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13th October 1999

Revised: 5th July 2000

Running Head: Spatial cues in the AB task.

Keywords: object permanence, A-not-B error, spatial coding, motor history.

The effect of spatial cues on infants' responses in the AB task, with and without a hidden object.

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Abstract

The errors made by infants in the AB task were taken by Piaget (1954) as an indication of an inability to update their representations of the spatial location of a hidden object. This paper presents an experiment designed to further investigate the role of spatial representations in the production of the error. The introduction of strong visual cues to spatial location was found to reduce the traditional A-not-B search error. However, it also increased perseveration when a 'lids-only' analogue of the AB task was used, in which infants are simply cued to pick up lids, rather than encouraged to search for a hidden object. These results present a challenge to the dynamic systems account of the error given by Smith, Thelen, Titzer, and McLin (1999), and indicate that the traditional A-not-B search error arises from a difficulty in updating representations of the spatial location of hidden objects. The relation of these results to Munakata's (1998) PDP model, and Thelen, Schöner, Scheier, and Smith's (in press) most recent dynamic systems model of the A-not-B error is also discussed.

The effect of spatial cues on infants' responses in the AB task, with and without a hidden object.

After a period of relative quiet, interest in Piaget's A-not-B error (1954) has re-emerged, and further challenges have been levelled at his analysis of the error in terms of the development of the object concept. The A-not-B error, since Piaget, has had many interpretations, and there has been a plethora of different experimental manipulations of the effect (eg. Butterworth, 1977; Cummings and Bjork, 1983; Bremner, 1985; Diamond, 1985; Harris, 1989).

In the traditional AB task the infant observes an experimenter hiding an object at two different locations, first at A and then at B. When allowed to search for the object, a 9-month-old infant will typically search at the hiding place that was used first (A), even when she has seen the object hidden at the other location (B). Piaget originally interpreted this result as being due to infants' incomplete understanding of reality, specifically in relation to their 'object concept'. The error arises at stage four of Piaget's sensori-motor period. Piaget's view was that, while infants at this stage search for objects once they are no longer directly visible, the existence of the hidden object is still tied to their action in retrieving it from one location in space, and thus their object concept is not fully objective. Thus, when the object's location changes, the infants make errors.

A recent explanation of the error comes from Smith, McLin, Titzer and Thelen (1995), and Smith, Thelen, Titzer and McLin (1999). These two papers argue that, in a dynamic systems approach to development, the error can be explained as perseveration due to the establishment of a repeated action. As such, the error is the result of motor history. Quoted in Munakata (1997), Smith et al (1995) claim that:

> 'The theoretical question to be answered then is not one about hidden objects but one about reaching....(T)he A-not-B error is not about hidden objects and not about infants' representations of objects.'

Smith et al (1999) suggest that the error arises because:

> 'The system that creates a reach remembers its own previous activity and so reach direction is always a combination of the current input and memories of just previous reaches.'

This is said to be the basis of the strongly perseverant goal directed reaching. They provide evidence for this theory, by showing that the perseverant error occurs even when there are no objects present, and infants are simply prompted to pick up the lids by the experimenter. In this way Smith et al (1999) question the need to appeal to the object concept as a knowledge structure. Knowledge, in their terms, is embodied as the system dynamics of action in, and on, the world.

However, some criticism has been levelled at this approach. In particular, Munakata (1997) has attempted to show that, while the error seems to be manifested in both 'hidden-object' and 'lids-only' versions of the AB task, these two tasks are in fact represented differently by the infant. In her first experiment, Munakata (1997), after 'lids-only' A-trials for all subjects, introduced an object on B-trials for half the subjects. She found that while the A-not-B error does occur in the 'lids-only' condition, it does not occur in the 'hidden-object' condition. In order to test whether this effect is due merely to the novelty of the object on B-trials Munakata conducted a second experiment in which hidden objects were used on all A-trials but removed on B-trials for half the participants. In this case the error occurs in both conditions. Munakata proposed that the reduction of the error in the object condition of the first experiment shows that hidden objects and lids alone are represented in different ways.

The distinction between objects and lids is maintained in Munakata's (1998) PDP model of the A-not-B error. In this model B-trials are active traces competing against latent weight changes set up by the A-trials. However, both the active and latent traces are proposed to be weaker when lids alone are used. Thus, in the object condition of her first (1997) experiment:

> '...strong activations at B compete against weak weight changes toward A.' (Munakata, 1998).

