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# Tests of a Dynamic Systems Account of the A-not-B Error: The Influence of Prior Experience on the Spatial Memory Abilities of Two-Year-Olds

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Recently, Smith, Thelen, and colleagues proposed a dynamic systems account of the Piagetian "A-not-B" error in which infants' errors result from general processes that make goal-directed actions to remembered locations. Based on this account, the A-not-B error should be a general phenomenon, observable in different tasks and at different points in development. Smith, Thelen, et al.'s proposal was tested using an A-not-B version of a sandbox task. During three training trials and three "A" trials, 2-year-olds watched as a toy was buried in a sandbox at Location A. Following a 10-s delay, children searched for the object. Across five experiments, children's (total $N = 92$) performance on the A trials was accurate. After the A trials, children watched as a toy was hidden at Location B, 8 to 10 inches from Location A. In all experiments, children's searches after a 10-s delay were significantly biased in the direction of Location A. Furthermore, this bias toward Location A decreased with repeated trials to Location B, as well as when children completed fewer trials to Location A. Together, these data suggest that A-not-B–type errors are pervasive across tasks and development.

## INTRODUCTION

There are experimental phenomena that are so tightly linked to particular developmental periods that they both define and are defined by that stage of development. Piaget's (1954) A-not-B error is one of these phenomena. In this task, an infant watches as an object is hidden at one location—Location A. After a delay of several seconds, the infant is allowed to search for the object and typically does so correctly. After several hidings and findings at Location A, the object is hidden at another location—Location B. Infants aged 8 to 10 months routinely reach back to and search at Location A for the object just hidden at Location B. For Piaget, this error defined Stage 4 in the development of the object concept. The error represented important progress in that Stage 4 infants searched for hidden objects; however, it represented significant limitations in the object concept since object representation was inextricably linked to the infant's own past actions. Since Piaget's writings on this subject, there have been a number of alternative explanations of the A-not-B error in terms of the egocentric representation of space (e.g., Acredolo, 1985; Bremner, 1978; Bremner & Bryant, 1977), the immaturity of pre-frontal cortex (e.g., Diamond, 1990a, 1990b; Diamond & Goldman-Rakic, 1989), and the fragility of object memory (e.g., Munakata, 1998; Munakata, McClelland, Johnson, & Siegler, 1997), among others. These alternative explanations, like Piaget's original explanation, emphasize the unique insights this error provides about the state of infants' minds (or brains) at one particular point in development.

Recently, Smith, Thelen, and colleagues (Smith, Thelen, Titzer, & McLin, 1999; Thelen, Schöner, Scheier, & Smith, 2001) proposed an account of the A-not-B error in terms of the processes that underlie goal-directed reaching. Importantly, they proposed that the processes that lead to the error in the A-not-B task are not specific to a particular point in development but, instead, are general processes that produce goal-directed actions to remembered locations throughout development. According to this dynamic systems account, the error is the product of the visual and attentional processes involved in perceiving the locations of important objects in the world, motor processes involved in planning and executing actions that move the hand from a starting location to a target location, short-term memory processes involved in maintaining task-relevant information from second to second in the absence of salient perceptual cues, and longer-term memory processes that store information about past actions. If this claim is correct, then the A-not-B error should *not* be specific to a particular task or a particular point in development. Instead, this classic error should be one example of a broader class of spatial memory errors that occur in a variety of tasks and at different ages.

In the present study, we provide a first test of this general claim. The results show that 2-year-olds make A-not-B–type errors: after repeated hiding and finding events at one location, 2-year-olds' reaches to a new hiding location are systematically biased toward the original location. These data support our contention that A-not-B–type errors are pervasive in early development. Furthermore, the results of the present

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study show that 2-year-olds' spatial memory biases may originate from trial-to-trial experience in a task, rather than being given a priori by the structure of the task space and children's categorization abilities, as has been previously thought. Thus, the dynamic systems explanation of the A-not-B error at one age leads to novel insights into phenomena thought to index cognition at a different age.

## A Dynamic Systems Account of the A-not-B Error

According to the dynamic systems account proposed by Smith, Thelen, and colleagues (Smith et al., 1999; Thelen et al., 2001), the A-not-B error is a result of how infants plan and remember actions to specific locations in the context of the different events that happen in the canonical A-not-B task. Figure 1 illustrates the central aspects of this account. The upper panel of Figure 1 captures the second-to-second evolution of an action plan on a typical trial to an A location, in this case, the second trial to Location A in the canonical A-not-B task. The lower panel of Figure 1 shows the evolution of an action plan on the first trial to a B location.

Action plans in Figure 1 are captured by time-dependent distributions of "activation" in a *motor plan-*

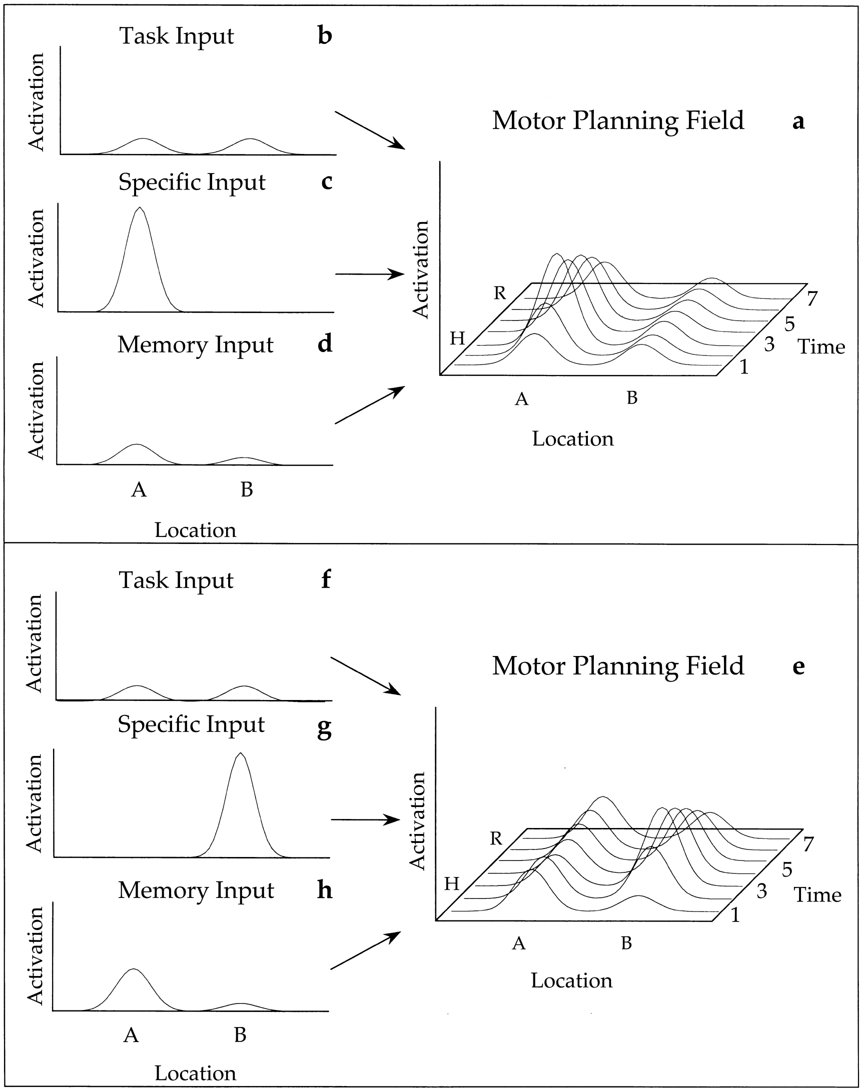

**Figure 1 A dynamic systems account of the A-not-B error. Upper panel shows time-dependent changes in the motor planning field (a) in the context of three inputs (b, c, d) on the second A trial in the canonical A-not-B task. Lower panel shows time-dependent changes in the motor planning field (e) in the context of the same three inputs (f, g, h) on the first B trial. H = end of hiding event, R = reaching.**

*ning field* (see Figures 1a, 1e), where activation indicates the likelihood that an infant will move to a particular location at any moment in time. For example, at Time 1 in Figure 1a, there is slightly more activation at Location A than Location B. This indicates that the infant is more likely to reach to Location A than Location B at Time 1.

Activation values in the motor planning field are influenced by three inputs shown at the left in the upper panel of Figure 1. The first of these is the *task input* (Figure 1b). This represents the stationary location cues in the task space that specify the different behavioral alternatives. In the task input in Figure 1b, there are two small activation peaks at the A and B locations. These represent the two lids covering the A and B hiding locations. These activation peaks are small because in the canonical A-not-B task, the lids are not very salient perceptual cues—they are typically painted the same dull color as the box on which they rest. The second input is the *specific input* (Figure 1c). This input captures the phasic visual cue that specifies the hiding location—the experimenter waving or tapping a toy and hiding it under the A or B lid. The strong specific input at the A location shown in Figure 1c represents a hiding event at Location A. It is important to emphasize that this is a phasic input. The specific input is only "on" during the hiding event. At other times during a trial, this input is set to zero activation. The third input is the *memory input* (Figure 1d). The memory input captures the infant's memory of past actions to Location A or Location B. In the memory input in Figure 1d, there is more activation at Location A than at Location B. Recall that the trial depicted in the upper panel of Figure 1 is the second trial to the A location. The bias in the memory input reflects the infant's memory of the reach to Location A on the first A trial.

The motor planning field in Figure 1a reflects the time-dependent integration of the three inputs. At the start of the A trial in Figure 1a—before any events have happened—there is activation at both the A and B locations, with slightly larger activation at Location A. This reflects the combined task and memory inputs. At Time 2, the toy is shown to the infant and hidden (H) at Location A. In the presence of strong specific input, a large peak of activation builds up at Location A in the motor planning field. This peak of activation decays during the delay, when the specific input is set to zero (i.e., when the toy has been hidden). Finally, the infant is allowed to reach (R) at Time 7. The infant reaches to Location A at this time because the A location has the highest activation in the motor planning field.

