Spatial Expectations of Young Human Infants, Following Passive Movement

ABSTRACT: Three experiments are described that investigate 4.5-month-old infants’ spatial thinking during passive movement using a task that required no manual or visual search. In these experiments, infants habituated to a display located near one corner of a table. Before the test trial the infants were either moved to the opposite side of the table or they remained in the same position that they held during the habituation trials. Also, between the habituation trials and the test trial, the display was either surreptitiously moved to the diagonally opposite position on the table, or the display remained stationary. The results showed that infants generally dishabituated when the actual (allocentric/objective) location of the display was changed between habituation and test. However, in Experiment 3, in which infants had reduced experience moving around the testing chamber, infants dishabituated to a change in their egocentric spatial relationship to the display. The results of this experiment suggest that experience moving around the testing chamber was a prerequisite for such location constancy. Taken together, the findings presented here indicate that with enough experience, young infants become aware of key spatial relationships in their environment during passive movement.

INTRODUCTION

Most of the earliest studies of infant spatial cognition purported that infants younger than 11 months of age were limited to forming egocentric representations of space. This meant that infants encoded the locations of objects with respect to their own bodies and not an external coordinate system nor some kind of landmark. For example, Bremner and Bryant (1977) and Bremner (1978a,b) found that 9-month-old infants who witnessed a toy being hidden in a well on the right side of a table, continued to reach to their right even after they had been moved around to the opposite side of a table (so that the toy was now in the hiding well to the infant’s left). Acredolo (1979) and Acredolo and Evans (1980) reported similar findings using a head turning task where infants learned to expect a face to appear in a window to either their right or left before they were moved around to the opposite side of the apparatus. Infants then generally looked in the same body-centric direction as they did before passive movement (as expected if they had an egocentric representation).

Arguably, an infant limited to egocentric representations is in an entirely separate representational universe from the rest of us. Such an infant, once moved to a new location, has no effective means of representing the location of a previously represented object. It implies a solipsistic view where the world is built up and torn down each time the infant is moved or even attends to events in a new egocentric direction. At the time that spatial egocentrism was first suggested, such claims of representational limitations were relatively unremarkable in the field of child psychology. Empiricist and Piagetian Constructivist views of infant developmental psychology, by definition, attribute the newborn infant with very little inborn representational ability (Piaget, 1954).
Interestingly, studies of non-human animals have always been in some conflict with the notion that human infants suffer from such limited representational abilities. Although studies with developing rats show initial reliance on local cues before going on to use distal cues (e.g., Akers & Hamilton, 2007; Rudy, Stadler-Morris, & Albert, 1987), there is little evidence that mammals of any developmental stage are limited to forming purely egocentric representations of space. Because the cognitive and neurological processes underlying spatial memory and navigation of adult human and non-human animals show remarkable similarities (Landau & Lakusta, 2009; Sandstrom, Kaufman, & Huettel, 1998; Wang, Hermer, & Spelke, 1999), there is reason to question dramatic differences between developing human and non-human animal spatial cognition.

Indeed, later work with human infants established that infants were less likely to engage in egocentric search under a number of varied experimental conditions. For example, infants searched at about chance levels or in a manner consistent with landmark-based coding when very salient or direct landmarks existed (Acredolo & Evans, 1980; Bremner, 1978a; Lockman & Dai, 1996; McKenzie 1987; Rieser, 1979), when the experiment took place in the infant's home (Acredolo, 1979, 1982) and when infants had experience with self-produced locomotion (Acredolo, Adams, & Goodwyn, 1984; Bai & Bertenthal, 1992). Plainly, the notion of the spatially egocentric infant underestimates their representational abilities.

Moreover, despite early indications to the contrary (e.g., Bremner & Bryant, 1977), recent studies have shown that infants as young as 6 months demonstrate an ability to use indirect landmarks in spatial orientation tasks. For example, Lew, Foster, Crowther, and Green (2004) have shown that in a peek-a-boo task, 6-month-old infants, following a passive displacement, looked towards the correct goal location with significantly more success when indirect landmarks could be used than when they were unavailable. Additionally, evidence from studies varying passive movement trajectories (e.g., Kellman, Gleitman, & Spelke, 1987; Newcombe, Huttenlocher, & Learmonth, 2000) make a convincing case that dead reckoning is an ability available to young infants—provided that the passive movements involved are ones that the child has accumulated a certain amount of experience with.

A significant difficulty in studying infant spatial representations is the inherent confounding of representation and motor ability needed to act upon these representations. Many infant experiments that suggest egocentrism can also be explained by poor reaching proficiency. Diamond (1988) for example, has shown that infants have difficulty inhibiting a previously learned reaching behavior. Such difficulties can explain why infants continue to reach in a particular direction even once they are moved to the other side of the apparatus. This complicates any animal and human comparisons as rat pups are more capable at swimming than a 6-month-old infant is at reaching. For rats, a spatial study that requires motor action is more likely to reflect true representational capacity than a reaching study is for human infants, because thinking while acting requires divided attention until the action is well-practiced and automatic (Boudreau & Bushnell, 2000).

