)*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Simulated self	6.85	3.96	19.78	17.24	102.08	80.38	16.48	13.08
Object	6.90	4.21	26.99	29.40	126.00	101.31	20.34	15.78
Condition	$F(1, 36) = 0.002$, *ns*		$F(1, 36) = 0.85$, *ns*		$F(1, 36) = 0.69$, *ns*		$F(1, 36) = 0.68$, *ns*	
Direction	$F(1, 36) = 1.10$, *ns*		$F(1, 36) = 0.01$, *ns*		$F(1, 36) = 1.72$, *ns*		$F(1, 36) = 1.83$, *ns*	
Cond × Direction	$F(1, 36) = 0.80$, *ns*		$F(1, 36) = 0.001$, *ns*		$F(1, 36) = 0.16$, *ns*		$F(1, 36) = 0.02$, *ns*	

the four main effects, the only significant result was for trial, *F*(1, 36) = 13.18, *MSE* =86.88, $p < .005$, $\eta^2_p = .268$. This effect indicated more looking on the first pair of test trials (*M* = 16.74, *SD* = 18.44) than the second (*M* = 11.4, *SD* = 11.95). Of the six two-way effects, there was a significant Trial × Order interaction, *F*(1, 36) = 10.15, *MSE* = 86.88, $p < .005$, $\eta^2_p = .220$, and a significant Trial × Condition interaction, *F*(1, 36) = 4.76, *MSE* = 86.88, $p < .05$, $\eta^2_p = .117$. In both of these interactions, although infants generally showed more looking on the first trial than the second trial, the effect was more pronounced for infants seeing the test trials starting with the incorrect display relative to the correct display, or for infants habituated to object movement relative to simulated self-movement. Given that these results collapse across experimentally critical comparisons (habituation condition and test display type, respectively), however, their interpretative significance is questionable. Most important, and directly relevant to the primary experimental hypotheses, there was a significant Test Display × Movement Condition interaction, *F*(1, 36) = 4.19, *MSE* = 154.89, $p < .05$, $\eta^2_p = .104$. This interaction appears in Figure 2, and reveals greater looking at the incorrect display than the correct display following simulated self-movement, but no difference following object movement. Further exploration of this interaction using planned comparisons revealed a marginally significant difference between correct and incorrect displays following simulated self-movement, *t*(19) = –1.71, *p* = .052 (one-tailed), but no difference following object move-

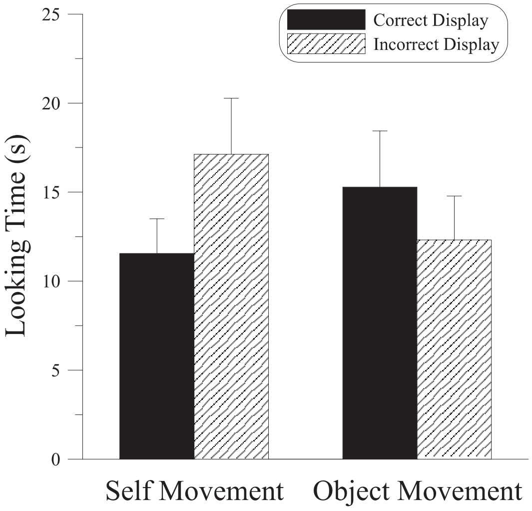

FIGURE 2 Looking time (and SEs) as a function of the display type (correct vs. incorrect) and movement conditions (simulated self vs. object).

ment, *t*(19) = 1.25, *ns*. There were no significant effects for the remaining three- or four-way interactions.[1]

Following this analysis, test trials were also examined to look for evidence of dishabituation relative to the habituation sequence. Although frequently ignored in recent work using habituation, demonstrating dishabituation is essential in establishing that infants were actually familiarized with the habituation information. Failure to examine for dishabituation is frequently justified on the grounds that because the test displays are markedly different than the habituation sequence, infants will likely dishabituate to all of the displays, thus rendering such effects ambiguous as to their implications. This argument, however, is specious for two reasons. First, evidence of dishabituation to multiple test events does not preclude comparisons of the test events themselves, thereby providing a more exact determination of relative degrees of discrimination. Second, this argument ignores the fact that habituation is fundamentally a discrimination procedure (Bogartz & Shinskey, 1998; Bogartz, Shinskey, & Schilling, 2000; Bogartz, Shinskey, & Speaker, 1997; Cashon & Cohen, 2000; Haith, 1998; Haith & Benson, 1998). Without evidence of dishabituation, it is unclear whether or not infants even abstracted any information from the habituation displays, thus undermining all claims as to the purported roles of this prior exposure.