The A-not-B error is depicted in the lower panel of Figure 1. The three inputs on the first B trial are shown at the left. The task input in Figure 1f is identical to the task input in the upper panel, because in the canonical A-not-B task, the characteristics of the box and lids are not changed on the first B trial. The specific input in Figure 1g shows strong activation at the B location because that is where the toy is hidden. Finally, the memory input in Figure 1h shows a stronger bias toward the A location, because in the canonical A-not-B task, an infant has generally reached to Location A many times before the first B trial. Figure 1e shows how activation in the motor planning field changes from second to second in the context of these inputs. At the start of the trial (Time 1), there is stronger activation at the A location, reflecting the bias in the memory input. Then, the toy is hidden (H) at Location B. In the presence of the strong specific input, a strong peak of activation builds up in the planning field at the B location. During the delay, this peak decays, and is eventually overtaken by the strong memory input at the A location. Consequently, when infants are allowed to reach (R), they reach to Location A and not Location B.

To summarize, according to Smith, Thelen, and colleagues (Smith et al., 1999; Thelen et al., 2001), the A-not-B error results from the general processes that make goal-directed actions to remembered locations in the context of the events that occur in the canonical A-not-B task. Specifically, across the A trials, infants construct a relatively strong, longer-term memory of the A location. At the start of the first B trial, infants plan a movement to the B location to retrieve the attractive toy. In the absence of salient perceptual cues that specify the B location, this plan to move to Location B decays during the delay. After several seconds have passed, a plan to move to Location A—created and maintained by the longer-term memory of the A location—begins to dominate. Consequently, infants reach back to Location A.

It is important to note that none of the processes that operate in this account are specific to the A-not-B task or to a particular period in development, even though the details in Figure 1—the buildup of action plans from second to second, the characteristics of decay in the planning field, the strength of activation in the memory input—certainly are. This implies that A-not-B–type errors should occur across a range of tasks, provided that some aspects of the canonical A-not-B task are maintained, such as the memory delay or the lack of salient visible cues to specify the hiding locations. Similarly, A-not-B–type errors should occur across a range of ages, again with the provision that age-appropriate modifications to the task are made. For instance, older children might only make an A-not-B–type error after many trials to the A location or after long delays. Indeed, Diamond and Doar (1989) found that as age increased, infants could tolerate longer delays in an A-not-B task. Specifically, 8-month-olds performed more accurately in an A-not-B task following no delay than following a 3-s delay, 10-month-olds performed better following a 3-s delay than an 8-s delay, and 12-month-olds performed better following an 8-s delay than a 12-s delay.

### Testing the Dynamic Systems Account

To test the broader implications of the dynamic systems account, a variant of the sandbox task from Huttenlocher, Newcombe, and Sandberg (1994) was used. On each trial in this task, a child watches as a small toy is hidden somewhere in a long, rectangular sandbox. After the toy has been covered up, the experimenter directs the child's gaze away from the hiding location, there is a short delay, and the child is then allowed to search for the hidden toy. The experimenters record the location of the child's first contact with the sand so that they can examine patterns of error across trials in different experimental conditions.

For example, Huttenlocher and colleagues (1994) hid toys at nine locations equally distributed throughout the sandbox. Across trials in this study, 16- to 24-month-olds showed a systematic pattern of error: children's responses were biased toward the center of the sandbox. For instance, when searching for toys hidden in the left half of the sandbox, children searched at locations a few inches away from the actual hiding locations and in the direction of the center of the sandbox. Huttenlocher et al. proposed that this center bias was a result of how young children categorize locations in the sandbox task. Specifically, children treat the sandbox as one large category with a spatial prototype at the center of the category, that is, at the center of the sandbox. During recall, children combine their memory of the target location with this prototypical location. This leads to a response bias toward the center because all locations are weighted with the same prototype (for related ideas, see Engebretson & Huttenlocher, 1996; Huttenlocher, Hedges, & Duncan, 1991; Newcombe, Huttenlocher, Sandberg, Lie, & Johnson, 1999; Sandberg, Huttenlocher, & Newcombe, 1996).

The sandbox task has several attractive features that make it ideal in the context of the present report. First, the purpose of this study was to examine parallels between the memory errors made by infants in the A-not-B task and those made by young children in a different task. The sandbox task is one of the few tasks that has been used with children as young as 16 months, and even young children enjoy this task. Consequently, they will tolerate relatively long delays and are willing to perform a number of trials. Second, 8 to 10-month-old infants reliably make the A-not-B error if the lids covering the hiding locations—the task input—are not perceptually salient (e.g., brown lids on a brown box). The task input in the sandbox task is even more extreme: there are no salient visible cues in the sandbox that specify the hiding locations. The sand itself is homogeneous, the sandbox is large, making it difficult for children to use the edges as a frame of reference, and, typically, external landmarks are concealed by hanging curtains around the laboratory (e.g., Huttenlocher et al., 1994; Newcombe, Huttenlocher, Drummey, & Wiley, 1998). The homogeneity of the sand is also useful in that it allows researchers to measure graded responses by the participants. Thus, rather than simply recording the presence or absence of an error, one can measure the magnitude of children's errors in different experimental conditions.

Finally, according to the dynamic systems account, there should be a relation between the general processes that produce the A-not-B error in infancy and the processes that produce spatial memory errors in different, but related, tasks later in development. Currently, there is a gap in the literature between studies of spatial memory abilities in infancy and at 2 years of age. Whereas infants' errors in the A-not-B task are thought to be informative about the object concept (e.g., Munakata, 1998; Piaget, 1954), inhibition of a prepotent response (e.g., Diamond, 1990b), and so on; 2-year-olds' errors in the sandbox task are thought to be indicative of an early form of spatial categorization, and how young children encode locations relative to external cues (Newcombe et al., 1998). If a clear connection can be made between performance in these tasks, it may offer insight not only into what general processes make goal-directed actions to remembered locations, but also into how these general processes change between infancy and 2 years of age.

## EXPERIMENT 1

To test the dynamic systems account of the A-not-B error, an A-not-B version of the sandbox task was used to determine whether 2-year-olds make A-not-B–type errors. The sandbox task was designed to parallel the canonical Piagetian A-not-B task (see Smith et al., 1999). The experimenter sat on one side of the sandbox; the child sat with a parent on the opposite side. One hiding location was to the left of center and the other was to the right of center, from the child's perspective. The task began with several training trials at Location A. Training was followed by three A trials in which a toy was completely hidden at Location A. Children then completed two B trials in which a toy was completely hidden at Location B. According to the dynamic systems account of the A-not-B error, children should construct a relatively strong memory of Location A across the training and A trials. Consequently, they should show a bias toward Location A on the B trials, that is, children should search for the hidden toy not at the correct location, but at a location biased in the direction of Location A.

## Method

*Participants.* Twelve 2-year-olds participated in this experiment ($M = 29$ months, *range* = 27–31 months; 8 females, 4 males). Children were recruited from a participant database at Indiana University. All children were from middle-class, English-speaking families.

*Materials.* A sandbox 60 inches long, 16 inches wide, and 18 inches high was constructed from 1-inch plywood and painted green (see Figure 2). The sandbox had a false bottom 6 inches from the top edge, and was filled with 5 inches of sterile play sand. On the inside wall of the sandbox facing the experimenter, there were white markings located at 1-inch intervals to help the experimenter identify the hiding locations and to help the scorer code each child's reaching responses. These marks could not be seen by the child. On the outside wall of the sandbox facing the experimenter, a tape measure served as an additional guide to the experimenter and scorer. The toys hidden were approximately 5 cm × 3 cm and included a small purple dinosaur, a toy cupcake, a police car, and a figurine of a girl.

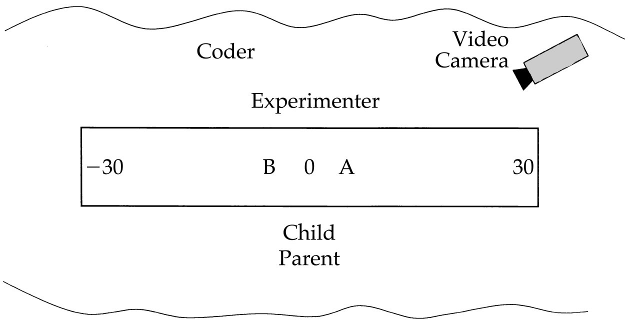

**Figure 2 Experimental setup. Position of the child, parent, experimenter, coder, and video camera are shown relative to the rectangular sandbox. A and B mark two possible hiding locations. The left edge of the sandbox was at −30 inches from the child's perspective; the right edge of the sandbox was at 30 inches. The center of the sandbox is at 0. Curtains (wavy lines) were hung to prevent the use of external landmarks as memory aids in the task.**

During the hiding events, the child stood on a mat marked with two footprints. This mat was placed at the center of the sandbox. The parent sat in a chair behind the child, and the experimenter sat in a chair opposite from the child. A scorer sat in a chair behind the experimenter. All sessions were videotaped to allow for later coding. The video camera was placed behind and to the left of the experimenter. Finally, curtains were hung from the ceiling behind the experimenter and behind the child to limit the child's ability to use external landmarks to help remember the locations of the hidden toys.

*Procedure.* At the start of the experiment, the parent, child, and experimenter touched and played with the sand until the child was comfortable with the sandbox. Then, the child stood on the footprints aligned with the center of the sandbox and the parent sat in the chair behind the child. Next, the experimenter selected one of the toys and began the training trials. The training trials served to establish the procedure and purpose of the game for the child and to build a strong memory of the A location. The procedure on the training trials mimicked what happens in the canonical A-not-B task (see Smith et al., 1999). On the first training trial (T1), the object was placed at an A location on top of the sand, while the parent hugged the child to prevent her from reaching for the toy. As soon as the toy was in position, the child was released by the parent and allowed to retrieve the toy. On Trial T2, the child was once again placed on the footprints and hugged by the parent as the toy was placed at Location A. This time, however, the toy was buried in the sand so that only its top was visible. Immediately after the toy was positioned, the parent released the child, who then retrieved the toy. The final training trial (T3) was identical to the first two trials except that the experimenter completely buried the toy at Location A in a way that left indentations in the sand that clearly marked the toy's location. Once again, the child was allowed to search immediately after placement of the toy.