In order to overcome this difficulty we used a task that did not involve motor actions that are known to be problematic for young infants. Instead a visual habituation procedure was used similar to one initially employed by Kaufman and Needham (1999) with older infants. In Kaufman and Needham (1999), 6-month-old infants experienced habituation trials watching a puppet at one corner of a table. Following these trials, the infant was either moved to the opposite side of the table or remained in the same position. The puppet was also either moved (surreptitiously) to the other diagonal corner of the table or remained in the same position. The results were that infants dishabituated whenever there was a real change in the puppet’s position and continued to show low levels of looking when the puppet remained stationary—regardless of the infant’s egocentric relationship to the puppet. That infants did not regain interest at an egocentric change when not accompanied by an actual change was surprising—as we expected infants to be interested in a display that looked different regardless of the spatial elements. We concluded that at this age, infants were able to maintain an objective spatial representation of the puppet’s location through their passive movement to the opposite side of the table. To be clear, by objective we mean a representation that is not purely based on the person’s spatial relationship with the outside world. An objective spatial representation would allow the encoding of the relationship between elements in the environment without respect to one’s own current position in that environment. Objective representations can be landmark based, based on geometric cues in the environment, or based on an external coordinate system.

To better understand what aspects of infant spatial cognition develop and what types of spatial representations are available to infants in at younger ages, this basic procedure was adapted in three different experiments with 4.5-month-old infants. One important reason to examine infants at this age is the difference in reaching ability between 4.5- and 6-month-old infants. In this period there is considerable development in both the prevalence and effectiveness of visually guided reaching (Clifton, Muir, Ashmead, & Clarkson, 1993; von Hofsten & Fazel-Zandy, 1984). The ability to reach for and interact with visually presented objects could be an important driver of early
Spatial representational abilities (Bremner, Holmes, & Spence, 2008), and so work that elucidates spatial skills in 4.5-month-olds could help us better evaluate this possibility. As such, the series of experiments described here have three main objectives. The first is to determine if young infants (aged 4.5 months) are capable of forming and using non-egocentric spatial representations. The second aim is to determine if infants at this age are capable of maintaining this representation through passive movement. The third is to further probe the development of the infants’ spatial representations. Specifically, we aim to learn if, like the 6-month-olds tested in Kaufman and Needham (1999), younger infants would also disregard egocentric changes and only dishabituate to actual changes in the puppet’s spatial location. In order to meet these aims, we propose four hypotheses relating to 4.5-month-old infants’ spatial representations and specify how infants should respond in a Kaufman and Needham (1999)-style task according to each of the hypothesized levels of spatial ability. These are described in the Introduction Section to Experiment 1 below.

EXPERIMENT 1

All infants in this experiment were habituated to the same scene: A pig puppet rotating in a small wooden cage at one corner of the table. Only the test trial differed according to the infant’s condition (outlined in Tab. 1).

Half of the infants were assigned to a condition in which they were moved to the opposite side of the table instead of being moved back to their habituation position. The other half were moved back to their prior position. While the infants’ view of the table was occluded, an experimenter quietly approached the testing table and moved the pig-cage display. For half the infants, the cage was moved to the diagonally opposite table corner, and for the other half of the infants it was simply picked up and returned to its previous position.

We determined that there were three likely patterns of results, each indicative of a particular view of infant spatial ability. Specifically, we were interested in which testing conditions would lead to significant dishabituation in the test trial. Our hypothesis/predictions are delineated in Table 1.

Our main three hypotheses (Hypothesis 4, we deemed very unlikely) all predicted dishabituation in the infant-unchanged/puppet changed condition. This is because, regardless of their spatial abilities, infants should be expected to dishabituate to a scene that is visually different from the one they habituated to (especially, in the absence of an expectation that it should appear different). Similarly, each of these hypotheses predicted continued habituation in the infant-unchanged/puppet-unchanged condition, as here the display looked exactly the same (and there was no reason for their to form an expectation that it should appear different). The predictions differed when the infant was moved to the opposite side of the table in test.

Hypothesis 1 is that infants are effectively limited to an egocentric frame of reference. In this case, they should dishabituate only when the egocentric relationship changes. That is, if the display looks different from the habituation display, they will recover interest. A related possibility (denoted Hypothesis 1b) is that even if infants are not limited to egocentric representations, this pattern would still be predicted if infants are unable to keep track of their passive movement and thus unable to determine that they are in a new location once they reach the opposite side of the table. In other words, even if the infant knows exactly where the toy should be relative to some aspect of the room, she would still appear to be egocentric if she does not realize that she is now in a new position.

Hypothesis 2, most liberal in terms of infant spatial cognition ability, is that the participants are able

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+, indicates an expected increase in looking (visual dishabituation); –, indicates no increase in looking (continued habituation); ?, indicates that either dishabituation or continued habituation is consistent with Hypothesis 2.
to, (1) form representations of an object’s location based on a non-egocentric coordinate system; and (2) keep track of their passive movement as they are moved to the opposite side of the table. If infants have these abilities, then they should dishabituate in the infant-moved/puppet-moved condition—despite the fact that the scene looks identical to the one they had seen during habituation. In the infant-moved/puppet-unchanged condition, it is difficult to make firm predictions. Even if the infants have some awareness that the puppet is in the same actual position (despite its change in position relative to the infant), they may dishabituate simply because the scene looks different from the new vantage point.

A third possibility (Hypothesis 3) is that infants may be limited to using an egocentric frame of reference, and additionally, they are also affected by their new passive movement directly prior to the test trial. Research on habituation has shown that introducing new stimuli following habituation can cause recovery to the habituated stimulus (Rescorla, 1988; Sokolov, 1963). Thus, the movement to the other side of the table could act as an unexpected stimulus and lead infants to look longer for reasons unrelated to their spatial abilities. In this case, we would expect to see dishabituation in both of the infant-moved conditions.

