REPORT

Objective spatial coding by 6.5-month-old infants in a visual dishabituation task

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Abstract

Forty 6.5-month-old infants were tested in a visual dishabituation variation of Bremner and Bryant’s reaching task used to evaluate the spatial representations of infants. In the visual dishabituation version of this task, infants were habituated to a display in which an object held a constant position at a corner of the table. Following habituation, the object was either moved to the opposite table-corner or nothing on the table was changed. Also, the infant either remained in her starting position or she moved to the opposite side of the table. The results show that, following habituation to an object, infants dishabituated to a change in the actual location of an object and not to a change in the egocentric relationship between the infant and the object. We conclude that even in a landmark-free environment (1) 6.5-month-old infants are capable of representing space allocentrically, and (2) they have the ability to update their location during passive movement.

A fundamental question at the root of infant cognition is: what do young infants understand about three-dimensional space? Because space is universal to all organisms, one could hypothesize that knowledge of the metric properties of space should be innate. Alternatively, one could assume – as Piaget (1954) did – that space and all of the external world only becomes represented as separate from the infant over time and through the infant’s own interactions with space. The earliest studies of infant spatial thinking and action concluded that young infants are generally incapable of forming objective allocentric representations of space (Bremner & Bryant, 1977; Acredolo, 1978; Cornell & Heth, 1979; Rieser, 1979). In other words, it was believed that infants represented the spatial location of any objects in the external world relative to their own body without respect to an objective coordinate system. Thus, young infants were thought to be limited to forming self-oriented or egocentric spatial representations. This conclusion was based on experimental results that showed that 6- to 11-month-old infants search for a hidden target in a location that would be correctly specified by an egocentric spatial representation. For example, in a study by Acredolo (1978), infants were first trained to look for a rewarding face towards a window to their left and were then passively moved (i.e. were moved by someone else) to the opposite side of the apparatus. Following this relocation, infants less than 11 months of age continued to look to their left to find the face while older infants looked towards the correct position of the hidden experimenter. Similar results were found in other studies that examined infants’ visual search ability (Cornell & Heth, 1979; Rieser, 1979) as well as manual reaching towards a particular position on a table (Bremner & Bryant, 1977).

Later experiments revealed that there were a variety of experimental conditions in which infants as young as 8 months of age did not make perseverative errors in the types of passive rotation experiments described above. Many factors influence infants’ behavior in these tasks including the shape of the testing room, familiarity with the testing environment, presence of stable or unstable landmarks, maintenance of attention towards the target, mobile experience of the infant, and complexity of passive movement (e.g. simple rotation in place versus rotation with displacement) (Bremner, 1978a; Acredolo,
relocation following passive movement and is the ability to use features of the environment to aid in this reorientation hypothesis implies that what develops is the infant’s ability to reorient herself following passive movement rather than an inability on the part of the infant to accurately update her position during and/or following passive movement. Subsequent explanations for infants’ perseverative errors in the early tasks designed by Acredolo, Bremner and Rieser have focused on two possibilities. The first is that infants are not limited to egocentric representations, but rather they have a ‘choice’ of representational framework or search strategies and this choice is influenced by a combination of the factors listed above (Bremner, 1978a, 1978b; Acredolo, 1979). The second is that what develops is the infant’s ability to reorient herself following passive movement rather than an ability to accurately represent space (McKenzie, 1987). This reorientation hypothesis implies that what develops is the ability to use features of the environment to aid in relocation following passive movement and/or an ability to accurately update one’s location during passive movement.

Although it is beyond the scope of this paper, we ultimately aimed to investigate a strong version of the reorientation hypothesis: from birth infants may be able to form accurate representations of space; and that what appears to be egocentric responding is the result of an inability on the part of the infant to accurately update her position during and/or following passive movement. However, before this long-range goal could be achieved, it was necessary to develop a task that could tap the spatial abilities of pre-reaching infants. Thus, we developed a non-reaching version of the Bremner table task. In our version of this task, infants were given a number of habituation trials to a display in a constant location upon a table. Following each trial the infant was moved partway around the table and back again to her previous position. Once the infant had habituated to the display (see the Method section for details) the infant was given a single test trial. In this trial the infant was moved either (a) around to a new position on the opposite side of the table, or (b) back to the position she was in during the habituation trials. During this trial, the display was either surreptitiously moved to the opposite location on the table or remained in the same location. During the test trial, we measured the amount of time the infant looked at the target in its new actual or new egocentric position. Habituation theory predicts that, following habituation, infants will increase their responding to the stimulus configuration that appears novel, and conversely will remain at steady state or decrease their responding to the stimulus configuration that appears most similar to the habituation display (Sokolov, 1963; Slater, Morison & Rose, 1983; Kaplan & Werner, 1986). Thus, by comparing the looking times of the infants in the four experimental groups we can determine if an object in a new position appears novel to infants and/or if an object with the same position but with a new egocentric relation to the infant appears novel.