To test for dishabituation, looking times to correct and incorrect events (averaged across trial) were compared to the final two habituation trials. For simulated self-movement, both correct (*M* = 11.56, *SE* = 1.94) and incorrect events (*M* = 17.13, *SE* = 3.15) exceeded the last two habituation trials (*M* = 6.08, *SE* = 1.38),

---

[1] One worrisome issue involving the looking times toward the test events is that because the minimum look criterion built into the habituation procedure was shorter than the length of the event sequence itself, infants might have look durations shorter than it would take for a complete repetition of the test event. In response to this concern, the data for the test trials were examined for all fixations less than 4.0 sec, which was roughly the amount of time required to see the object reappear out of the cup in the two dishabituation events. For the object movement condition, 25% and 30% of the trials fell below this critical time for the correct and incorrect trials, respectively; for the simulated self-movement condition, 32.5% and 10% of trials fell below this critical time. Although there do appear to be a substantial proportion of trials falling below this critical value, there are reasons not to be overly concerned by this fact. First, despite there being some trials in which looking times were indeed short, infants' mean looking on the test trials was long enough to have seen the entire test sequence at least twice (between 12 sec and 16 sec); hence, they clearly did generally see the critical reappearance information on average. Second, a comparable analysis to that reported in the text of looking times to the test events, removing data falling below this critical time, produced similar results, with the Test Display × Movement condition almost reaching significance, *F*(1, 15) = 4.05, *MSE* = 180.77, *p* = .06. The fact that this interaction is now only marginally significant is to be expected, given that removal of looking times less than 4.0 sec trims the data of those trials showing the strongest generalization between habituation and test, and thus more selectively affects the data for the correct trials of the simulated self-movement condition than any other condition (a fact borne out by the percentage of trials falling below this critical value, as described earlier).

*t*s(19) = 2.51 and 3.77, *p*s < .05 and .01, respectively. For object movement, neither the correct (*M* = 15.28, *SE* = 3.16) nor incorrect events (*M* = 12.32, *SE* = 2.47) differed from the last two habituation trials (*M* = 8.52, *SE* = 2.50), *t*s(19) = 1.59 and 1.36, *ns*.

DISCUSSION

This study demonstrated that after viewing an object being hidden infants had stronger expectations for where that object should reappear after seeing simulated self, as opposed to object movement, through the world. This finding was indicated by differential responses to the test trials between the conditions, and by differences in dishabituation between the conditions.

Before discussing the theoretical implications of this finding, it should be recognized that these results diverge from other findings suggesting that young infants will show evidence of spatial understanding for object movements when tested using visual measures, as opposed to manual reaching measures (e.g., Baillargeon, DeVos, & Graber, 1989; Baillargeon & Graber, 1988; Newcombe, Huttenlocher, & Learmonth, 1999; Wilcox, Nadel, & Rosser, 1996; Wilcox, Rosser, & Nadel, 1994). Although it is difficult to definitively account for this divergence, there are a number of factors that might underlie this difference. Most obviously, there are the myriad methodological differences between this study and the previous work. For instance, there is the fact that previous work has tended to use live action displays, which are potentially extremely attention holding, whereas this study relied on videotaped presentation. Additionally, previous work in this area has typically shown infants invisible object displacements in which an object is hidden at one location and then magically (with no relevant intervening information) reappears at a different location as the impossible (spatially violating) display. Such displays might drive infants' interest for any number of reasons, some having nothing to do with spatial violations. For example, it might be that infants' interest in the impossible event is due to the object having moved without their having seen it move; in this case, the focus is on the invisible displacement and not on the violation of spatial relations. Or it might be that the impossible display is interesting from a numerical point of view, in that it implies two hidden objects, as opposed to the one object with which infants were familiarized, and that reappeared in the possible display. Current research on infants' perception of number does suggest sensitivity to increases in quantity, particularly with small sets of one to three items (e.g., Carey & Xu, 2001; Feigenson, 2005; Feigenson, Dehaene, & Spelke, 2004; Xu, 2003).