Finally, it is possible that infants could be increasing their looking on the test trials in general due to spontaneous recovery (Hypothesis 4). Although such a finding would be unexpected, infants have been shown to spontaneously reestablish interest in visual stimuli following habituation (Bertenthal, Haith, & Campos, 1983). If this is occurring in our paradigm, then infants should appear to dishabituate in all four conditions—including the condition in which nothing changes from the last habituation trial.

**Method**

**Participants.** Participants were 39 healthy, full-term infants ranging in age from 120 to 151 days ($M = 134.9$ days; $SD = 9.6$ days). Twenty infants were male and 19 were female. Each infant was randomly assigned to one of four experimental conditions (Infant-unchanged/Puppet-unchanged, Infant-unchanged/Puppet-moved, Infant-moved/Puppet-unchanged, Infant-moved/Puppet-moved). The habituation position of the puppet was counterbalanced across infants. It either sat on the front right corner of the table (with respect to the infant) or the far left corner. Ten additional infants were tested and eliminated from the analysis: 7 due to fussiness, and 3 due to procedural errors.

**Apparatus.** Testing took place in a 231-cm square room created with blue muslin curtains. Centered in this room was a 115-cm × 70-cm table. The main reason for the curtained room and for centering the table within it is that a featureless environment is the only way to ensure that dishabituation to the Infant-moved/Puppet-moved condition is due to objective spatial coding and not simply dishabituation to a different view of features in the room. Also, such an impoverished environment would allow for a disambiguation of evidence for tracking of passive movement versus reorientation with respect to landmark features. The environment was replicated from Kaufman and Needham (1999). Four 14-cm diameter holes were drilled in the tabletop so that the center of each hole was 28.5-cm from each corner of the tabletop. A purple tablecloth covered the tabletop and reached down to the floor concealing the experimenter under the table. Four slits were cut into the tablecloth corresponding to each of the holes in the tabletop. Two yellow screens 51-cm tall × 77-cm wide stood at the shorter sides of the rectangular table so that an infant that was moved 90° to the side of the table (from the starting point) could not see what was on the tabletop.

The display consisted of a gold-colored wooden cage (28-cm tall × 28-cm wide × 28-cm deep), which had a roof but no floor. Inside the cage was a pig puppet that could be manipulated by an experimenter who sat under the table and held a Plexiglas device that allowed her to rotate the puppet without producing extraneous movements in the puppet itself. Together the pig and cage formed the Pig-cage display to which infants were expected to direct their attention.

Each infant sat in a custom made highchair on wheels. The highchair was constructed of two parts: a wooden base with four swivel wheels, and a plastic booster seat that was securely attached to the wooden base. The booster seat and wooden base together were 76-cm high.

The infants were strapped into the booster seat during the session. The booster seat was equipped with a protective bar made to prevent the infants from slipping forward.

Two video cameras recorded the infant’s face while she was centered on either of the longer sides of the rectangular table. The cameras were outside of the curtains and only the lens was visible to the infant. The video cameras were connected to a monitor outside the testing room so that another experimenter could monitor the habituation trial length and determine if and when the infant had habituated.

**Procedure.** The experiment consisted of three phases: an initiation phase, a habituation phase and a test phase. The habituation and test phases are depicted in Figures 1 and 2.

**Initiation phase.** Before the infant entered the room, an experimenter hid underneath the table so that she could
move the pig puppet during the experiment. The Pig-cage display was put its habituation position. While the infant was being placed into the experimental chair, the experimenter under the table moved the pig puppet so that the infant would notice it once the experiment began. After the infant was securely strapped into the chair, the parent was shown how to change the position of the chair as required by the experimental procedure (see below). Additionally, the parent was instructed to stand behind the chair so that she would not serve as a distraction from the display. The initiation phase usually lasted between 3 and 5 min.

**Habituation phase.** The habituation phase consisted of 6 to 16 20-s trials in which the infant watched the pig puppet rotate in place within the cage. The pig rotated to the sound of a metronome hidden under the table at one 180° turn/s. The puppet began facing the infant and then, with the first metronome click, the puppet was turned so that the infant saw the puppet’s back. The puppet then turned to face the

![FIGURE 1 Depiction of the habituation phase procedure. (A) The infant begins the experiment on the side of the table where an occluding screen blocks the view of the tabletop. (B) The infant is moved to the front of the table for 20 s before being moved to the side of the table (S, occluding screen; PIG, Pig-cage Display; C, infant chair; V, Video Camera).](image1)

![FIGURE 2 Depiction of the test phase procedure. The four possible test conditions are illustrated. The infant is either moved back to the position held during the habituation phase (Infant-unchanged) or is moved to the opposite side of the table (Infant-unchanged). The display is either moved to the opposite table-corner (Display-changed) or remains stationary (Display-unchanged) (S, occluding screen; PIG, Pig-cage Display; C, infant chair; V, Video Camera).](image2)
infant with the following metronome click and so on. The puppet and cage remained in the same table position (Front-right or Far-left) for the duration of the habituation phase. Each habituation trial began with the infant-chair positioned on the side of the table so that the view of the tabletop was completely occluded by one of the yellow screens (see Fig. 1a). After 5 s in this position, an experimenter who was outside of the curtains instructed the parent to move the chair so that the infant faced the front of the table (see Fig. 1b). The infant remained in this position for 20 s and her face was recorded on videotape. At the end of the 20-s habituation trial, the parent was instructed to move the infant-chair back to the starting position to begin the next test trial.