Three A trials followed the training trials. (In the canonical A-not-B task, what we refer to as the first A trial is generally considered to be part of the training period. This is followed by *two* A trials. Given that all three A trials are identical, we have chosen to group these trials together to allow for a more complete analysis of performance to the A location.) These A trials were identical to the training trials, with three exceptions: (1) extra care was taken to ensure that the child attended to and watched the hiding event, (2) the object was completely hidden at the A location and smoothed over with sand so that no telltale marks remained, and (3) a delay of 3 s was imposed between the end of the hiding event and the moment when the parent released the child. During this delay, the parent restrained the child and the experimenter used a puppet or called the child's name to direct visual attention away from the sand and toward the experimenter's face. After the 3-s delay, the child was allowed to search for the hidden object. If the child did not find the toy after roughly 10 to 20 s, the experimenter helped the child uncover the toy.

Two B trials followed the A trials. The B trials were identical to the A trials, with two exceptions: (1) the toy was hidden at a new location 10 inches from the A location, and (2) the delay was increased to 10 s.

It is important to note that different delays were used on the A and B trials to increase the strength of children's longer term memory of the A location and, consequently, the likelihood that they would make A-not-B–type errors. According to the dynamic systems account, activation in the planning field decays during the memory delay. Thus, at shorter delays on an A trial, there will be greater activation at Location A and, consequently, a stronger longer term memory of Location A. A longer delay was used on the B trials to increase the likelihood that the stronger memory of A would influence children's responses, that is, to increase the likelihood of A-not-B–type errors. Recall that Diamond and Doar (1989) found that 12-month-olds performed better following an 8-s delay in an A-not-B task than following a 12-s delay. Based on these data, we expected that 2-year-olds would tolerate a 10-s delay on the B trials.

*Experimental design.* Toys were hidden at one of two possible locations: −5 inches (5 inches to the left of center from the child's perspective) and 5 inches (5 inches to the right of center from the child's perspective). The position of the A and B locations was counterbalanced across children such that Location A was to the left of center (−5 inches) for half the children and to the right of center (5 inches) for the other half (see Figure 3).

*Behavioral scoring.* All sessions were videotaped in such a way that the marking tapes were clearly visible. On each trial during the experiment, the scorer, who sat behind the experimenter, scored the position of the child's hand at first contact with the sand to the nearest 1-inch mark on the tapes. A second scorer, naive to the hypotheses, scored each response using the videotapes. The largest single deviation between the two scorers was 1 inch. The mean deviation (absolute value) was .3 inches ($SD$ = .29 inches). The on-line scorer's values were used in all statistical analyses.

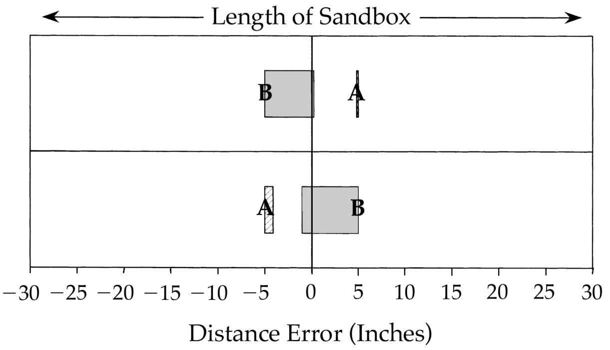

**Figure 3** Mean distance errors in Experiment 1 across the three A trials (striped bars) and two B trials (solid bars) for each layout of A and B locations (see upper and lower panels). Positive scores indicate errors to the child's right; negative scores indicate errors to the child's left. The figure is scaled to the lateral dimensions of the sandbox (60 inches). Position 0 (zero) indicates the center of the sandbox.

## Results and Discussion

Children were very accurate when searching for toys on the A trials. Data from these trials at each hiding location are shown in Figure 3. Distance errors on the A trials were less than 1 inch at both hiding locations (±5 inches). A Condition (Location A at 5 inches, Location A at −5 inches) × Trial (A1, A2, A3) ANOVA, with Condition as a between-subjects factor and Trial as a within-subjects factor, revealed no significant effects. Nevertheless, there appeared to be a small bias toward the center of the sandbox on the A trials: the mean distance error to the −5-inch target was positive ($M$ = .89 inches; $SD$ = 2.68 inches) or toward the center; the mean distance error to the 5-inch target was negative ($M$ = −.17 inches; $SD$ = 2.33 inches) or toward the center. To determine whether these effects differed significantly from zero, a one-sample $t$ test was conducted on the A data from each condition. This yielded no significant effects, indicating that the biases toward the center of the sandbox were not statistically reliable.

Children's performance on the A trials was considerably more accurate than 2-year-olds' performance in the study by Huttenlocher et al. (1994). In that study, 2-year-olds searched for toys hidden at different locations on each trial. The mean distance error when toys were hidden at ±6 inches from the center position (the locations closest to the ones used here) was 2.1 inches ($SD$ = 3.72 inches) as compared with .36 inches in this study ($SD$ = 2.53 inches). Thus, repeatedly searching for an object at the same location during three training trials appears to strengthen the memory of this location, thereby improving performance on subsequent A trials. Note that this effect is consistent with the prototype model proposed by Huttenlocher et al. (1991). According to that model, repeatedly searching for an object at the same location should strengthen children's "fine-grained" memory of the location, thereby decreasing their reliance on categorical (i.e., prototypical) information.

On the B trials, there was a clear response bias toward the A locations. As can be seen in Figure 3, when B was at ±5 inches, children searched for the hidden toy near the center of the sandbox—roughly 5 inches away from the correct location and in the direction of the A location. A Condition (Location B at −5 inches, Location B at 5 inches) × Trial (B1, B2) ANOVA revealed a significant main effect of Condition, $F(1, 10) = 31.54$, $p < .001$. No other effects were significant. Thus, as predicted by the dynamic systems account, 2-year-olds made an A-not-B–type error in the sandbox task, that is, their search was systematically biased toward a location at which they had previously searched.

Nevertheless, the magnitude of the errors on the B trials raises questions about whether children's responses are truly being pulled toward Location A or whether these responses are biased toward the center of the sandbox, as reported by Huttenlocher et al. (1994). Two factors argue against the second interpretation. First, on the majority of B trials across conditions, children's mean responses *overshot* the center of the sandbox in the direction of the A location: when Location A was at −5 inches, children overshot the center by 1.3 inches on Trial B1 and .6 inches on Trial B2; when Location A was at 5 inches, children overshot the center by .7 inches on Trial B1. If children's responses were biased toward a prototypical location at the center of the sandbox, it is not clear why they would overshoot the spatial prototype. Second, the magnitude of the errors in the present experiment was considerably larger than that of the errors toward the center of the sandbox in Huttenlocher et al. (1994). As mentioned above, the average error toward the center of the sandbox from ±6 inches in Huttenlocher et al.'s study was 2.1 inches. The mean error on the B trials in this experiment was 5.6 inches. This occurred despite children's very accurate performance on the A trials. They clearly could be accurate in the task, but were not.

Although several factors argue against the idea that children's responses were biased toward the center of the sandbox, it is important to note that a bias toward Location A and a bias toward the center of the sandbox are not mutually exclusive. Children are sensitive to multiple location cues in the sandbox task (see Huttenlocher et al., 1994; Newcombe et al., 1998). Thus, it is possible that children's responses are biased toward both locations (i.e., Location A and the center). To test these alternative possibilities, we conducted a second experiment in which the A and B hiding locations were positioned in either the left or the right half of the sandbox.

## EXPERIMENT 2

The goal of the second experiment was to determine if children's responses in Experiment 1 were biased toward the A location, toward the center of the sandbox, or toward both locations. There were four conditions in this experiment. In two conditions, Location B was in the left half of the sandbox; in the other two conditions, Location B was in the right half of the sandbox. The A locations were always 8 inches from B. In two conditions, Location A was "inside" Location B, or closer to the center of the sandbox. In the other two conditions, Location A was "outside" Location B, or farther from the center of the sandbox.

If children's responses on the B trials in Experiment 1 were pulled toward Location A, then B responses in the present experiment should be pulled toward Location A with the same magnitude across all four conditions. If children's responses on the B trials in Experiment 1 were pulled toward the center of the sandbox, then B trial responses here should be pulled toward the center in all conditions. Finally, if children's responses on the B trials are influenced by both the memory of previous reaches to the A location *and* the center of the sandbox, responses in the present experiment should be pulled toward Location A more strongly when Location A is inside Location B (and both biases are in the same direction) than when Location A is outside Location B (and the biases are in opposite directions).

### Method

*Participants.* Twenty-eight 2-year-olds participated in Experiment 2 ($M = 27.4$ months, *range* = 26–29 months; 14 females, 14 males). Seven additional children participated but their data was not used in the final analyses—4 because they refused to touch the sand, 2 because they always searched for objects by sweeping their hand over a large distance, and 1 because of experimenter error. Children were recruited from a participant database at Indiana University. All children were from middle-class, English-speaking families.

*Materials, procedure, and behavioral scoring.* The materials and procedure were identical to those in Experiment 1. All sessions were videotaped and scored

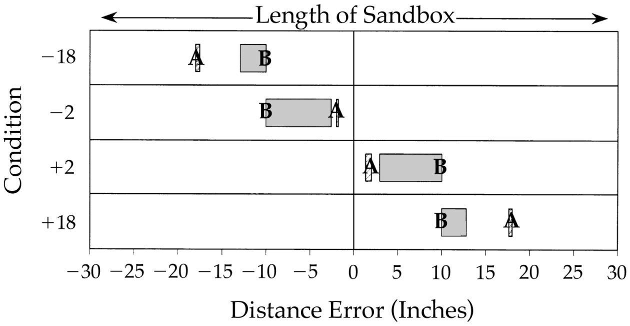

**Figure 4** **Mean distance errors in Experiment 2 across the three A trials (striped bars) and two B trials (solid bars) for four layouts of A and B locations. Positive scores indicate errors to the child's right; negative scores indicate errors to the child's left. The figure is scaled to the lateral dimensions of the sandbox (60 inches). Position 0 (zero) indicates the center of the sandbox.**

by two coders as in Experiment 1. The largest single deviation between the two coders was 1 inch. The mean deviation (absolute value) was .2 inches (*SD* = .21 inches). The on-line scorer's values were used in all statistical analyses.