The main goal of this study was to test the utility of our paradigm by replicating the finding that infants younger than 9 months respond egocentrically in an infant-rotation task in an unfamiliar, landmark-free room. We hypothesized that, following passive rotation, infants would be unable to update their current location and thus would dishabituate to the display in which the relation between the infant and the display changed and maintain low levels of responding to the display where the actual location of the display changed but the egocentric relation between the infant and the display remained unchanged.

Method

Participants

Participants were 40 healthy, full-term infants ranging in age from 180 days to 209 days (M = 193 days; SD = 8.3 days). Nineteen infants were female and 21 were male. Each infant was pseudo-randomly assigned to one of the eight experimental conditions formed by the two infant-movement conditions (infant-changed and infant-unchanged), the two display-movement conditions (display-changed and display-unchanged) and the two display starting locations (front-right and far-left). In order to achieve approximately even numbers of male and female infants in each condition, the randomly assigned condition would be switched if there were currently enough males or females in that particular condition.

Twenty-one additional infants were tested and eliminated from the analysis: seven due to fussiness, eleven due to procedural error, and three due to failure to decrease their looking times sufficiently during the habituation phase of the experiment (see Procedure section for a description of the habituation trials).

The infants’ names were obtained from the Durham County vital records office. Parents were contacted via letter and follow-up phone calls. They were offered reimbursement for their travel expenses but were not compensated for their participation.
Apparatus

Testing took place in a room 231 cm square created with blue muslin curtains. Centered in this room was a 115 cm × 70 cm table. Four holes 14 cm in diameter 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 shiny 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 were centered on the infant's face while she was centered on either of the longer sides of the rectangular table. The cameras were outside 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 the infant had habituated.

Procedure

Before the experiment began, an experimenter hid underneath the table so that she could move the pig puppet during the experiment. The pig–cage display was put in the start position determined by the experimental condition before the infant arrived in the testing room. 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 pig–cage display.

The experiment consisted of two phases: a habituation phase and a test phase, as depicted in Figures 1 and 2.

Habituation phase

The habituation phase consisted of six to eleven 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 per second. This rotation was discrete rather than fluid – 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 infant with the following metronome click and so on. The pig–cage display 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 at the side of the table so that the view of the tabletop was completely occluded by one of the yellow screens (see Figure 1(a)). After 5 s in this position an experimenter who was outside the curtains instructed the parent to move the chair so that the infant faced the front of the table (see Figure 1(b)). 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 determined in an infant-controlled manner. 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 15 s on the last test trial.1 Each infant experienced a maximum of 11

1 We chose to compare the last two trials to the preceding two trials rather than comparing them to the first two trials. This decision was based partially on pilot data which revealed that infants’ looking times sometimes show an increase over the first two trials before gradually decreasing. This finding is consistent with a well-documented sensitization process involved in infant attention (Kaplan & Werner, 1986, 1991). The 15 s maximum looking time at the last habituation trial was implemented because each trial was 20 s long and pilot data indicated that it was difficult to interpret the test data of infants who were looking this close to the maximum trial length on the last habituation trial.
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 infant was facing the screen, the pig–cage display was moved to another location. For half the infants, the display was moved to the diagonally opposite corner of the table (display-changed condition). 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 (display-unchanged condition). Next, half of the infants moved back to the same location where they had viewed the pig–cage display during the habituation trials (infant-unchanged condition), and half the infants were instead moved to the opposite side of the table (infant-changed condition). As in the habituation trials, the test trial lasted 20 s and the infant’s face was recorded on videotape.