The number of habituation trials was infant-controlled. All infants were run in at least six habituation trials. Additional trials were run if the infant had not met two criteria: (1) looked less at the Pig-cage display on the last two trials than on the previous two trials; and (2) looked less than 12 s on the last test trial. Each infant experienced a maximum of 16 habituation trials. Once these criteria were met, the procedure entered the test phase.

### Test phase.

The test phase consisted of a single trial and is depicted in Figure 2. This test trial was identical to the habituation trials with two exceptions. First, during the beginning portion of the trial, while the puppet and cage were hidden from the infant by the screen, the puppet and cage were moved. For half the infants, the display was moved to the diagonally opposite corner of the table (Puppet-moved conditions). This was accomplished by another experimenter who was unseen by the infant. For the other half of the infants, the experimenter also came out to move the display but simply moved it to the other side of the table and then back to its original location (Puppet-unchanged conditions). Next, half of the infants were moved back to the same location where they had viewed the puppet during the habituation trials (Infant-unchanged conditions), and half the infants were instead moved to the opposite side of the table (Infant-moved conditions). As in the habituation trials, the test trial lasted 20 s and the infant’s face was recorded on videotape.

### Results

#### Habituation Phase Analysis.

Looking times from the habituation phase were analyzed using a three-way ANOVA with Infant-movement and Display-movement as the between groups factors and repeated measures on one factor (looking time in the last six habituation trials). None of the four possible interactions were significant (all $F_s < 1.0, p > 0.05$). This analysis did reveal a significant effect of Trial, $F(5,32) = 30.8, p < 0.0001$. Infants in all four groups (as determined by Infant-movement and Display-movement conditions) decreased their looking at the Pig-cage display as habituation progressed.

#### Test Phase Analysis.

An initial ANOVA with condition as the single between-subject factor (with four levels consisting of the combinations of Infant-movement and Display-movement) on the arithmetic difference in looking time between the final habituation trial and the test trial indicated that there was a significant effect of condition, $F(3,38) = 3.7, p < 0.05$. The results of this experiment are summarized in the Experiment 1 column of Table 2. Two-tailed paired samples $t$-tests on infants’ looking time in the final habituation trial and test trial were performed to test the specific hypotheses laid out in Table 1. These revealed that infants dishabituated (i.e., looked longer on the test trial than in the last habituation trial) in three conditions: Infant-stationary/

### Table 2. Results of Experiments 1–3

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<th>Toy Position</th>
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<td>$0.2$</td>
<td>$6.7^{**}$</td>
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<tr>
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<td>Changed</td>
<td>$4.3^{**}$</td>
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Change in looking time in seconds from last habituation trial to test trial. Significance levels are denotes as follows: $^{*}p < 0.01$, $^{**}p < 0.005$, $^{***}p < 0.001$. 

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Kaufman and Needham

Developmental Psychobiology
Puppet-moved, \( t(10) = 3.7, \ p < .005; \) Infant-moved/ Puppet-Stationary, \( t(9) = 3.26, \ p < .01; \) and Infant-moved/Puppet-moved, \( t(8) = 4.2, \ p < .005. \) In the Infant-stationary/Puppet-stationary condition, there was no evidence of dishabituation, \( t(9) = 0.27. \) This pattern of results is incompatible with hypotheses 1 and 4, but is consistent with hypotheses 2 and 3. Thus it is possible that infants either correctly represented the actual (non-egocentric) location of the puppet and updated this representation as they were passively moved; or infants were motivated to look more at anything after experiencing a new kind of movement to the opposite side of the table (i.e., the new movement around the table aroused them such that habituation was disrupted).

**Discussion**

The results of Experiment 1 indicate that infants did not engage in spontaneous recovery (Hypothesis 4) nor did they display the behavior that would be most directly predicted by the "egocentric" hypothesis. However, these results on their own cannot be taken as definitive evidence for infants using and objective, non-egocentric frame of reference to guide their looking behavior. Although the results are consistent with the "advanced coding" hypothesis, they are also consistent with the "new movement arousal" hypothesis. Within the context of our initial hypotheses (Tab. 1), this result can be taken as evidence of two distinct possibilities. The first possibility is that the participants used a non-egocentric representation and dishabituated when the display did not match their expectation once they reached the other side of the table (in the infant-moved/puppet-moved condition). Additionally, these infants would also have dishabituated in the infant-moved/puppet-stationary condition because the display did look strikingly different from the habituation display. In other words, simply because infants had an expectation of what the display should look like following their passive movement, they still dishabituated when the puppet had not moved because they enjoyed looking at it from this new perspective.

The second possibility is that both of the Infant-moved conditions are basically uninterpretable because the infants’ movement around the table for the first time directly prior to the test trial put them in a state of arousal which disrupted the habituation and led them to look longer on the test trial. If this were the case, then there would be no way of determining from these results what type of spatial representations infants had formed during the habituation trials. Fortunately, the infant-arousal interpretation is easily evaluated with a slight modification to the testing procedure used in Experiment 1—and forms the basis for the next experiment.

Another possibility that is outside the scope of our initial hypotheses relates to a potentially confounding factor regarding what the infants saw as they initially rounded the table just prior to the test trial. This is discussed in greater detail in the General Discussion Section.

**EXPERIMENT 2**

If infants in Experiment 1 had been aroused by the new movement to the opposite side of the table (despite the frequent passive movements they had made between habituation trials), we would also expect them to show this behavior when the puppet’s location before and after habituation was in the center of the table. That is, if infant dishabituation in Experiment 1 was unrelated to their expectations of the visual scene based on their spatial representations, then they should dishabituate when they are moved around the table even if what is on the table is unambiguously identical to the habituation stimulus.