Along with methodological differences, it should be recognized that the evidence for 5- to 7-month-olds' abilities to correctly spatially orient to changing object locations using visual measures is not as consistent as is often assumed. Although a thorough review of the literature is beyond the scope of this article, it is instructive to look closely at some well-known studies of the spatial abilities of infants in looking studies. For instance, classic work by Baillargeon and Graber (1988) and Baillargeon et al. (1989) is often cited as evidence for the spatial abilities of young infants using looking time measures. One frequently overlooked aspect of this work, however, is that the evidence for spatial understanding in this work was only observed for relatively older infants, between 7.5 and 8 months old. In contrast, younger infants failed to demonstrate any spatial knowledge (Baillargeon & Graber, 1988). As another example, Newcombe et al. (1999) is often cited as providing evidence that 5-month-old infants look more toward the reappearance of a previously hidden object at a different location from where it was originally hidden, relative to recovery at the same location. What is not emphasized, though, is that in virtually every one of Newcombe et al.'s five studies, some aspect of the reported data and analyses (e.g., first look durations, total looking times) did not support this pattern, with the relevant measure often changing from study to study. Thus, although the general interpretation of infant behavior in this project may support spatial understanding in 5-month-old infants, the specifics of the findings were less consistent. Similarly, the well-known studies by Wilcox and colleagues (Wilcox et al., 1996; Wilcox et al., 1994) provide yet another example of the idea that young infants do not always display sophisticated spatial abilities when tested using looking time. Testing 6.5-month-old infants with a four-location hiding array, Wilcox et al. (1994) did not observe uniformly greater looking to incorrect object recoveries relative to correct object recoveries. Instead, such evidence was only found when objects were hidden and reappeared at particular locations in the hiding array, and not at others. In contrast, using a two-location hiding array, Wilcox et al. (1996) did find consistent evidence of spatial orientation in 6.5-month-olds regardless of the specific position of hiding. Finally, other studies employing visual measures have clearly indicated a failure of spatial awareness in young infants. Hofstadter and Reznick (1996), for instance, found that both 5- and 7-month-old infants (but not older infants) made a significant number of A-not-B errors (suggesting a failure of spatial updating) even when measured using a gaze direction response. As such, there do appear to be many situations in which 5- to 7-month-old infants' spatial abilities (as frequently indicated by more visual attention to incorrect relative to correct hidden object reappearances) are, at best, subpar. Thus, the findings here in the object movement condition are by no means unique.

Moving beyond this empirical issue, what theoretical frameworks are useful in understanding the observed differences in spatial abilities between simulated self and object movement conditions? Theoretically, these findings fit most comfortably with the idea that search behavior can be understood relative to the available information promoting more or less effective spatial orientation (Jewell, 1999; Jewell & Schmuckler, 2000; Presson & Somerville, 1985; Schmuckler & Tsang-

Tong, 2000). One such information source involves the availability of global optic flow in the simulated self-movement condition, as opposed to the more localized optic flow of the object movement condition. A second information source has to do with the fact that in the simulated self-movement condition the object never actually changed its objective location, with infants seeing this location from varying viewpoints in the world. In contrast, in the object movement condition the object actually did change objective location. This distinction is potentially powerful information for understanding the differences in the spatial position of the hidden object vis-à-vis infants' positions across the two conditions, and could easily have played a role in these results. Third, and along with information provided by movement through the world, the background information of the test events relative to the habituation sequence provides an additional cue to infants. In the simulated self-movement condition, because the camera observer rotated 180°, the actual background behind the hiding array during the habituation sequence differed from the background of the test events. In contrast, in object movement the background remained constant between habituation and test. This change in background after simulated self-movement might thus have provided infants with another reminder (in addition to the actual cup positions themselves) that they were viewing an array that differed spatially from what they had seen during habituation, information that was simply not available with object movement.

What is a theoretical alternative to this account? The primary alternative theoretical option involves the use of different frames of spatial reference. This approach focuses on what environmental contexts or observer states promote the use of one frame versus another, and as such emphasizes the structure of the mental representation of space in the observer. Unfortunately, one nagging problem for this approach in explaining the current data is that these accounts assume that significant environmental changes, often coupled with movement of the observer, are the impetus for using different spatial reference frames. This assumption has been most clearly articulated by Campos et al. (2000), for instance, who posited that varying locomotor experience or types of movements through the world differentially promote varying spatial strategies.