*Experimental design.* Children were randomly assigned to one of four conditions. In all conditions, the A and B locations were separated by 8 inches; however, the positions of these locations in the sandbox varied (see Figure 4). In the first two conditions, the A and B locations were in the left half of the sandbox, with Location B at −10 inches and Location A varying across the two conditions. In the −18 condition, Location A was at −18 inches, and in the −2 condition, it was at −2 inches. In the third and fourth conditions, the A and B locations were in the right half of the sandbox, with Location B at 10 inches. Once again, the A location varied: In the +2 condition, Location A was at 2 inches; in the +18 condition, it was at 18 inches.

## Results and Discussion

As in Experiment 1, children's responses were very accurate on the A trials. This was the case across all four conditions, despite the fact that the absolute A location in the sandbox varied across 36 inches. Figure 4 shows children's errors on the A trials. In all conditions, these errors were less than 1 inch. A Condition (4) × Trial (3) ANOVA revealed no significant effects. Furthermore, *t* tests indicated that the errors on the A trials in each condition did not differ significantly from zero. Thus, three training trials to Location A appeared to eliminate the bias toward the center of the sandbox reported by Huttenlocher et al. (1994).

The critical question was how children would respond across conditions on the B trials. In all four conditions, children reached back toward Location A on these trials (see Figure 4). However, the magnitude of the error toward Location A depended on whether Location A was inside or outside Location B (i.e., toward the center of the sandbox or away from the center in relation to Location B). When Location A was outside Location B, children's biases toward the A location were smaller. A Condition (4) × Trial (2) ANOVA confirmed this effect: there was a significant main effect for Condition, $F(3, 24) = 38.21, p < .001$. No other effects were significant. Post hoc analyses, Tukeys honestly significant difference (HSD), $p < .01$, established that the magnitude of the error on the B trials was smaller when Location A was outside Location B. Nevertheless, follow-up *t* tests confirmed that the errors toward Location A in each condition differed significantly from zero, Condition −18: $t(6) = -2.32, p < .05$; Condition −2: $t(6) = 8.76, p < .001$; Condition +2: $t(6) = -10.46, p < .001$; Condition +18: $t(6) = 2.30, p < .05$. Thus, children's responses on the B trials were significantly biased toward Location A, but the magnitude of this bias varied systematically as a function of where A and B were located in the sandbox.

These data demonstrate that, following a short delay, children's memory of a single location is biased toward a location repeatedly moved to in the past. This bias remains even when the previously moved-to location is *away* from the center of the sandbox. Thus, data from the present experiment replicate the findings from Experiment 1 and support our proposal that A-not-B–type errors are the product of general processes that make goal-directed actions to remembered locations. Furthermore, the biases away from the center of the sandbox found in this experiment are the first such biases reported using the sandbox task. These biases suggest that factors other than the location of the center of the sandbox may have a profound influence on 2-year-olds' location memory.

In addition to being pulled toward a location repeatedly moved to in the past (i.e., Location A), children's responses were affected by a second factor—the pull toward the center of the sandbox reported by Huttenlocher et al. (1994). When these two factors were in the same direction in relation to Location B (Condition −2, Condition +2), children made large errors toward the A location. When these two factors were in opposite directions from Location B (Conditions −18, Condition +18), children made smaller errors toward Location A. These data indicate that both factors modulate children's memory responses, but the pull toward a previously moved-to location is stronger than the pull toward the center of the sandbox. This is informative because the majority of studies that have used the sandbox task have focused primarily on the bias toward the center of the sandbox, whereas the data from this study indicate that not only is children's memory for location in this task affected by other factors, but these other factors have a more dramatic effect on children's responses.

Nevertheless, there is an alternative interpretation of these results. As suggested by Huttenlocher et al. (1994), 2-year-olds may encode locations near to them differently from those that are far away. Specifically, when Location A is far away (±18 inches), children might encode Location A as being closer to the center of the sandbox than it actually is. If this were the case, Location B would be perceived as relatively close to Location A. Consequently, there might be a relatively small pull toward Location A. In contrast, when Location A is nearby (±2 inches), children might encode Location A and the distance between Locations A and B more accurately. With this greater perceived distance, there might be a stronger pull toward Location A and, consequently, larger errors on the B trials. Experiment 3 examined whether children show stronger biases toward A locations relatively near to where they are standing, regardless of whether these nearby locations are close to the center of the sandbox.

## EXPERIMENT 3

The primary goal of Experiment 3 was to test two alternative accounts of the differential pull toward Location A on the B trials in Experiment 2 when A was far from versus near the center of the sandbox. According to the first account, this effect was caused by the pull toward the center of the sandbox reported by Huttenlocher et al. (1994); according to the second account, the effect was caused by children's underestimation of distances far from where they were standing.

To test these alternative accounts, children's position relative to the A and B locations was manipulated. In the child–center conditions, children stood at the center of the sandbox, as in Experiments 1 and 2. In the child–side conditions, children stood halfway between Locations A and B, which were positioned in the left half or right half of the sandbox. If children's differential responses toward Location A are caused by a pull toward the center of the sandbox, then there should be no differences in the error toward the A location on the B trials across the child–center and child–side conditions. Alternatively, if children have a tendency to underestimate locations far away from them, and if this, in turn, causes a weaker pull toward Location A, then response biases toward Location A on the B trials should be weaker in the child–center condition than in the child–side condition.

Huttenlocher and colleagues (1994) used the child–center versus child–side manipulation to test whether the center bias they reported was due to underestimation effects. They found no significant effects for moving children away from the center, which suggests that the center bias was caused by how children use location cues such as the edges of the sandbox to remember locations over short-term delays. Although these results suggest that 2-year-olds do not underestimate distance of locations in the sandbox task, it is possible that the differential pull toward the A location in Experiment 2 was caused by underestimation effects, even though the bias toward the center, reported by Huttenlocher and colleagues, is not.

In addition to the primary goal of the present study, there were several secondary goals. In all conditions, Location A was at ±15 inches and Location B was at ±5 inches. Location A was positioned outside Location B in an attempt to replicate the bias away from the center of the sandbox demonstrated in Experiment 2. In addition, the B locations from Experiment 1 were used (±5 inches) to see if the bias toward the center of the sandbox reported in that experiment could be reversed. Positioning Location B close to the center of the sandbox also allowed us to test whether the pull toward the A location was consistently stronger than the bias toward the center of the sandbox. If children treat the sandbox as one category with a prototype at the center, then they might be less influenced by the pull toward Location A when Location B is near this prototypical location.

Finally, in the previous two experiments, we noticed that errors toward Location A tended to be smaller on the second versus the first B trial. Although this trend was not statistically significant, it is consistent with data showing that the pull toward Location A in the A-not-B task decreases with repeated reaches to Location B (Smith et al., 1999). Thus, in Experiment 3, we added a third B trial to see if the reduced pull toward Location A across the B trials would become statistically reliable.

### Method

*Participants.* Twenty-four 2-year-olds participated in this experiment ($M$ = 28.5 months, *range* = 24–31 months; 14 females, 10 males). Children were recruited from a participant database at Indiana University. All children were from middle-class, English-speaking families.

*Materials, procedure, and behavioral scoring.* The materials, procedure, and method used to score each child's responses were identical to those of Experiments 1 and 2. The largest single deviation between the two scorers was 1 inch. The mean deviation (absolute value) was .32 inches (*SD* = .29 inches). The on-line scorer's values were used in all statistical analyses.

*Experimental design.* Children were randomly assigned to one of four conditions in a full factorial design. In all conditions, the A and B locations were separated by 10 inches as in Experiment 1, but we varied where these locations were positioned in the sandbox. In half the conditions, Location A was at −15 inches and Location B was at −5 inches, while in the other half, Location A was at 15 inches and Location B was at 5 inches. We also varied where the children were positioned during the hiding events. Half the children were assigned to the child–center condition. These children stood at zero inches—the center of the sandbox. The remaining children were assigned to the child–side condition. These children stood 10 inches from the center of the sandbox (±10 inches), halfway between the A and B locations.

## Results and Discussion

In contrast to the results of Experiments 1 and 2, children made relatively large errors on the A trials in Experiment 3. These data are shown in Figure 5. When Location A was to the left of center (upper panel), children's mean error was 1.86 inches (*SD* = 3.37 inches); when Location A was to the right of center (lower panel), children's mean error was −2.41 inches (*SD* = 3.64 inches). These errors were toward the center of the sandbox at both A locations. Data from the A trials were analyzed in a Condition (child–center, child–side) × Location (±15 inches) × Trial (A1, A2) ANOVA. The analysis revealed a main effect for Location only, $F(1, 20) = 14.19$, $p < .001$. No other effects approached significance. Follow-up *t* tests confirmed that the errors on the A trials differed significantly from zero: Position −15, $t(11) = 2.56$, $p < .05$; Position 15, $t(11) = -2.76$, $p < .01$. Thus, these results replicated two effects reported in Huttenlocher et al. (1994): 2-year-olds' responses were biased toward the center of the sandbox, and this bias was not influenced by where children stood during hiding and search. In contrast to Experiments 1 and 2, children made relatively large errors on the A trials in Experiment 3 and their responses were more variable. It is not clear why children's responses differed across these experiments.