**Method**

**Participants.** Participants were 16 healthy, full-term infants ranging in age from 120 to 151 days \((M = 135.4 \text{ days}; SD = 11.1 \text{ days}).\) Eight infants were male and eight were female. Each infant was pseudorandomly assigned to one of the two experimental conditions (Infant-moved and Infant-unmoved). In order to achieve approximately even numbers of male and female infants in each condition, the randomly assigned condition was switched if there were currently enough males or females in that particular condition. Two additional infants were tested and eliminated from the analysis: 1 due to drowsiness, and 1 due to failure of the infant to decrease his looking time sufficiently during the habituation phase of the experiment. Recruiting occurred as in Experiment 1.

**Apparatus.** The apparatus was nearly identical to that used in Experiment 1. The only notable difference was that the holes at the corners of the table were removed. A new hole in the center of the table was used in this experiment (see Fig. 3).

**Procedure.** The procedure for this experiment was the same as that of Experiment 1 with a few exceptions. Most importantly, the Pig-cage display always remained in the center position throughout the initiation, habituation, and test phases of the experiment. Also, each infant was assigned to one of two conditions: Infant-changed or Infant-unchanged.
Results

For both conditions (infant-moved and infant-unmoved) the looking times during the last habituation (Moved: $M = 11.5$, $SD = 1.8$; Unmoved: $M = 11.7$, $SD = 1.6$) and test trial (Moved: $M = 11.0$, $SD = 3.4$, Unmoved: $M = 12.5$, $SD = 3.1$) were analyzed with paired $t$-tests. This analysis found no significant effect of trial in the infant-moved condition ($t(7) = -1.32$) nor the infant-unmoved condition ($t(7) = 0.72$). Thus infants showed no evidence of increased interest simply from moving around the table. These results are summarized in Table 2.

Discussion

Recall that in Experiment 1, two of our initial hypotheses (2 and 3) were consistent with dishabituation results. Specifically, infants dishabituated in the Infant-moved/Puppet-stationary condition which is consistent with advanced spatial coding, but could also be explained by a new-movement arousal effect in which infants dishabituate simply because of the novel movement to the opposite side of the table. The results of this experiment strongly suggest that infants do not recover interest in a display simply because they have been moved to the opposite side of the table. Thus, we argue that the infants in Experiment 1 were demonstrating non-egocentric spatial coding.

Nonetheless, an issue that clearly needs addressing concerns the reason why infants did not continue to habituate in the Infant-moved/Puppet-stationary condition of Experiment 1. This is a developmentally pertinent question as the 6.5-month-old infants in Kaufman and Needham (1999) did not recover interest in this condition. Clearly, while infants at 4.5 months of age are capable of using non-egocentric frames of reference, they also demonstrate more sensitivity to egocentric coordinate systems compared with infants 2 months older. We return to this issue in the General Discussion Section.

Another important issue raised by Experiments 1 and 2 is that we do not know what aspect of this new paradigm precipitated this more precocious behavior. An obvious possibility stems from the difference in dependent measure—that is, we are measuring visual dishabituation while many studies of infant spatial cognition rely on measures of manual action. Indeed, analogous studies of the A not B error have shown that infants look longer when object permanence is violated in a looking-time version of the A not B task (Ahmed & Ruffman, 1998). However, the dependent measure is not the only difference between our study and earlier reaching studies. Another factor that may play a role is the extent to which infants are familiar with their passive movement and the testing environment. The importance of this factor is investigated in Experiment 3.

EXPERIMENT 3

Taken together, the results of Experiments 1 and 2 suggest that 4.5-month-old infants formed objective representations of space, which were maintained following passive movement. This finding is in stark contrast to prior research, in which infants 12–16 months of age were shown to consistently and accurately search for hidden objects in a lab setting without salient landmarks (e.g., Acredolo & Evans, 1980).

As such, these new findings raise the question: why are infants in the dishabituation paradigm used throughout this paper succeeding where much older infants in infant-rotation tasks typically fail? Other than the obvious difference in dependent measure (discussed in detail in the General Discussion Section), one factor that separates the infant search tasks from the dishabituation task is the amount of experience they have with moving around different parts of the environment. In many of the infant spatial cognition tasks that have been conducted, infants were not moved from the front of the table until the moments immediately preceding the test trial (e.g., Acredolo & Evans, 1980; Bremner & Bryant, 1977). In other studies (e.g., Bai & Bertenthal, 1992; Bremner, 1978a) infants were moved to the side of the table and back, however this occurred only 1–6 times before the test trial. In contrast, in Experiments 1 and 2 infants experienced a minimum of 6 and maximum of 16 habituation trials in which they were moved to a side of the table and back.

We hypothesized that this difference in experience in moving partially around the testing environment prior to the test trial could have led infants in Experiment 1 here and in Kaufman and Needham (1999) to outperform infants in manual search tasks. This hypothesis is based in the idea that failures in infant-rotation and search tasks are not the result of a representational limitation, but rather a failure on the part of the infant to realize that she is in a new location once she has reached the other side of the table.

FIGURE 3 The tabletop used in Experiment 2. The Pig-cage display sits over a hole in the center of the table.
testing apparatus (McKenzie, 1987; Newcombe & Huttenlocher, 2000). Thus, our hypothesis is that the extensive experience with passive movement around the chamber provides the infants with crucial practice at tracking their passive movement around the table prior to test.