However, it can be argued that the introduction of an object is much more distracting than the removal of an object, and thus the two are not synonymous. So the reduction of errors in Munakata's first experiment (Munakata, 1997) may be due to the distracting influence of the introduction of an object, rather than to infants' distinct representations of hidden objects and visible cued lids. In this way performance may be constrained by memory.

An experiment is needed to clarify whether or not objects have a different role in the A-not-B error than lids alone. The current study attempts to do this by investigating whether more distinctive markers for the A and B locations have a differential effect on infants' responses to the 'lids-only' and 'hidden-object' versions of the AB task.

Previous spatial manipulations of the task have shown that although infants fall back on previous-response-based egocentric locations in the AB task (Bremner and Bryant, 1977), they can be nudged into updating the spatiotemporal identity of an object by making a visual distinction between the hiding covers (Bremner, 1978; Butterworth, Jarrett and Hicks, 1983). Butterworth et al (1983) explain the error in terms of infants' difficulties in following the spatial transplantation of the object. In this way, the identity of the hidden object is inextricably linked to its location in a stable spatial framework. Recent evidence supporting the possibility that hidden object's identities are defined more by their spatiotemporal characteristics than by their shape, size, and colour, has been offered by Newcombe, Huttenlocher, Learmonth and Wiley (1997). They show that while 5-month-olds seem to be able to detect spatial violations of an object hidden in a continuous array (a sand pit), they do not react to object violations (i.e. if the wrong object emerges from the hiding place) when the spatial location of the object remains constant. If hidden objects are individuated more strongly by their spatiotemporal characteristics, it may be hypothesised that the introduction of salient spatial cues will reduce errors in the 'hidden-object' task, more than in the 'lids-only' task.

An experiment was designed to compare the effects of salient cues to location on both types of AB task. Two 'cover' groups were assigned either 'different' or 'same' lids. Each subject performed both types of 'task' ('lids-only' and 'hidden-object'), the order of which was counterbalanced. We decided to hide an object in all trials of the 'hidden-object' condition, in order to avoid distracting the infant by introducing a novel toy.

There is a complication in using distinctive covers to sway infants towards updating the spatiotemporal identity of a hidden object. Bremner (1978) found that distinctive covers only increased success in the AB task if the infants were moved round the hiding apparatus to the other side, making the external frame of reference even more salient. However, Butterworth et al (1983) found that distinguishing covers increased success even when the child was left stationary throughout the procedure. These results may be due to Butterworth et al (1983) having only used two A-trials while Bremner (1978) used five. Larger numbers of A-trials have since been found to affect the frequency of the error in a recent meta-analysis of AB studies (Marcovitch and Zelazo, 1999). As a standard task with no infant movement and a fairly large number of A-trials was needed for more direct comparison with Munakata (1997), we decided to make the covers as distinctive as possible in order to enhance the chances of a reduction in error.

Method

Design

There were two between-subjects 'cover' groups. One group used the 'same' lids and the other used the 'different' lids. Each child was tested on two task blocks; either 'hidden-object' or 'lids-only'. Each task block contained a maximum of 6 pre-trials, 2 A-trials and a maximum of 5 B-trials. Order of task blocks was counterbalanced across subjects. Between each task block the location of the A position was changed to the other well. First task block A position and the location of each lid in the 'different' covers group were counterbalanced across subjects. The location of the lids remained the same for the second task block. Table 1 shows how order and orientation factors were controlled by assigning participants to twelve counterbalanced groups.

Table 1 about here

Participants

Data were collected from 28 infants with a mean age of 10 months 13 days (+/- 24.5 days). Eleven were female and 17 were male. Another two infants were visited, but one was distracted by the brightly coloured lids, and the other by a sibling (both were in the 'different' group). Seven infants produced data only for the first block of trials (two belonged to the 'different' group and five to the 'same' group). Of these seven, six cases occurred when the 'lids-only' task block was second (five infants lost interest and one was distracted by the arrival of his sibling during the second task block), and one case occurred when the 'hidden toy' task block was second (the infant lost interest).

The infants who took part lived in the immediate vicinity of Oxford or Lancaster. Names were taken from the Oxford and Lancaster psychology departments' infant subject pools. It was arranged to visit the infants at home, and testing was carried out there.

Apparatus

As far as possible the same apparatus as Munakata's (1997) was used. The hiding location apparatus was a black, plywood box of dimensions 28.5cm x 22.5cm x 7cm (width, length and height relative to the infant, respectively). Two square wells of length and width 9cm, and depth 4cm, were centrally placed in the box, with their centres 14cm apart.