On the B trials, children's responses were pulled toward the A locations, even though the A locations were away from the center of the sandbox (Figure 5). When Location B was to the left of center, children's mean response error was −2.67 inches (*SD* = 3.11 inches), that is, toward the A location, and when B was to the right of center, the mean response error was 2.78 inches (*SD* = 4.30 inches), that is, again toward Location A. Data from the B trials were analyzed in a Condition (child–center, child–side) × Location (±5 inches) × Trial (B1, B2, B3) ANOVA. There was a significant main effect for location, $F(1, 20) = 20.21$, $p < .001$, indicating that children's responses were pulled toward Location A in the ±5-inch conditions. In addition, there was a significant Location × Trial interaction, $F(2, 40) = 7.79$, $p < .001$. The magnitude of children's errors toward Location A decreased across the three B trials when Location B was at −5 inches (B1: $M = -3.33$ inches, $SD = 2.77$ inches; B2: $M = -2.92$ inches, $SD = 2.75$ inches; B3: $M = 1.75$ inches, $SD = 3.74$ inches) and when Location B was at 5 inches (B1: $M = 5.17$ inches, $SD = 3.83$ inches; B2: $M = 2.33$ inches, $SD = 4.40$ inches; B3: $M = .83$ inches, $SD = 3.79$ inches). No other effects reached significance. Thus, children's response errors on both the A and B trials did not differ significantly depending on where they stood relative to the A and B locations.

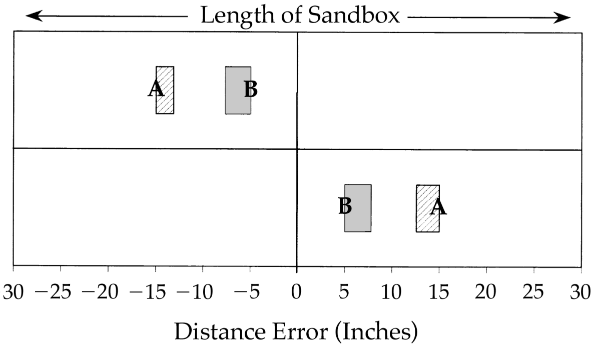

**Figure 5 Mean distance errors in Experiment 3 across the three A trials (striped bars) and three B trials (solid bars) for each layout of A and B locations. Positive scores indicate errors to the child's right; negative scores indicate errors to the child's left. The figure is scaled to the lateral dimensions of the sandbox (60 inches). Position 0 (zero) indicates the center of the sandbox.**

Results from the present experiment suggest that the differential pull toward Location A in Experiment 2 was not caused by children's underestimation of locations far from where they were standing. Instead, this differential pull was the result of two factors: children's responses were pulled toward a location repeatedly moved to in the past and toward the center of the sandbox. When these two factors competed (i.e., when Location A was outside Location B), 2-year-olds made 2- to 3-inch errors toward Location A on the B trials (see Figures 4 and 5). When these two factors cooperated (when Location A was inside Location B), 2-year-olds made 5- to 7-inch errors toward Location A on the B trials (see Figures 3 and 4). Data from Experiment 2 and Experiment 3 also demonstrate that the pull toward Location A on the B trials was consistently stronger than the center bias. Regardless of how close Location B was to the center of the sandbox, children erred toward Location A.

Finally, the reduction in error across the three B trials is consistent with data from Smith et al. (1999) showing that 8- to 10-month-olds are less likely to be pulled toward Location A in the A-not-B task once they have reached to B. These data emphasize the experience-dependent nature of location memory errors. On the first B trial—after reaching toward the A location six times—children's location memory is strongly biased toward location A. On the second B trial, this bias is weakened by the just-previous trial: having seen a toy hidden at Location B once before, and having reached toward Location B once before, children are more adept at overriding the pull toward Location A. On the third B trial, the bias toward Location A is weakened even more, and children's responses are much more accurate. It is important to note that the processes that underlie the reduction in error on the B trials are not specific to the B trials. These same general processes produce accurate searches to Location A following the three training trials.

## EXPERIMENT 4

In the previous three experiments, we established that, as predicted by the dynamic systems account of the Piagetian A-not-B error, 2-year-olds' location memory responses are biased toward a previously moved-to location in the sandbox task. The final two experiments tested two additional predictions of the dynamic systems account.

Recently, Smith and colleagues (1999) established that 8- to 10-month-old infants are more likely to make the A-not-B error as the number of repeated reaches to Location A increases (see also Marcovitch & Zelazo, 1999). This is in contrast to several reviews that have concluded that the likelihood of the error is not modified by the number of reaches to Location A (e.g., Butterworth, 1977; Wellman, Cross, & Bartsch, 1987). In Experiment 4, the generality of the Smith et al. results was tested. According to the dynamic systems account, infants are sensitive to repetition at the A location because with each hiding and finding event at Location A, the longer term memory of Location A becomes stronger. Consequently, there is a greater pull toward Location A on the B trials. If the buildup of strong location memories through repetition is a general process common to different periods of development and different tasks, then 2-year-olds should be influenced by the amount of repetition at Location A in the sandbox task.

In Experiment 4, the number of times 2-year-olds searched for toys at an A location was manipulated. All children completed three training trials at Location A as in Experiments 1 through 3. After training, one group of children completed one A trial (Condition 1A) before the B trials, while a second group completed three A trials (Condition 3A) as in Experiments 1 through 3. If the pull toward Location A observed in the previous experiments depends on the strength of the memory of the A location, and if the strength of this memory increases with repetition, then children in the 1A condition should show smaller biases toward Location A on the B trials than children in the 3A condition. All children completed three B trials as in Experiment 3. This allowed us to examine whether the reduced pull toward Location A across the B trials reported in Experiment 3 was a replicable effect.

### Method

*Participants.* Twelve children participated in this experiment ($M = 20.4$ months, *range* = 18–24 months; 6 females, 6 males). Children were recruited from a participant database at Indiana University. All children were from middle-class, English-speaking families.

*Materials and behavioral scoring.* The materials and the method used to score each child's responses were identical to those used in the previous experiments. The largest single deviation between the two scorers was 2 inches. The mean deviation (absolute value) was .5 inches ($SD = .39$ inches). The on-line scorer's values were used in all statistical analyses.

*Experimental design and procedure.* Children were randomly assigned to one of two conditions. Children in the 1A condition received three training trials as described in Experiment 1. The training trials were followed by one A trial and three B trials. Children in the 3A condition received the same training; however, training was followed by three A trials and three B trials. Because the primary concern in this study was how the relative pull toward Location A on the B trials changed across the 1A and 3A conditions, the A and B locations were counterbalanced across participants (rather than across conditions). For half the children in each condition, the A and B locations were in the left half of the sandbox (at −18 and −10 inches, respectively), and for the remaining half, the A and B locations were in the right half of the sandbox (at 10 and 18 inches, respectively). In addition, for half of the children in each condition, Location A was to the left of Location B (at −18 or 10 inches), and for the remaining half, Location A was to the right of Location B (at −10 or 18 inches). Finally, because it was observed in Experiment 3 that several children got tired of the task by the end of the third B trial, and given the primary interest in performance on the B trials in the present experiment, the delay on the A trials was eliminated. This shortened the task, making it a bit easier for the children to complete.

## Results and Discussion

Given that the absolute locations of A and B were counterbalanced across participants, modifications were made as to how errors were measured in the present experiment. Rather than measure the absolute direction of children's errors (i.e., toward the left or right edge of the sandbox), children's relative errors toward A were measured. Specifically, positive errors indicated an error in the direction of Location A relative to Location B. For example, if Location A was at −18 inches and Location B was at −10 inches, a positive error would be in the direction of A, that is, toward the left edge of the sandbox from the child's perspective. Alternatively, if Location A was at 18 inches and Location B was at 10 inches, a positive error would be in the direction of A, that is, toward the right edge of the sandbox.

Children in the 1A condition made larger errors on the A trial (*M* = −2.17 inches, *SD* = 2.56 inches) than did children in the 3A condition on three A trials (Trial A1: *M* = .5 inches, *SD* = .55 inches; Trial A2: *M* = .3 inches, *SD* = .52 inches; Trial A3: *M* = .3 inches, *SD* = .52 inches). The mean error on the A trial(s) is shown in Figure 6 for both conditions. Leftward errors in this figure indicate errors in the direction of Location A; rightward errors indicate errors in the direction of Location B. An independent-samples *t* test comparing performance on the first A trial (A1) across conditions revealed a small but statistically significant difference, $t(10) = 2.49$, $p < .05$. Similarly, there was a small but statistically significant difference in performance across conditions on the final A trial (Trial A1 in Condition 1A and Trial A3 in Condition 3A), $t(10) = 2.34$, $p < .05$. Next, we examined whether errors on the A trial(s) differed significantly from zero. This was not the case: A trial errors in the 1A condition, $t(5) = -2.07$, *ns;* A1 errors in the 3A condition, $t(5) = 2.24$, *ns;* A3 errors in the 3A condition, $t(5) = 1.58$, *ns*. Thus, although there was a small difference in performance on the A trial(s) across conditions, children were generally accurate on these trials, as in the previous experiments.

The critical question in this experiment was whether the different number of A trials across conditions would have an effect on the pull toward Location A on the B trials. As can be seen in the upper panel of Figure 6, children were not consistently pulled toward Location A on the B trials in the 1A condition. As in the previous experiments, however, children were reliably pulled toward Location A in the 3A condition (see Figure 6, lower panel). A two-way ANOVA with condition (2) and trials (3) as factors revealed a significant main effect for Condition, $F(1, 10) = 6.64$, $p < .05$, confirming that there was significantly less error toward Location A in the 1A condition. Follow-up *t* tests indicated that the small pull toward Location A on the B trials in the 1A condition did not differ significantly from zero, $t(17) = .41$, *ns*, but the bias toward Location A in the 3A condition did, $t(17) = 5.82$, $p < .001$. Finally, in addition to the effect for condition, there was a significant effect for trial, $F(2, 10) = 5.03$, $p < .05$. As in Experiment 3, there was a significant reduction in the pull toward Location A across the three B trials. This effect was particularly prominent in the 3A condition (B1: *M* = 6.00 inches, *SD* = 2.53 inches; B2: *M* = 5.83 inches, *SD* = 3.37 inches; B3: *M* = 1.50 inches, *SD* = 1.52 inches), but there was also a reduction in error in the 1A condition (B1: *M* = .33 inches, *SD* = 5.82 inches; B2: *M* = 2.30 inches, *SD* = 4.23 inches; B3: *M* = −1.30 inches, *SD* = 3.67 inches).