Experiment 3 addresses this possibility because infant participants were never moved to the side of the table and back (as infants in Experiment 1 were). Instead, between habituation trials they were simply rotated to face away from the table. As result, any difference in looking patterns in Experiment 3 from Experiment 1 are assumed to be the result of varying levels of experience moving around the table between trials.

**Method**

**Participants.** Participants were 33 healthy, full-term infants ranging in age from 120 to 151 days (\(M = 141\) days; \(SD = 9.6\)). Fifteen infants were male and 18 were female.

Eight additional infants were tested and eliminated from the analysis: two due to drowsiness, three due to fussiness, and three due to failure of the infant to decrease his looking time sufficiently during the habituation phase of the experiment.

The method for recruiting participants was the same as in the previous studies.

**Apparatus and Procedure.** The apparatus used in Experiment 3 was identical to that of Experiment 1. The procedure for Experiment 3 was nearly identical to that of Experiment 1. The one difference was that instead of moving the infants to the side of the table (to face the occluding wall) between trials, the infants were rotated in place so that they faced the curtain. Infants faced the occluding wall only between the last familiarization trial and the test trial.

**Results**

**Habituation Phase Analysis.** Looking times from the habituation phase were analyzed using a three-way ANOVA with Infant-movement and Display-movement as the between groups factors and repeated measures on one factor (Trial). None of the four possible interactions were significant (all \(Fs < 2.0\)). This analysis did reveal a significant effect of Trial, \(F(5, 25) = 25.3, p < .0001\).

**Test Phase Analysis.** An initial ANOVA with condition as the single between-subject factor (with four levels consisting of the combinations of Infant-movement and Display-movement) on the arithmetic difference in looking time between the final habituation trial and the test trial indicated that there was a significant effect of condition, \(F(3, 32) = 11.05, p < .0001\). The results of this experiment are summarized in the Experiment 3 column of Table 2. Two-tailed paired samples \(t\)-tests were performed to test the specific hypotheses presented in Table 1. These revealed that infants dishabituated (i.e., looked longer on the test trial than in the last habituation trial) in two conditions: Infant-stationary/Puppet-moved, \(t(7) = 4.22, p < .005\); Infant-moved/Puppet-Stationary, \(t(9) = 6.41, p < .0001\). In the Infant-stationary/Puppet-stationary condition, there was no evidence of dishabituation, \(t(7) = 0.26\), nor was there in the Infant-moved/ Puppet-moved condition, \(t(7) = .63\). This pattern of results is compatible with Hypothesis 1 (egocentric coding or an error in orientation following passive movement) and incompatible with Hypotheses 2 (objective spatial coding with accurate orientation), 3 (new movement arousal), and 4 (spontaneous recovery).

**Discussion**

The results of Experiment 3 showed that the experience of the infants in the familiarization had clear and influential effects on how they performed in test. Taken together, the results of Experiments 1 and 2 showed that 4.5-month-old infants were not limited to forming egocentric representations of the display, and that they could likely track their passive movements around the apparatus. In both of these experiments, the infants were moved to the side of the table between each of the 6–16 habituation trials. In contrast, in Experiment 3, when infants did not move to the side of the table and back between habituation trials, infants displayed egocentric looking patterns.

There are a number of possible explanations for why being moved to the side of the table between the habituation trials helped infants more than simply being rotated in place between habituation trials. One possible reason is that passive movement to the side of the table may have enabled infants to more easily track their own passive movement before the test trial. In other words, because infants were moved to the side of the table many times during the habituation phase, they habituated to the excitement of being moved and, after enough repetitions, attended to the spatially important aspects of their movement preceding the test trial. Infants in Experiment 3, who did not move to the side of the table and back between habituation trials, may have been more interested in the novel movement and, in turn, may not have directed their attention to their changing position.

Thus, when the infants in Experiment 3 arrived at the other side of the table, they may not have realized that they were actually in a new position and assumed that they were in the spatially identical location that they had been in.
It should be noted that (as discussed above) some reaching studies also moved infants to the side of the table between training trials (e.g., Bai & Bertenthal, 1992; Bremner, 1978a). However, these studies used on average fewer training trials (1–6) than we had habituation trials (6–16). More importantly, because we used a habituation procedure, it was necessarily the case that by the end of the lengthy habituation phase, infants were looking away from the pig and directing their attention elsewhere. This may have led to better encoding of the surrounding environment or to their own passive movement. In the reaching studies, we expect that the movements to the side of the table would have afforded less encoding of the room or of their passive movements as infants in this case were likely to be more focused on their upcoming opportunity to reach for the desirable toy. This seems especially likely when one considers how much difficulty infants at this age (7–9 months) have at reaching for hidden objects (Piaget, 1954). In most instances, they will not reach for hidden objects at all unless there are extremely motivated and have considerable practice. Because in reaching studies, infants only progress to the testing phase after demonstrating successful reaching, it is necessarily the case that they were in fact very motivated to reach for the object which may have interfered with their motivation for or opportunity to encode other spatially important aspects of the room or their passive movement.

Another possible explanation for the beneficial effects of passive movement to the side of the table between habituation trials is that it allowed infants to form more accurate spatial representations of the tabletop. That is, because infants were able to watch the tabletop as they were moved behind the occluding wall, they were better able to extrapolate the display’s current position once the tabletop was out of view. This extrapolation may have improved with each passive movement to the side of the table until, by the time the test trial commenced, infants were able to form an accurate objective spatial representation of the display’s current position. Infants in Experiment 3 only rotated in place; thus they never received any of the information that would have allowed them to extrapolate the display’s position.