Two pairs of plywood lids were made for the wells. The first pair were the same: square (10cm x 10cm) with a 3cm high yellow hourglass-shaped knob on each. Both displayed a pattern that consisted of a thin yellow diagonal cross set on a blue background. The second pair was distinct in colour, shape and pattern. One was square (10.5cm x 10.5cm) and had the same pattern and knob as above (SLid). The other 'different' lid was circular (13cm in diameter), had a blue 3cm high knob, and displayed a pattern that consisted of a thin blue horizontal-vertical cross on a yellow background (CLid). All the lids had square 9cm cork spacers on their undersides, so that they remained accurately positioned on top of the wells when put in place. The square lids were positioned so that their sides were parallel with those of the box.

The object used in the 'hidden-object' block came from a selection of toys which consisted of: a set of shiny keys, a yellow toy car, a yellow stickle brick, a wind-up paddling duck, and a wooden toy house with a green roof. The equipment was all transported to the infants' houses, where the experiment was conducted over a table with the experimenter seated at one side and the infant seated, on a parent's lap, at the opposite side.

Procedure

Familiarisation. The infants were first given enough time to become relatively familiar with the box, and the lids. In the case of the ‘hidden-object’ task the infant was then presented with an array of toys (specified above). The toy that he or she showed most interest in was used as the hidden object. In the second task block no familiarisation was needed.

Pre-trials. In ‘hidden-object’ task blocks, the preferred toy was waved in the air above the box, which was held beyond the infant’s reaching distance, while the experimenter called the infant’s name. Once the infant’s eyes fixated the object it was lowered into the A-well. The A-well was only covered if the infant’s eyes followed the toy to rest. If not, the process was repeated again until the infant’s eyes did follow the toy to rest[1]. In the ‘lids-only’ task blocks, the same procedure was undertaken, except a lid was waved and not a toy. In this case, the infant had to fixate the lid, both when waved and when at rest, if he was to be allowed to reach.

Once the well was covered and the infant had followed the toy or lid to rest, the box was immediately put within reaching distance. If the infant failed to retrieve the lid within 15 seconds the whole procedure was repeated. If the infant uncovered a hidden object then she was allowed to reach, and play with it for a short time[2]. If an incorrect uncovering occurred, then the box was removed from reach. Pre-trials were repeated until the infant had successfully uncovered the A-well on four consecutive occasions, or a maximum of six pre-trials (in which the infant had uncovered either well) had been reached. The B-well was covered by the other lid throughout all of these trials, unless the infant was unsuccessful on his/her first and second pre-trial, in which case the B-lid was removed for one pre-trial[3].

A-trials. The A-trials were the same as the pre-trials, except that there was a delay of 5 seconds between covering the well and allowing the infant to reach. There were two compulsory A-trials, from which accuracy was scored.

B-trials. The B-trials were exactly the same as the A-trials except the B-well was used. There were two compulsory B-trials from which accuracy was scored. There was also a maximum of three more B-trials that took place if the infant had failed to uncover the B-well on both compulsory trials. Trials were stopped if the infant reached correctly. The number of extra trials that an infant needed before she uncovered correctly was scored as an error measure.

Coding

Infants' responses were scored for accuracy in the compulsory A- and B-trials. 0 points were awarded for an incorrect uncovering, 1 point was awarded for uncovering both lids simultaneously, and 2 points were awarded for a correct uncovering only. Scores were added for each trial group, so subjects received an accuracy score out of 4 for both A- and B-trials. Subjects were also given an error score out of 3 for the number of extra B-trials that they required before uncovering the B-well. The number of reaches to both locations on A- and B-trials was also recorded so that a complete record of infants' motor history was available.

Predictions based on the hypothesis were: i) Accuracy scores will be higher in the 'different' covers condition, but only in the 'hidden-object' task. This difference in accuracy will be more noticeable in the B-trials than the A-trials, thus reducing the error. ii) Extra B-trials required before a correct uncovering will be fewer in the 'different' covers condition, but only in the 'hidden-object' task. We anticipate making a priori comparisons specific to these predictions.