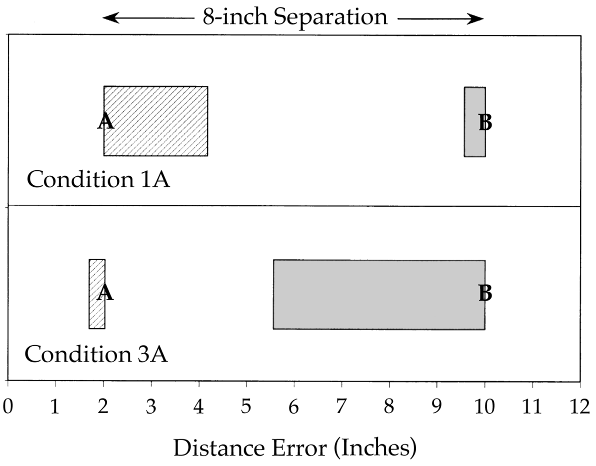

**Figure 6** **Mean distance errors in Experiment 4 across the three A trials (striped bars) and three B trials (solid bars) in the 1A condition (upper panel) and 3A condition (lower panel). The distance between Locations A and B is to scale (8 inches); however, the labels along the *x*-axis do not indicate the absolute locations of A and B in the sandbox because these locations were counterbalanced across conditions. Leftward errors indicate errors toward Location A; rightward errors indicate errors away from Location A.**

In summary, data from the present experiment demonstrated that the strength of the pull toward Location A reported in Experiments 1 through 3 depended on the number of reaches to the A location. Because 2-year-olds repeatedly observed hiding events at Location A and found a toy at this location, their memory of Location A became stronger and more accurate. Consequently, children's responses were more strongly biased toward Location A on the B trials. These results are consistent with data from Smith et al. (1999), which show that 8- to 10-month-old infants are sensitive to repetition at Location A in the A-not-B task. Thus, once again, the data reported here suggest that the processes that underlie location memory biases in the A-not-B task are not confined to one period in early development or to the canonical Piagetian A-not-B task.

## EXPERIMENT 5

The A-not-B task and the sandbox task used in Experiments 1 through 4 placed children in an odd situation. Children were confronted with a task space with few salient location cues, and they watched hiding events and found attractive toys at one location—the A location—many times before anything interesting happened elsewhere in the task space. This raises a fundamental question: were the location memory errors children made in these tasks quirky errors that occurred only after repeated reaching to the same hiding location? If so, this would place constraints on the generality of the processes central to the dynamic systems account. In Experiments 1 through 4, it was demonstrated that 2-year-olds made A-not-B–type errors in the sandbox task when the procedure mirrored what happens in the canonical A-not-B situation. Experiment 5 diverged from the canonical A-not-B procedure to test whether the pull toward Location A could be generalized to cases in which the A location was not fixed, but varied from trial to trial.

According to the dynamic systems account, children's longer term memory of the A location can be captured by distributions of "activation" centered at Location A, where activation indicates the likelihood that a child will search at any given location (see also Kopecz & Schöner, 1995; Schöner, Dose, & Engels, 1995; Thelen et al., 2001). For instance, in Figure 7A, the smallest distribution indicates how a child might represent a hiding and finding event at 10 inches (the A location). With repeated hiding and search events at Location A, the strength of activation increases such that by the final A trial, the child's longer term memory of the A location is quite strong. Consequently, there is a strong pull toward Location A on the B trials.

Given the graded nature of the memory of A proposed by the dynamic systems account, children should show a bias toward Location A on the B trials even when Location A is not fixed, but instead varies from trial to trial. Consider, for example, the following sequence of trials distributed around an average A location at 10 inches: T1 at 6 inches, T2 at 12 inches, T3 at 8 inches, A1 at 14 inches, and A2 at 10 inches. This

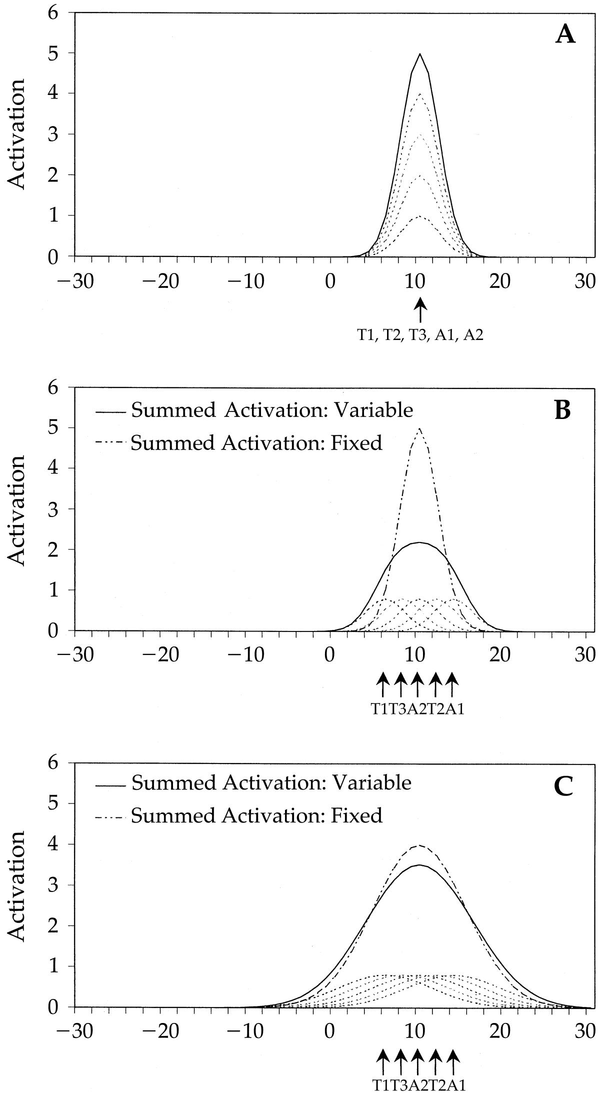

**Figure 7** (A) Buildup of activation in longer-term memory across three training trials (T1–3) and two A trials (A1 and A2) when toys were hidden at 10 inches. Solid line = activation at end of Trial A2. Arrow indicates hiding location. (B) Buildup of activation in longer-term memory when toys were hidden at variable locations (see arrows). Dotted lines = activation generated by each trial. Solid line = activation at end of Trial A2 with variable hiding locations. Dash-dot line = activation at end of Trial A2 with fixed hiding locations. (C) Same as (B), but activation generated by each hiding event (dotted lines) is more broadly distributed.

sequence is captured by the overlapping distributions in Figure 7B, each centered at a different target location. The resulting activation after the final A trial is represented by the solid line. For comparison, the dotted line shows the resultant activation when Location A is fixed. As can be seen in Figure 7B, the strength of the longer term memory of the average A location is weaker than in the fixed condition, but this activation may still be large enough to produce a bias toward Location A on the B trials. Indeed, if the memory of each location is even more broadly distributed, the pull toward the average A location may be rather strong. This is shown in Figure 7C. The overlapping distributions in this figure are centered at the same hiding locations as in Figure 7B. The only difference is that the memory of each location is distributed more broadly than in the middle panel. Consequently, the difference between the resulting activation after the final A trial in the fixed and variable conditions is less noticeable. Thus, the pull toward the average A location on the B trials would be comparable to the pull toward Location A in the fixed condition.

Experiment 5 examined if A-not-B–type errors generalize to conditions in which the A location is not fixed, but instead varies around an average A location. If the dynamic systems account is correct and children's memory of the A location is graded, then children should show a pull toward the average A location on the B trials in the variable A condition.

### Method

*Participants.* Sixteen children participated in this experiment ($M = 21.3$ months, *range* = 18–24 months; 8 females, 8 males). Children were recruited from a participant database at Indiana University. All children were from middle-class, English-speaking families.

*Materials and behavioral scoring.* The materials and the method used to score each child's responses were identical to the previous experiments. The largest single deviation between the two scorers was 1 inch. The mean deviation (absolute value) was .22 inches ($SD = .19$ inches). The on-line scorer's values were used in all statistical analyses.

*Experimental design and procedure.* Children were randomly assigned to one of two conditions—fixed A and variable A. The procedure in the fixed A condition was similar to that in Experiment 1. Children in this condition received three training trials at an A location, followed by two A trials and two B trials. As in Experiment 1, there was a 3-s delay on the A trials and a 10-s delay on the B trials. The A and B locations were counterbalanced, as in Experiment 4. For half the children, the A and B locations were in the left half of the sandbox (at −18 and −10 inches, respectively), and for the remaining half, the A and B locations were in the right half of the sandbox (at 10 and 18 inches, respectively). In addition, for half of the children, A was to the left of B (at −18 or 10 inches), and for the remaining half, A was to the right of B (at −10 or 18 inches).

The procedure used in the variable A condition was identical to that in the fixed A condition, with one exception: the hiding locations on the training and A trials varied around the average A locations used in the fixed A condition. Consider, for example, a participant in the fixed A condition with A at 10 inches and B at 18 inches. This child saw a toy being hidden first at 10 inches on three training trials (T1–T3), then at 10 inches on two A trials (A1 and A2), and, finally, at 18 inches on two B trials (B1 and B2). For a child in the variable A condition, with A at 10 inches and B at 18 inches, the toy was positioned at the following locations: T1, 6 inches; T2, 12 inches; T3, 8 inches; A1, 14 inches; A2, 10 inches; B1, 18 inches; and B2, 18 inches. Thus, the average hiding location across the training and A trials was 10 inches, and the hiding location on the B trials was 18 inches. It is important to note that the final A trial in the variable A condition was always at the average A location. Thus, participants in the fixed A and variable A conditions searched for toys at identical locations on the A2, B1, and B2 trials.