Similarly, infants in the prior experiments may simply have directed more attention to the objective location of the display. In Experiment 1 the egocentric relationship between the puppet and the infant changed as the infant was moved to the side of the table. Because a single egocentric representation of the tabletop was inaccurate while infants moved to the side of the table, infants in these experiments may have been enticed into forming an objective representation of the tabletop. However, in Experiment 3, in which the egocentric relationship between the infant and the display did not change during the habituation trials, infants may not have had any reason to attend to the objective position of the display. Thus, when the test trial commenced, they may have resorted to the egocentric representation that they had formed during the habituation trials.

Although we cannot determine exactly why infants benefited from extensive experience with the passive movement to the side of the table, it is clear that some aspect of the infant’s movement between habituation trials was necessary in order for them to display non-egocentric looking patterns. Hence, it seems that to whatever degree infants at 4.5 months of age can form objective spatial representations; this ability is easily disrupted without sufficient familiarity with the testing environment.

**GENERAL DISCUSSION**

Throughout this paper we have described hypotheses and interpreted findings under the assumption that infants would primarily respond to the display’s position relative to their expectation of how the display would appear following the infant’s passive movement. However, differential looking procedures with infants are a relatively simple technique whose boundaries of interpretation at times can seem limitless. Consequently, before continuing to explain the significance of our findings, it is important to identify potential confounding factors that may have influenced looking time in this context.

In particular, our assumption that infants were responding to the display once they were centered at one side of the table should be considered thoughtfully as without this assumption there is an entirely reasonable alternative explanation for our results. In the infant-moved conditions, just prior to the test trial when the participant turns the corner to reface the display from the other side of the table, the participant very briefly (for approximately 1.5 s) has a novel egocentric relationship to the puppet (e.g., depending on the puppet starting position, the infant might be directly in front of the puppet for the first time during the session). Thus, an alternative explanation for our findings is that this simple and transient perceptual change rather than the subsequent longer-lasting allocentric change drives infant looking patterns.

Under such an explanation, the infants in Experiment 1 should dishabituate under any and all conditions in which something visually changes either during their movement around the table (the transient change) or after they are finally situated (the final change). Infants continued to habituate in the infant-unchanged/puppet-unchanged
condition, but dishabituated in all other conditions. Specifically, in the infant-stationary/object-moved and infant-changed/object-stationary conditions there was both transient change and a final change; in the infant-changed/object-changed there was only a transient change. By this account infants did not dishabituate to the infant-moved/puppet-moved condition because they expected it to be in a different position on the table, but because of the transient change prior to the beginning of the test trial.

Assuming this brief experience prior to the test trial was more influential in guiding infant looking behavior than what infants see for the remaining 20 s, this would also be an important finding that advances current knowledge of infant spatial cognition. Although we already know that by 4 months of age infants are sensitive to changes in depth (e.g., Slater, Mattock, & Brown, 1990; Yonas, Pettersen, & Granrud, 1982), this had not yet been explored in a paradigm in which the change in depth occurs only briefly and during passive movement of the infant. Moreover, it has never been shown (to our knowledge) that infants are so keenly aware of their egocentric relationship to objects in their environment that even a very brief and transient change in this relationship continues to affect their looking behavior once the change is no longer visible. Such sensitivity to one’s spatial relationship to objects at 4 months of age would be remarkable and while it may not be evidence of objective spatial coding per se, it signifies that very young infants are attending to and influenced by the very visual stimuli that would be crucial to locating objects in the environment across change in position and orientation.

Nonetheless, it is our view that infant looking times in each of the four conditions should be interpreted in accordance with the hypotheses delineated in Table 1. That is, their looking patterns are mainly driven by what they are seeing during the 20 s test trial and not the brief view of the object prior to this trial. This view is based largely on the results of Experiment 3, which do not easily fit with this alternative explanation. In Experiment 3, infants do not increase looking time in the infant-changed/puppet-changed test trial, despite the fact that in this trial infants see the puppet from a new angle as they round the corner prior to the test trial. In fact, because infants had no experience moving around the table during the habituation phase, arguably infants (by this account) would be expected to dishabituate to all of the test conditions because only just prior to the test trial are they ever brought around the table where they have a novel view of the entire apparatus. Yet, this is not what occurs. This is a strong indicator that infants are not primarily responding to brief, transient experiences just prior to the test trial and are, in line with our initial hypotheses, responding to what is seen during the 20 s test trial.

In fact, the finding of non-egocentric spatial coding is a novel one for this young age group, it is not one that should be wholly unexpected. Indeed, Rieser (1979) found that non-mobile infants at 6 months of age exhibit similar abilities, thus the link between self-produced locomotion and non-egocentric spatial representations (Acredolo et al., 1984; Bai & Bertenthal, 1992) was already weak in some circumstances. Furthermore, reviews by and McKenzie (1987) and Newcombe et al. (2000) have clearly demonstrated that a number of factors (e.g., familiarity with the environment and saliency of landmarks) influence infants’ performance on spatial tasks similar to those described in the experiments here.

Our results seem to indicate that infants were acting as if they were in a familiar environment. Previous research (with older infants) has shown that infants are more likely to display behavior reflective of allocentric spatial representations when tested in a familiar environment rather than an unfamiliar lab (e.g., Acredolo, 1982). Furthermore, in a study of retinocentric and egocentric representations with 4-month-olds, Kaufman, Gilmore, and Johnson (2006) also found that familiarity led to more advanced infant looking patterns. It seems reasonable that a key driver of development in this area is not the ability to form a particular type of representation, but rather an ability to rapidly become familiar enough with one’s surroundings so that one can determine how a display should appear from different vantage points. Supporting this view are a number of studies showing that tasks in which the child rotates are actually easier in many circumstances than tasks in which the apparatus rotates (e.g., Bremner, 1978b; Huttenlocher & Presson, 1979).