Data analysis

Coders were instructed and trained to examine the behavior of the infants to obtain two specific measures. The first measure was the duration of looking at the pig–cage display. The second measure was the number of looks to the alternative (and vacant) position for the pig–cage display. For the looking time data, each coder used a stopwatch to measure how long each subject looked at the pig–cage display. Timing began the moment that the parent stopped moving the infant chair and proceeded for the following 20 s. An infant was determined to be looking at the display if her eyes were directed at either the puppet or cage portion of the pig–cage display. The average discrepancy per trial among the two coders was 0.89 s. Coding for alternative position glances began the moment the infant was visible to the coder. An infant was determined to have glanced at the alternative position of the pig–cage display if she looked from the actual location of the cage to the former location of the pig–cage display without continuing her head movement away from the tabletop altogether. Additionally, the infant was determined to have made an alternative position glance if she was looking towards the alternative position the moment that she was visible to the coder.²

² The majority of the data were coded both at test time and later from the videotapes (N = 35). The remaining five subjects were coded only once and only for their looking times and not for glances towards the alternative position. Unfortunately, glance data for these five subjects are not accessible.
Results

Preliminary analyses

Looking times were analyzed using a five-way analysis of variance (ANOVA) with Infant movement, Display movement, Sex, and Position of the pig–cage display during testing (front-right or far-left) as the between-groups factors and repeated measures on one factor (Trial). This analysis revealed that there were no significant effects or interactions involving Sex (all $F$ values less than 2.5, $p > 0.05$). Number of looks to the alternative location analyzed with a four-way ANOVA (with all the between-subjects factors as the previously described ANOVA) revealed no significant effects or interactions involving sex and cage position at test. Thus, sex was eliminated from all analyses and cage position was eliminated from all subsequent analyses of looks to the alternative location.

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 was significant (all $F < 2.0$, $p < 0.05$). This analysis did reveal a significant effect of Trial, $F(5, 155) = 49.92$, $p < 0.001$. Figure 3 illustrates that infants in all four groups (as determined by Infant movement and Display movement) decreased their looking at the pig–cage display as habituation progressed.
Test phase analysis

We used two measures to examine the degree to which infants dishabituated during the test trial. The first measure was the time spent looking at the display during the test trial (see Figure 4). Looking times during the test trial were analyzed using a three-way ANOVA with three between-groups factors (Display movement, Infant movement, and Cage position during test). This revealed a significant main effect of Display movement, $F(1, 32) = 23.07, p < 0.001$, with participants looking longer during test in the Display-changed condition ($M = 14.27, SD = 2.87$) than in the Display-unchanged condition ($M = 10.05, SD = 3.15$). A main effect of Cage position was also found, $F(1, 32) = 8.65, p < 0.01$. Participants looked longer when the cage was in the near-front position ($M = 13.45, SD = 3.56$) than when it was in the far-back position ($M = 10.97, SD = 3.31$). Infant movement was not significant, $F(1, 32) = 0.13$, nor were there any significant interactions with this factor (all $F < 2.5, p > 0.05$). Planned comparisons confirmed that the infants in the infant-changed condition looked longer after the pig–cage display had been changed ($M = 13.90, SD = 2.42$) than when it was unchanged ($M = 10.74, SD = 3.74$), $F(1, 32) = 6.53, p < 0.05$. Planned comparisons also revealed that infants in the infant-unchanged condition looked longer at the display in the display-changed condition ($M = 14.65, SD = 3.30$) than in the display-unchanged condition ($M = 9.36, SD = 2.55$), $F(1, 32) = 17.88, p < 0.001$.

The second measure of dishabituation was the percentage difference in looking from the last habituation trial to the test trial (see Figure 5). This percentage difference measure was analyzed in an identical fashion to the raw looking times described above. The analysis revealed a significant main effect of Display movement, $F(1, 32) = 41.26, p < 0.001$, with a greater percentage increase in looking in the display-changed condition ($M = 46, SD = 34$) than in the display-unchanged condition ($M = 12, SD = 22$). The effects of Infant movement and Cage position during the test trial were not significant (all $F < 2.5, p > 0.05$).

![Figure 3 Looking times during the last six habituation trials.](image1)

![Figure 4 Looking times during the test trial.](image2)
Planned comparisons confirmed that the increase in looking among infants in the infant-changed/display-changed condition ($M = 34, SD = 41$) was significantly greater than it was for infants in the infant-changed/display-unchanged condition ($M = 8, SD = 21$), $F(1, 32) = 11.06, p < 0.005$. Planned comparisons also revealed that infants in the infant-unchanged condition had a larger percentage increase in looking at the pig–cage display when it changed its position ($M = 58, SD = 22$) than when its position remained unchanged ($M = 16, SD = 24$), $F(1, 32) = 33.03, p < 0.001$.