### Results and Discussion

Children's searches were relatively accurate on the A trials in both conditions (see Figure 8). It was somewhat surprising that children's mean accuracy on the A trials was greater in the variable A condition ($M = .19$ inches) than in the fixed A condition ($M = -1.38$ inches), but this effect must be considered in the context of the variability of children's responses in the two conditions. Children's responses varied much more in the variable A condition ($SD = 5.27$ inches) than in the fixed A condition ($SD = 2.06$ inches). A Condition (2) × Trial (2) ANOVA revealed no significant effects. Furthermore, a one-sample $t$ test indicated that errors in the variable A condition did not differ significantly from zero, $t(15) = .14$, *ns*. Nevertheless, errors in the fixed A condition did differ significantly from zero, $t(15) = -2.67$, $p < .05$. We examined whether individual children's errors on the A trials in the fixed A condition were biased toward the center of the sandbox. This was the case for only one child on one A trial.

On the B trials, children's responses in both conditions were strongly biased toward Location A, although there was a stronger pull toward Location A

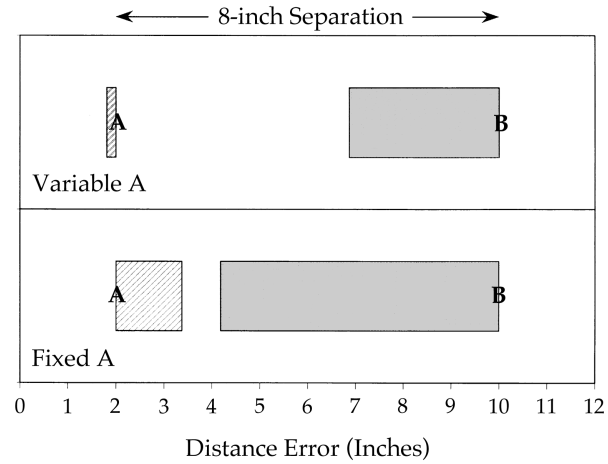

**Figure 8** Mean distance errors in Experiment 5 across the A trials (striped bars) and B trials (solid bars) in the Variable A condition (upper panel) and Fixed A condition (lower panel). The distance between Locations A and B is to scale (8 inches); however, the labels along the *x*-axis do not indicate the absolute locations of A and B in the sandbox because these locations were counterbalanced across conditions. Leftward errors indicate errors toward Location A; rightward errors indicate errors away from Location A.

in the fixed A condition (see Figure 8). An ANOVA with condition (2) and trial (2) as factors revealed no significant effects. However, *t* tests showed that the errors toward Location A on the B trials differed significantly from zero in both the fixed A, $t(15) = 4.92$, $p < .05$, and variable A conditions, $t(15) = 2.29$, $p < .05$. Thus, children's responses were biased strongly in the direction of Location A, even when the A location varied across an 8-inch region rather than being fixed.

Results from the present experiment are consistent with the proposal that young children's memory for each hiding location is not very precise. Instead, 2-year-olds' memory can be captured by graded distributions similar to the distributions depicted in Figure 7. Indeed, the lack of significant effects of condition on the B trials suggests that children's memory of each hiding event may be quite broadly distributed, as in Figure 7C. In this case, shifting the A location across an 8-inch spatial range has a quantitatively small effect on children's performance because their memories of each hiding event overlap considerably.

This result may provide an important bridge between the experiments reported here and other studies using the sandbox task. As discussed previously, Huttenlocher and colleagues (1994) reported that children's memory responses were biased toward the center of the sandbox when they searched for toys hidden at nine randomly ordered locations distributed throughout the sandbox. These researchers proposed that the center bias was caused by the way children categorized objects in the sandbox: children treated the sandbox as one large category with a spatial prototype at the center. However, Huttenlocher et al. have not explained why children categorize in this way, that is, they have not explained the origins of the spatial prototype.

The data from the present experiment suggest one possibility, namely, that the spatial prototype may emerge, in part, from children's trial-to-trial experience in the task. This possibility is depicted in Figure 9. Figure 9A shows the summed activation that would result if children's memory for locations in the sandbox task was broadly distributed (see also Figure 7C) and centered at the nine hiding locations used in Huttenlocher et al. (1994). As can be seen in this figure, there is stronger activation near the center of the sandbox than at the edges of the sandbox. Thus, on average, one might expect young children to show memory biases in the direction of the center. It is also clear from the broadly distributed summed activation in Figure 9A, however, that a center bias may not be precisely toward the center of the sandbox. Furthermore, data from the present experiment suggest that the presence of a center bias should depend on the specific sequence of trials each child experiences. For

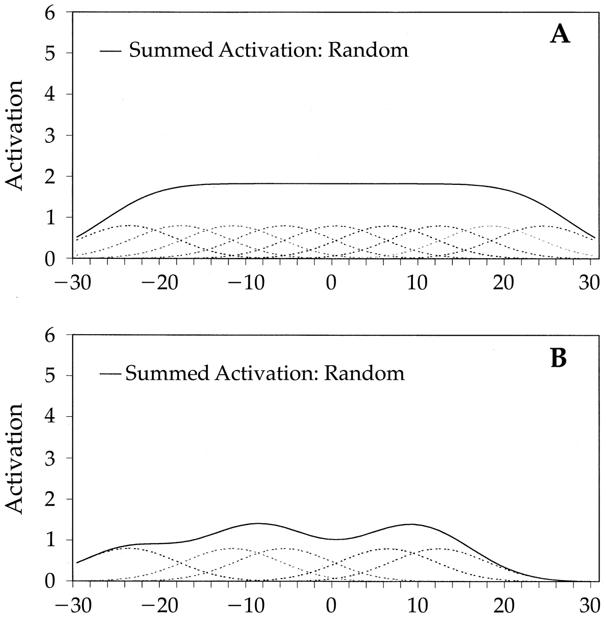

**Figure 9** (A) Activation in longer-term memory built up across trials to the nine hiding locations used in Huttenlocher et al. (1994). Dotted lines = activation generated by each trial. Solid line = activation at end of final trial. (B) Same as (A), but activation profile is shown following trials to five randomly selected hiding locations.

instance, Figure 9B shows the activation that might be observed following a sequence of five, randomly selected target locations. In this case, subtle variations in the summed activation across children could produce a noncentral bias. Across children with different random orderings, however, a noncentral bias might not be detected.

Although Huttenlocher and colleagues did not examine the possibility of trial-by-trial effects, their data do show the type of experiment-to-experiment variability that might be expected from the broad distribution of activation shown in Figure 9A. Specifically, across the first four experiments in Huttenlocher et al. (1994), children showed a bias toward the following locations (zero = center of the sandbox): 0 inches in Experiment 1; −6, 0, 6, 12, and 18 inches in Experiment 2; 0 and 6 inches in Experiment 3; and 0, 6, and 12 inches in Experiment 4. It is certainly possible that some of this variation is noise; however, this variation may also reflect the trial-by-trial construction of a memory bias as we have proposed here.

Although our account can capture data from Huttenlocher et al. (1994), it is important to note that this account is incomplete. Specifically, data from Experiment 2 of this article demonstrated that children's memory responses were modulated relative to the center of the sandbox. This may indicate that children use the geometry of the task space (e.g., the midline axis of the sandbox) to help them remember locations (Huttenlocher et al., 1991; Huttenlocher et al., 1994). Alternatively, this result could be explained by our dynamic systems account if it is assumed that children's memory of locations near the center is stronger because these locations are aligned with other visible reference cues such as the location of the experimenter (for related ideas, see Smith et al., 1999). Clearly, more investigation is needed to determine which of these accounts is correct. Nevertheless, the dynamic systems account described in this article illustrates a more general point: what infants do in the strange situation called the A-not-B task may be fundamentally related to what children do in other spatial memory tasks at other points in development.

## GENERAL DISCUSSION

Across the experiments presented in this report, we have established five novel results. First, after seeing and finding a toy hidden at an A location on three training trials and three subsequent A trials, 2-year-olds' search responses to a hiding event at a B location were biased in the direction of Location A. Thus, 2-year-olds made the A-not-B error. Second, in addition to the pull toward Location A, children's responses on the B trials were biased toward the center of the sandbox. This is congruous with data from Huttenlocher et al. (1994), although we did not see a consistent bias toward the center on the A trials. Third, the bias toward Location A was stronger than the bias toward the center of the sandbox, and neither effect was related to where children stood relative to the A and B locations. Fourth, the magnitude of the pull toward Location A depended on the number of times toys had been hidden at that location. Finally, the bias toward Location A remained even when the locations on the training trials and A trials were distributed over an 8-inch region. Thus, A-not-B–type errors in the sandbox task generalized to conditions in which the A locations are not identical.

These five results are consistent with the dynamic systems account of the A-not-B error proposed by Smith, Thelen, and colleagues (Smith et al., 1999; Thelen et al., 2001). According to this account, the A-not-B–type errors described in the present article resulted from four factors: the graded and time-dependent nature of spatial memory, the sequence of events in the task, the limited visible location cues in the task space, and the memory delay on the B trials. Specifically, on the first three training trials, children watched as an attractive toy was partially buried in the sand at an A location. Because visual cues specifying the toy's location were always present, these training trials helped establish a graded, yet relatively strong, longer term memory of the A location. Next, on the A trials, children watched as a toy was buried in the sand at the same (or a similar) location. In conjunction with the longer term memory of the target location, the hiding event at Location A formed a graded representation of the target location that decayed over the delay between hiding and searching. Nevertheless, given the extra boost from the longer term memory of the A location and the relatively short delays used (3 s), children once again accurately found the toy. Finally, after several trials to Location A, children watched as a toy was hidden at Location B. Once again, in the presence of perceptual input specifying the B location, children initially formed a strong, graded representation of the target location. Now, however, they were asked to remember this location for 10 s in the absence of salient visual cues. During the delay, the memory of the B location decayed, such that after 10 s had passed, the longer term memory of the A location biased children's responses in the direction of Location A.

In addition to accounting for the A-not-B–type effects in Experiments 1 through 3, the dynamic systems account captures results from the final two experiments. Data from Experiment 4 demonstrated that, as with 8- to 10-month-old infants in the A-not-B task (see Smith et al., 1999), the strength of the pull toward Location A for 2-year-olds in the sandbox task depended on the number of A trials, that is, the strength of the longer term memory of Location A. Data from Experiment 5 showed that 2-year-olds made A-not-B–type errors even when toys were hidden at variable A locations. This is consistent with the proposal that the memory of the A and B locations is graded and broadly distributed. Consequently, varying the A location had little effect on the pull toward Location A because the memories of the A hiding events overlapped considerably (see Figure 7C).