We propose that like the infants in Kaufman and Needham (1999), the 4.5-month-olds tested here were able to learn about their passive movements and the testing environment in a way that is typically unlikely in reaching paradigms. They are able to do so precisely because they lose interest in the puppet as the habituation phase progressed. This is in stark contrast to reaching studies where, because the objects are hidden, infants are necessarily very interested in the object itself (so that they are motivated to obtain it) prior to their passive movement around the apparatus. Experiment 3 offers more evidence for this conclusion as infants who were not given experience moving around the testing chamber responded as though they were limited to an egocentric representation.

Of course infants may not actually be tracking their passive movements in this task. Infants could demonstrate the same looking patterns without such ability provided that they encode and maintain the display’s position relative to the specific occluder that they are moved around between trials. In other words, the occluder could be used as a local cue and the infants could keep track of
the display’s relationship to this cue with a calculation of trajectory using visual flow information as they are passively moved. Arguably, however this is an even more difficult task than tracking one’s own position around a room. Indeed, in reaching tasks, infants are considerably better at localizing a hidden toy on a tabletop when the infants are moved than when they watch a tabletop being moved (Bremner, 1978a). Regardless, such an interpretation does not alter the overall theme of this work that young infants have accurate expectations of how a display should appear from different vantage points.

Comparing 4.5- to 6.5-month-olds examined in Kaufman and Needham (1999) raises important questions, as the older infants exhibited a different pattern of results than the younger infants. Specifically, younger infants dishabituated if the location actually changed, but also (unlike the older infants) dishabituated if there was only an egocentric change—whereas 6.5-month-olds only dishabituated to an actual change.

It is possible that although the younger infants knew where the display was located in space, they did not have an accurate representation of exactly what the display would look like from its new vantage point. In contrast, the older infants may have acquired enough experience seeing objects from different vantage points that they were no longer as interested when a familiar object was visible from a new location.

Two lines of research provide evidence for this interpretation. The first is Slater, Mattock and Brown’s (1990) work on size constancy. They found that although newborn infants could detect differences in on object’s actual size, they still preferred to look at the object from a novel distance. Only when infants were familiarized with the object from a variety of distances (i.e., retinal sizes) did they demonstrate a tendency to prefer looking at the object with the novel actual size. In contrast it is not until 18 weeks of age that infants lose interest in seeing the object at a different retinal size without such familiarization (c.f., Day & McKenzie, 1981; McKenzie, Tootell, & Day, 1980). Analogously, it is plausible that the infants in the Infant-moved/Puppet-unmoved condition of Experiment 1 dishabituated not because they are predominantly egocentric, but because they needed further familiarization with the objects before ceasing to become interested in different views (and different retinal sizes of the object). Further evidence comes from Bremner, Bryant, and Mareschal (2006) showing that once infants are familiarized with an object in a number of orientations, their interest in looking at the same object in a novel location wanes.

Another important difference between 4.5- and 6.5-month-olds is in their reaching ability and experience. As mentioned in Introduction Section, we expected our results to clarify the role of reaching experience in the formation of spatial representations. It appears that, at least under some conditions, extensive reaching experience is not a prerequisite for knowing where things are following passive movement. However, it is certainly plausible that reaching experience acquires particular relevance if the participant is required to reach for an object. In this case, infants would have multiple representations of space and how these representations manifest depends on the task demands.

Thus, it could be that early in life, infants find it difficult to use an allocentric framework in guided reaching but can access the allocentric framework in a habituation task. Similar arguments have been posed many times to explain why infants can appear to have impressive representational abilities in violation-of-expectation tasks while showing limited understanding when tested with reaching tasks. This idea is a familiar one in the area of object representation (e.g., Cepeda & Munakata, 2007; Charles & Rivera, 2009; Kaufman, Mareschal, & Johnson, 2003; Keen, 2003; Mareschal, 2000; Munakata, 2001).

The issue of multiple representations also relates to the types of cues available in the paradigm. We created an impoverished environment in order to make the tabletop in the infant-moved/puppet-moved condition as similar as possible to the infant-stationary/puppet-stationary condition. How infants might have reacted had we had multiple cues available is unknown. In a review of adult and animal navigation literature Cheng, Shettleworth, Huttenlocher, and Rieser (2007) convincingly demonstrate that Bayesian methods of cue combination can provide effective means for resolving conflicts between cues from sources with differing levels of reliability. Interestingly, more cues do not always lead to more sophisticated behavior, but it would still be informative to examine how multiple cues affect performance in a habituation task similar to ours.

We certainly acknowledge that infants’ access to certain types of spatial representations may be related to the type of task they are engaged in and the cues available. For the purposes of this paper however, we are mainly focused on the most complex level of representational thought infants can engage in. This focus is driven by our desire to know about infant expectations in the real world before they are able to act upon them. While it is important to study the cognitive and physical limitations on infants’ ability to act upon objects in space, simply knowing what infants expect to see as they are moved around in space tells us a lot about whether they are living in a similar or very different visual world from that of adults. Regardless of whether infants’ looking patterns were driven by the visual display during the test trial or by a keen awareness of their egocentric relationships to the display as the moved around it, we believe that the
results of this work demonstrate more similarities than differences.

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REFERENCES