In addition to the dishabituation measure, the number of glances towards the alternative location of the display during the test trial was analyzed in the same fashion as the previous two analyses above (see Figure 6). This revealed a significant main effect of Display movement, $F(1, 31) = 12.6, p < 0.005$, with infants glancing more at the alternative location of the display during the test trial in the display-changed condition ($M = 2.1, SD = 1.1$) than in the display-unchanged condition ($M = 0.94, SD = 0.80$). Infant movement was not significant, nor was there a significant Infant movement × Display movement interaction (all $F < 1.0$, $p > 0.05$). Planned comparisons confirmed that infants in the infant-changed condition made more alternative glances when the pig–cage display changed its position ($M = 2.3, SD = 1.3$) than when its position remained unchanged ($M = 1.1, SD = 0.93$). Similarly, planned comparisons revealed that infants in the infant-unchanged condition made more alternative glances when the pig–cage display changed its position ($M = 2.0, SD = 1.0$) than when its position remained unchanged ($M = 0.78, SD = 0.67$).
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Discussion

The results of this experiment demonstrate that in our task 6.5-month-old infants dishabituated to a new actual location of a stimulus and not to a new egocentric relation between the infant and the stimulus. This finding has important consequences concerning our understanding of infant spatial cognition.

Contrary to our predictions, our results show that even in an unfamiliar setting with no salient landmarks available 6.5-month-old infants are able to update their current position during and/or following passive movement around a table. These results raise some perplexing questions concerning why the infants in our experiment did not appear to rely on landmarks and geometric cues to update their position, whereas infants in the visual and manual search tasks apparently need these cues.

We propose two different types of explanation for the discrepancy in findings. The first set of explanations focuses on the possibility that the different measures used to assess spatial ability (dishabituation versus manual/visual search) tap different levels of representational ability. The second set of explanations focuses on ways in which our task may be less cognitively demanding than tasks used in prior research.

One way to approach the differences between our results and those of search tasks is to examine differences in dependent measures used. It is possible that visual dishabituation to a stimulus tells us something different from manually or visually searching for a stimulus. For instance, perhaps reaching towards a covered hiding well or looking towards a window is a measure of explicit knowledge while dishabituation of looking time is a measure of implicit knowledge. While this is certainly possible, we do not think that this is a useful way to think about the data. As long as the infants tested in these paradigms are pre-verbal, it seems unlikely that there will be a direct way of determining which paradigm (if any) is tapping ‘conscious’ knowledge. And because consciousness of knowledge is a requirement for that knowledge to be explicit, it appears that differentiating the two tasks on the basis of an implicit versus explicit distinction is of limited value.

Another possible explanation is that the search tasks require the infant to correctly recall the actual location of the hidden toy while our dishabituation task merely requires that the infant recognize that the object has changed location. Although this explanation would account for the looking time data, it runs into trouble when considering the data on glances to the alternative location. Infants made significantly more glances towards the alternative location of the display in the display-changed condition than in the display-un-

changed condition. Contrary to the recognition hypothesis, the glancing data suggest that during the test trial infants did recall the approximate location of the display during the previous habituation trials.

The difficulties involved with explanations based on either an implicit/explicit memory distinction or a recognition/recall distinction lead us to focus instead on how our task may have fewer cognitive demands which led our subjects to exhibit a more advanced understanding of space.

One appealing answer to this puzzle is that, unlike our task, the tasks which measure infant search behavior often train the infants to commit themselves to a particular motor response early in the session which they are unable to inhibit during subsequent testing. Indeed, many of the experiments that find egocentric responding do require the infant to take part in such motor training (Bremner & Bryant, 1977; Acredolo, 1978; Bremner, 1978a; Cornell & Heth, 1979; Acredolo & Evans, 1980). For example, Bremner (1978a) has found that when 9-month-old infants are given training trials in which they reach to a particular side of the table, they are significantly more likely to reach in the same egocentric direction during test trials than infants who are not given the training trials. This, of course, results in what is coded as an ‘egocentric’ response, or a response driven by an egocentric representation of space.

However, the motor habit hypothesis cannot be the entire answer because there are a number of examples of egocentric responding in tasks that required subjects to manually search for a target but did not require training of a motor action towards a particular side of the testing apparatus (Bremner, 1978a, 1978b; Acredolo, 1979; Bai & Bertenthal, 1992). Yet, such egocentric responding without motor training is only found when infants are tested in unfamiliar environments or without salient landmarks marking the target location.