A final result from the present study—the bias toward the center of the sandbox—was not explicitly predicted by the dynamic systems account. Nevertheless, the center bias may be consistent with this account. As described previously, the bias toward the center of the sandbox may reflect the increased strength of the memory of the A location when A is near the center, because visible perceptual cues such as the location of the experimenter and the midline axis of the sandbox are aligned with this location. Thus, the center bias may reflect the same general processes that operate to reduce A-not-B errors in other tasks in which salient perceptual cues in the task space specify the hiding locations (e.g., Diedrich, Highlands, Thelen, & Smith, 2001).

In summary, the robust effects reported here support two general claims of the dynamic systems account. First, the A-not-B error is not specific to the canonical Piagetian A-not-B task, but is observable in other tasks as well. Second, the A-not-B error is not specific to one period in development, but instead reflects the more general processes that make goal-directed actions to remembered locations.

## Implications for Interpretations of the A-not-B Error

Some readers may be skeptical that our data show that 2-year-olds make the A-not-B error. After all, the sandbox task is quite different from the canonical A-not-B task, and 2-year-olds are certainly different from infants in many ways. Indeed, the task and age group in this study were selected for these very reasons. We contend, however, that these differences raise a fundamental question about the Piagetian A-not-B error: Is there some essence of the A-not-B error that uniquely informs researchers about the state of young children's knowledge of hidden objects?

A central premise of the dynamic systems account of the A-not-B error is that *there is no special essence to this error.* The error is multiply determined from processes that act in many situations across many different points in development. Consequently, there is not one special A-not-B task, nor is there one special age at which children make the error. Furthermore, because the error is made from a collection of general processes that produce goal-directed actions toward remembered locations, A-not-B–type errors do not uniquely inform researchers about the object concept (e.g., Munakata, 1998; Munakata et al., 1997; Piaget, 1954), the development of spatial coding (e.g., Acredolo, 1985; Bremner, 1978; Bremner & Bryant, 1977; Newcombe & Huttenlocher, 2000), or young children's ability to inhibit a prepotent response (e.g., Diamond, 1988, 1990a, 1990b; Diamond & Goldman-Rakic, 1989; Diamond, Zola-Morgan, & Squire, 1989). Instead, A-not-B–type errors, the conditions under which they occur, and how they change over development inform us about changes in the underlying processes that make the behavior. Thus, studies of A-not-B–type errors need a change in focus—away from what infants *know* about hidden objects toward what young children *do* in location memory tasks in different situations and at different points in development.

Although the present experiments have radical implications for interpretations of the A-not-B error, it is important to consider an alternative perspective: Can other accounts of the A-not-B error explain the data presented in this article? For instance, in Experiment 4, 2-year-olds made smaller A-not-B–type errors after only one A trial (versus three). These results are consistent—at least at a conceptual level—with a recent neural network model by Munakata (Munakata, 1998; Munakata et al., 1997). Specifically, manipulating the number of A trials can be thought of as changing the strength of a "latent" memory trace of the A location. Nevertheless, ties to the Munakata model must remain speculative because, in its current form, this model only represents three discrete locations. Thus, it does not consider activation across a continuous spatial dimension and, consequently, cannot account for changes in the magnitude of 2-year-olds' response errors between Locations A and B. At a more general level, however, it is important to emphasize that no single result is central to the dynamic systems account. It is equally important to capture changes in children's behavior when the strength of a location in memory is altered, when the perceptual cues available in a task are modified, and when the memory delay is manipulated. Thus, the critical question is whether other accounts can explain the full pattern of results reported here *and* the wide range of results reported in the A-not-B literature (see Smith et al., 1999; Thelen et al., 2001). The answer to this question awaits a more detailed presentation and extension of the alternative accounts.

## What Spatial Abilities Develop between 10 Months and 2 Years?

The experiments in this report represent a first step toward expanding our understanding of the processes that underlie A-not-B–type performance. In these initial tests of the dynamic systems account proposed by Smith, Thelen, and colleagues (Smith et al., 1999; Thelen et al., 2001), striking parallels were discovered between the performance of infants in the canonical Piagetian A-not-B task and that of 2-year-olds in the sandbox task, suggesting that the same general processes operate in different tasks at different points in development. A central question that remains is how these processes change between 10 months and 2 years.

Two-year-olds' location memory abilities are certainly different from the abilities of 10-month-old infants. In the present study, 2-year-olds were able, with training, to remember the A location precisely enough to find hidden toys in the absence of unique perceptual cues. Errors on the A trials in Experiments 1 through 5 differed significantly from zero in only two conditions. This high degree of accuracy exceeds the performance of 2-year-olds in other studies using the sandbox task (e.g., Huttenlocher et al., 1994; Newcombe et al., 1998), which supports the claim of the dynamic systems account that 2-year-olds build up a strong memory of the A location across the training and A trials. Two-year-olds' performance in this study contrasts sharply with infants' performance in the A-not-B task. Infants sometimes spontaneously reach for the incorrect lid on the A trials (Smith et al., 1999). Although 2-year-olds in the present study showed precise performance on the A trials, there were important limitations to this precision: children made large errors on the B trials, even when the A trials were distributed across a range of locations.

A second factor that clearly separates the performance of infants from that of young children in A-not-B–type tasks is young children's ability to maintain information over longer delays. Although delays on the B trials were not explicitly manipulated in the present study, data from other studies show that the ability to accurately maintain information in memory over short-term delays improves between 8 months and 16 months (Brody, 1981; Diamond & Doar, 1989). In the present report, a relatively long delay (10 s) was used to challenge 2-year-olds' memory abilities. We suspect, however, that young children would show A-not-B–type errors at even shorter delays in the sandbox task given the homogeneity of the visual field. Consistent with this proposal, Schutte and Spencer (in press) recently found that 3-year-olds make A-not-B–type errors in a task quite similar to the sandbox task. It is notable that 3-year-olds' errors increase systematically over delays of 0 to 10 s, and are present at delays as short as 5 s. These data underscore the context- and time-dependent nature of A-not-B–type errors and the temporal continuity of the processes that produce them.

The homogeneity of the task space is certainly an important component of A-not-B–type errors. For instance, Diedrich and colleagues (2001) showed that 8- to 10-month-old infants make the A-not-B error less often if the lids covering the A and B wells are different colors. It is possible that the addition of less dramatic visual cues would influence 2-year-olds' performance in the sandbox task used here. Consistent with this proposal, Newcombe et al. (1998) found that 22- to 36-month-old children remembered the locations of hidden toys in the sandbox more accurately when external landmarks were present than when curtains blocked their view of these landmarks. Similarly, we suspect that changes in young children's ability to selectively direct visual attention will lead to developmental differences in performance on A-not-B–type tasks. For example, Smith et al. (1999) showed that the occurrence of the A-not-B error in 8- to 10-month-old infants was affected by the direction of their visual gaze during the delay between hiding and searching. This does not have a dramatic impact on 2-year-olds' performance in the sandbox task. In the present study, as in other sandbox-task studies (Huttenlocher et al., 1994; Newcombe et al., 1998), we made sure that 2-year-olds looked up from the sandbox during the delay. Despite our distraction techniques, however, children were still quite accurate on the A trials.

Finally, between 10 months and 2 years, children's memory for locations becomes more resilient in response to shifts in body position and visual perspective. Smith et al. (1999) reported that 8- to 10-month-old infants' memory of the A location was linked to an egocentric body position, such that standing infants up on the B trial reduced the occurrence of the A-not-B error (for related results, see Diedrich, Thelen, Smith, & Corbetta, 2000). By contrast, Newcombe et al. (1998) showed that 16- to 36-month-olds can find a hidden toy in the sandbox, even when the children were moved to the opposite side of the sandbox after the hiding event. In this case, accuracy declines, but it is still better than chance. These data raise important questions about the nature of the information infants and young children remember in these tasks. At some point in early childhood, memory for locations becomes less bound to the specific actions needed to move to the target location and more strongly linked to external location cues.

In summary, although a link between the spatial memory abilities of infants and 2-year-old children has been demonstrated, there are clearly important developmental changes that take place between 10 months and 2 years. A fundamental question that remains is how these developmental changes occur. Thelen et al. (2001) outlined one possibility that stems from the dynamic systems account of the A-not-B error. They demonstrated that changes in excitatory connections in the action planning field can lead to changes in infants' ability to sustain location information in memory during long delays, even in the absence of salient perceptual cues. Thus, changes in young children's ability to sustain location-related information in working memory may underlie developmental changes between 10 months and 2 years. It is important to note, however, that there are many ways to enhance excitatory connections in the dynamic systems account. This can be accomplished by changes in the strength of perceptual inputs via perceptual learning, changes in attention that sharpens localized peaks of activation, or changes in the intrinsic dynamics of working memory itself. Thus, once again, changes in excitatory connections are just one piece of a general processes account. Clearly, further specification of these ideas is needed. The data presented here are an important first step in this direction in that they bridge the gap between the performance of infants in the A-not-B task and the performance of older children in a different task.

## CONCLUSIONS

The Piagetian A-not-B error has captivated developmental psychologists for decades. Researchers have examined the ages at which the error occurs, the delays at which it occurs, how perceptual cues modify the error, how the error relates to changes in motor skill, and so on. Nevertheless, after decades of research, it is still not clear what the error means—what mysteries of early development it uniquely explains. The dynamic systems account of the A-not-B error tested in this article seeks not to isolate the meaning of the error, but to integrate the error with what is currently known about the general processes that make goal-directed actions to remembered locations. From this perspective, the A-not-B error is not special. It is one of a class of spatial memory errors that children make in different contexts and at different points in development. Indeed, recent data demonstrate that even adults show memory biases similar to the biases reported here when they are asked to remember a location in a homogeneous task space for delays ranging from 5 to 20 s (Spencer & Hund, in press). Results such as these demand a change in focus away from what 8- to 10-month-old infants know as revealed in a decades-old task, to how the general processes that build memories for locations operate in different contexts and change over development.

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