In this regard, Campos et al.'s (2000) ideas are interesting given that the infants in this study were prelocomotor 6-month-olds. Thus, evidence that whole-field optical movement is still more compelling than local movement information, even in observers devoid of the relevant locomotor experience (independent locomotion), presents a challenge for this approach. It might be argued that 6-month-olds have considerable experience with whole-field movements through being carried around, and that it is this experience that enables them to perform well in the simulated self-movement condition. For this argument to hold, though, it is critical that such experience exceed 6-month-olds' exposure to object movement in the world (or, possibly, rotational object movement). Although the relative frequencies of 6-month-old infants' experiences of being carried versus seeing object movement are unknown, intuitively they do not seem to support this line of argumentation.

Accepting, then, that these results are explainable via the information available for spatial orientation, it becomes important to more exactly specify what information is being used in such situations, with an eye toward developing a quantitative model of spatial orientation. In fact, there are many possible sources of such information. First, for instance, is the evidence of the importance of environmental structure, either in the form of familiar versus unfamiliar environments (e.g., Acredolo, 1978, 1979), salient individuals or objects (Acredolo & Evans, 1980; Cornell, 1981; Presson & Ihrig, 1982), direct (e.g., beacon) versus indirect landmarks (e.g., Bushnell, McKenzie, Lawrence, & Connell, 1995; Lew et al., 2000; Lew et al., 2004; Lucas & Uzgiris, 1977; Sutton, 2006), the geometric structure of the world (Hermer & Spelke, 1994), and so on. A second source of information is how the world has changed relative to the infant (e.g., Campos et al., 2000; Landau & Spelke, 1988), how such changes are specified to infants (e.g., global vs. local flow), and the infants' role in this transformation (Acredolo, Adams, & Goodwyn, 1984; Benson & Uzgiris, 1985; Bertenthal, Campos, & Barrett, 1984; Jewell, 1999; Jewell & Schmuckler, 2000). A third source is the characteristics of the infant observer, including attentional allocation and visual tracking (Acredolo et al., 1984; Horobin & Acredolo, 1986; Jewell & Schmuckler, 2000) and perceptual-motor capabilities (e.g., being prelocomotor, crawling, or walking; Bai & Bertenthal, 1992; Bertenthal et al., 1984; Campos et al., 2000; Clearfield, 2004). Although attempting to formalize such a diverse array of information into a coherent model is a daunting task, such an approach can provide quantifiable predictions of spatial abilities, and could easily incorporate developmental changes in spatial abilities through, for instance, weighting parameters, factor codings, and so on.

In sum, this study demonstrates that, based on visual information only, prelocomotor infants show better spatial orientation when presented with visual information specifying self-movement, as opposed to object movement. Such findings fit a theoretical approach emphasizing the availability and subsequent nature of spatial information. More generally, these findings provide a first step toward a more formal analysis of spatial orienting.

ACKNOWLEDGMENTS

This research was supported by a grant from the Natural Sciences and Engineering Council of Canada to Mark A. Schmuckler. Portions of this work were presented at the biennial meetings of the Society for Research in Child Development, Minneapolis, MN, April 2001. We wish to thank Dina Lew and two anonymous reviewers for their helpful comments on this article.

REFERENCES

Acredolo, L. P. (1978). Development of spatial orientation in infancy. *Developmental Psychology, 14,* 224–234.

Acredolo, L. P. (1979). Laboratory versus home: The effect of environment on the 9-month-old infant's choice of spatial reference system. *Developmental Psychology, 15,* 666–667.

Acredolo, L. P. (1990). Behavioral approaches to spatial orientation in infancy. In A. Diamond (Ed.), *The development and neural bases of higher cognitive functions* (pp. 596–607). New York: New York Academy of Sciences.

Acredolo, L. P., Adams, A., & Goodwyn, S. W. (1984). The role of self-produced movement and visual tracking in infant spatial orientation. *Journal of Experimental Child Psychology, 38,* 312–327.

Acredolo, L. P., & Evans, D. (1980). Developmental changes in the effects of landmarks on infant spatial behavior. *Developmental Psychology, 16,* 312–318.