One possibility is that infants in manual search tasks are easily distracted from adequately updating their current position during passive movement because they are anticipating their upcoming search opportunity. Perhaps infants are able to determine their position following passive rotation in the presence of a salient cue, but not in the absence of such a cue. This scenario would explain our data nicely because infants in our task are never required to do anything more than examine the display. Thus, we would not expect them to be as distracted from noticing their passive rotations. This seems especially likely in the later training trials where infants in our study had tired of examining the pig–cage display whereas infants in search tasks typically continue to search throughout the training session.
The infants in our task also received considerably more exposure to our testing room than infants who make egocentric errors in search tasks. For example, in Bremner’s (1978b) study, infants received less than a minute of exposure to the hiding event. In contrast, each of the subjects in our experiment sat in front of the table with the display in its starting location for approximately 5 min (six 20 s habituation trials plus approximately 3 min while the experimenter briefed the parent prior to the first habituation trial). Future studies may determine the relative importance of the extended exposure to the display’s location and the reduced task demands of the habituation paradigm.

Another important procedural difference between our task and most of the earlier tasks aimed at assessing infant spatial ability is that the object displacement in our task occurred in more than one dimension. Object displacements in earlier experiments were typically in the horizontal plane only, whereas in our task the pig–cage display was moved both horizontally and in depth. One possible explanation for the results of our experiment is that, during passive movement, infants calculate the distance to the desired object. In the display-changed condition, the distance between the infant and the pig–cage display is different from what the infant would expect if she accurately calculated the new distance to the object from the opposite side of the table. In the majority of the search tasks employed in previous research this is not the case. For example, in Bremner’s studies the hiding wells are equidistant from the infant on both sides of the table. Alternatively, because our study is unique in that the two hiding places are separated in depth, it may be the case that infants simply represent depth (or how close an object is to the infant) more accurately than lateral distance.

It is also possible that what develops between 6 months and 12 months is not a representational ability per se, but rather an ability to utilize an understanding of space instrumentally. Such a phenomenon has been found in a number of domains. For example, Oden, Thompson and Premack’s (1990) work with infant chimpanzees demonstrated that, while the chimpanzees normally erred in a non-matching to sample task, the same subjects were quite proficient at analogous experiments using a familiarization–novelty procedure.

Finally, it should be mentioned that there is some recent evidence supporting the finding that 6-month-old infants are able to form adult-like spatial representations. In their research on spatial frames of reference for saccades, Gilmore and Johnson (1997) found that at around 6 months of age infants were able to make correct saccades towards a visible target even in situations in which they were required to take into account their eye movements. Gilmore and Johnson conclude that 6-month-old infants are not limited to forming retinoscopic (i.e. eye-centered) representations of space. Nonetheless, they acknowledge the discrepancy between their findings and those of Acredolo (1990) and Bremner (1978a) and suggest that what develops over the next 6 months is an ability to form more complex spatial frames of reference ranging from the retina to other body parts or external landmarks. Gilmore and Johnson suggest that further cortical development is necessary before the more complex frames of reference are available to the infant. What the research presented here indicates is that, if further development of cortical circuitry is required, it is not for use of external frames of reference, but instead for overcoming some of the non-spatial aspects (e.g. response inhibition, excitement of the upcoming reach opportunity etc.) of spatial tasks involving reaching for the hidden object following passive rotation around a table.

Of course, without further experimentation we cannot fully rule out any of the possible explanations for why 6.5-month-old infants in our dishabituation task appear to demonstrate spatial orientation/representational abilities exceeding those of infants previously studied using manual search tasks. Nonetheless, even without further experimentation we can safely conclude that 6.5-month-old infants have the ability to represent and orient themselves within a landmark-free three-dimensional space. Using the dishabituation task we devised, future research should determine if this ability is present earlier in an infant’s life.

Acknowledgements

The research reported in this article was supported by an American Psychological Association Dissertation Research Award to the first author and by a National Institute of Child Health and Human Development First Independent Research Support and Transition (FIRST) award (HD-32129) to the second author. We thank Erika Holz, Christina Inness, Avani Modi, Sharon Nikfarjam, Cynthia Ramirez and Henry Walke for their help in developing the procedures and stimuli used in this research; the undergraduate students working in the Infant Perception Laboratory at Duke University for their help with data collection and coding; and Carol Eckerman, Carl Erickson, Ted Hall, Kevin Myers and Christina Williams for their useful commentary on the experimental design and/or earlier drafts of this manuscript. Finally, we also thank the parents and infants who gave their time and effort to make this research possible.
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Received: 7 October 1998
Accepted: 22 January 1999