Ahmed, A., & Ruffman, T. (1998). Why do infants make A not B errors in a search task, yet show memory for location of hidden objects in a nonsearch task? *Developmental Psychology, 34,* 441–453.

Bai, D. L., & Bertenthal, B. I. (1992). Locomotor status and the development of spatial search skills. *Child Development, 63,* 215–226.

Baillargeon, R., DeVos, J., & Graber, M. (1989). Location memory in 8-month-old infants in a non-search A not B task: Further evidence. *Cognitive Development, 4,* 345–367.

Baillargeon, R., & Graber, M. (1988). Evidence of location memory in 8-month-old infants in a non-search AB task. *Developmental Psychology, 24,* 502–511.

Benson, J. B., & Uzgiris, I. C. (1985). Effect of self-initiated locomotion on infant search activity. *Developmental Psychology, 21,* 923–931.

Bertenthal, B. I., Campos, J. J., & Barrett, K. C. (1984). Self-produced locomotion: An organizer of emotional, cognitive, and social development in infancy. In R. N. Emde & R. J. Harmon (Eds.), *Continuities and discontinuities in development* (pp. 175–210). New York: Plenum.

Bogartz, R. S., & Shinskey, J. L. (1998). On perception of a partially-occluded object in 6-month-olds. *Cognitive Development, 13,* 141–163.

Bogartz, R. S., Shinskey, J. L., & Schilling, T. H. (2000). Object permanence in five-and-a-half-month-old infants? *Infancy, 1,* 403–428.

Bogartz, R. S., Shinskey, J. L., & Speaker, C. J. (1997). Interpreting infant looking: The event set × event set design. *Developmental Psychology, 33,* 408–422.

Bremner, J. G. (1978a). Egocentric versus allocentric spatial coding in 9-month-old infants: Factors influencing the choice of code. *Developmental Psychology, 14,* 346–355.

Bremner, J. G. (1978b). Spatial errors made by infants: Inadequate spatial cues or evidence of egocentrism? *British Journal of Developmental Psychology, 69,* 77–84.

Bremner, J. G., & Bryant, P. E. (1977). Place versus response as the basis of spatial errors made by young infants. *Journal of Experimental Child Psychology, 23,* 162–171.

Bushnell, E. W., McKenzie, B. E., Lawrence, D. A., & Connell, S. (1995). The spatial coding strategies of one-year-old infants in a locomotor search task. *Child Development, 66,* 937–958.

Campos, J. J., Anderson, D. I., Barbu-Roth, M. A., Hubbard, E. M., Hertenstein, M. J., & Witherington, D. (2000). Travel broadens the mind. *Infancy, 1,* 149–219.

Carey, S., & Xu, F. (2001). Infants' knowledge of objects: Beyond object files and object tracking. *Cognition, 80,* 179–213.

Cashon, C. H., & Cohen, L. B. (2000). Eight-month-old infants' perception of possible and impossible events. *Infancy, 1,* 429–446.

Clearfield, M. W. (2004). The role of crawling and walking experience in infant spatial memory. *Journal of Experimental Child Psychology, 89,* 214–241.

Cornell, E. H. (1981). The effects of cue distinctiveness on infants' manual search. *Journal of Experimental Child Psychology, 32,* 330–342.

Crowther, H. L., Lew, A. R., & Whitaker, C. J. (2000). The development of beacon use for spatial orientation in 6–8.5-month-old infants. *Infant Behavior and Development, 23,* 41–59.

Feigenson, L. (2005). A double dissociation in infants' representations of object arrays. *Cognition, 95,* B37–B48.

Feigenson, L., Dehaene, S., & Spelke, E. S. (2004). Core systems of number. *Trends in Cognitive Sciences, 8,* 307–314.

Haith, M. M. (1998). Who put the cog in infant cognition? Is rich interpretation too costly? *Infant Behavior and Development, 21,* 168–179.

Haith, M. M., & Benson, J. B. (1998). Infant cognition. In D. Kuhn & R. Siegler (Eds.), *Handbook of child psychology: Vol. 2. Cognition, perception, and language development* (pp. 199–254). New York: Wiley.

Hermer, L., & Spelke, E. S. (1994). A geometric process for spatial reorientation in young children. *Nature, 370,* 57–59.

Hermer, L., & Spelke, E. S. (1996). Modularity and development: The case of spatial reorganization. *Cognition, 61,* 195–232.

Hofstadter, M., & Reznick, J. S. (1996). Response modality affects human infant delayed-response performance. *Child Development, 67,* 646–658.

Horobin, K., & Acredolo, L. P. (1986). The role of attentiveness, mobility history, and separation of hiding sites on Stage IV search behavior. *Journal of Experimental Child Psychology, 41,* 114–127.

Horowitz, F. D., Paden, L., Bhana, K., & Self, P. (1972). An infant-control procedure for studying infant visual fixations. *Developmental Psychology, 7,* 90.

Jewell, D. T. (1999). *The importance of active versus passive body movement cues in infant search.* Unpublished masters thesis, University of Toronto, Toronto, Canada.

Jewell, D. T., & Schmuckler, M. A. (2000, July). *Active versus passive movement in infant search.* Paper presented at the 12th International Conference on Infant Studies, Brighton, England.

Kaufman, J., & Needham, A. (1999). Objective spatial coding by 6.5-month-old infants in a visual dishabituation task. *Developmental Science, 2,* 432–441.

Landau, B., & Spelke, E. (1988). Geometric complexity and object search in infancy. *Developmental Psychology, 4,* 512–521.

Lew, A. R., Bremner, J. G., & Lefkovitch, L. P. (2000). The development of relational landmark use in six- to twelve-month-old infants in a spatial orientation task. *Child Development, 71,* 1179–1190.

Lew, A. R., Foster, K. A., Crowther, H. L., & Green, M. (2004). Indirect landmark use at 6 months of age in a spatial orientation task. *Infant Behavior and Development, 27,* 81–90.

Lucas, T. C., & Uzgiris, I. C. (1977). Spatial factors in the development of the object concept. *Developmental Psychology, 13,* 492–500.

Newcombe, N. S., & Huttenlocher, J. (2000). *Making space: The development of spatial representation and reasoning.* Cambridge, MA: MIT Press.

Newcombe, N. S., Huttenlocher, J., Drummey, A. B., & Wiley, J. G. (1998). The development of spatial location coding: Place learning and dead reckoning in the second and third years. *Cognitive Development, 13,* 185–200.

Newcombe, N. S., Huttenlocher, J., & Learmonth, A. (1999). Infants' coding of location in continuous space. *Infant Behavior and Development, 22,* 483–510.

Presson, C. C., & Ihrig, L. M. (1982). Using mother as a spatial landmark: Evidence against egocentric coding in infancy. *Developmental Psychology, 18,* 699–703.

Presson, C. C., & Somerville, S. C. (1985). Beyond egocentrism: A new look at the beginnings of spatial representation. In H. M. Wellman (Ed.), *Children's searching: The development of spatial skill and spatial representation* (pp. 1–26). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Rosenblum, L. D., Schmuckler, M. A., & Johnson, J. A. (1997). The McGurk effect in infants. *Perception & Psychophysics, 59,* 347–357.

Schmuckler, M. A., & Tsang-Tong, H. Y. (2000). The role of visual and body movement information in infant search. *Developmental Psychology, 36,* 499–510.

Sophian, C., & Wellman, H. M. (1983). Selective information use and perseveration in the search behavior of infants and young children. *Journal of Experimental Child Psychology, 35,* 369–390.

Spencer, J. P., & Hund, A. M. (2003). Developmental continuity in the processes that underlie spatial recall. *Cognitive Psychology, 47,* 432–480.

Sutton, J. E. (2006). The development of landmark and beacon use in young children: Evidence from a touchscreen search task. *Developmental Science, 9,* 108–123.

Wang, R. F., & Spelke, E. S. (2000). Updating egocentric representations in human navigation. *Cognition, 77,* 215–250.

Wilcox, T., Nadel, L., & Rosser, R. (1996). Location memory in health preterm and full-term infants. *Infant Behavior and Development, 19,* 309–323.

Wilcox, T., Rosser, R., & Nadel, L. (1994). Representation of object location in 6.5-month-old infants. *Cognitive Development, 9,* 193–209.

Xu, F. (2003). Numerosity discrimination in infants: Evidence for two systems of representations. *Cognition, 89,* B15–B29.