Results

On inspection of the accuracy means (see table 2) the use of distinctive covers in the 'hidden-object' version of the task appears to produce a increase in accuracy on B-trials, whereas in the 'lids-only' task there seems to be a decrease in accuracy from A- to B-trials (an A-not-B error) whether the covers are 'different' or 'same'. In the 'hidden-object' task the number of extra B-trials needed is smaller in the 'different' cover group than in the 'same' cover group. However, in the 'lids-only' task the 'different' covers group has a larger number of extra B-trials than the 'same' covers group (see table 3).

Table 2 about here

Accuracy measure. A repeated measures ANOVA of two within-subjects variables (task type (hidden-object/lids-only) and trial (A/B)), and two between subjects variables (cover type and order of task blocks) was carried out[4]. The effects of trial (within task blocks), and task type, and covers (between task blocks) were examined using a priori comparisons also, as the effects of these variables are relevant to our predictions. There were two main effects, and two second-order interactions: i) A difference in accuracy between trial type (A or B), regardless of cover type or task type variables, demonstrating the A-not-B error, ($F=19.7$; $df=1, 17$; $p=0.001$). ii) A difference in general accuracy between task type. The 'hidden-object' task encouraged more accuracy than 'lids-only'. This suggests perhaps that there was more interest in the 'hidden-object' task, ($F=9.343$; $df=1, 17$; $p=0.008$). iii) An interaction between task, trial and covers ($F=5.2$; $df=1, 17$; $p=0.04$) indicated a differential effect of the different covers on the accuracy between the two task types. This interaction is explored more fully below using a priori comparisons. iv) An interaction between task, trial and order that indicated greater accuracy at A on the second task block regardless of whether the subject was searching for a hidden object or reaching for a lid only, ($F=5.188$; $df=1, 17$; $p=0.04$).

A priori comparisons, revealed that A- and B-trial differences are significant in the case of: i) 'hidden-object' with 'same' covers ($t=4.82$, $df=17$, one-tailed $p<0.0001$), (this replicates the traditional error), ii) 'lids-only' with 'same' covers ($t=2.55$, $df=17$, one-tailed $p=0.01$), (this replicates Smith et al's (1999) findings), and iii) 'lids-only' with 'different' covers ($t=3.99$, $df=17$, one-tailed $p=0.0005$). A significant difference was also found between accuracy on B-trials for 'hidden-object' task with 'different' covers, and accuracy on B-trials for 'lids-only' task with 'different' covers ($t=5.94$, $df=17$, two-tailed $p<0.0001$). There was also a significant difference between accuracy on B-trials for 'hidden-object' task with 'same' covers and accuracy on B-trials for a 'hidden-object' task with 'different' covers ($t=2.43$, $df=17$, two-tailed $p=0.03$). Thus, it seems that the only case in which 'different' covers reduce the difference in accuracy, is in a 'hidden-object' version of the task.

Extra B-trials measure. A separate analysis was made of the number of extra B-trials infants required in each task block before they made a correct uncovering. A repeated-measures ANOVA of one within-subjects factor (task type) and two between-subjects factors (cover group, and order) revealed a significant effect of task type ($F=5.244$, $df=1,17$, $p=0.04$). An interaction was also observed between task type and cover group ($F=7.985$, $df=1,17$, $p=0.01$). A priori comparisons reveal a significant effect of cover group in 'hidden-object' ($t=2.6$, $df=17$, $p=0.02$), and 'lids-only' ($t=2.3$, $df=17$, $p=0.03$) versions of the task. There is also a significant effect of task type in the 'different' cover group ($t=3.52$, $df=17$, $p=0.003$). However, this is not the case in the 'same' cover group ($t=0.62$, $df=17$, $p=0.54$). Thus, 'different' covers, as well as having an effect on infants' responses in the 'hidden-object' task (as was observed in the accuracy analysis), also have an effect on infants' responses in the 'lids-only' task. However, looking at the means in table 3, the number of responses to A on extra B-trials of the ‘lids-only’ task appears to be increased by ‘different’ covers, rather than decreased as is the case in the ‘hidden-object’ task.

Table 3 about here

Full details of reaching history. As motor history is important to the dynamic systems account of the error, full details of the infants reaching history were recorded[5, 6].

Table 4 about here

As Smith et al (1999) and Thelen et al's (in press) account of the error explains perseveration in terms of the motor history, it is appropriate to examine whether the accuracy on B-trials in each condition is reflected in the prior number of reaches to B on A-trials. Table 4 demonstrates that the mean number of reaches to B on A-trials in each condition did not follow a pattern consistent with the measures reported above. A repeated-measures ANOVA of one within-subjects factor (task type (hidden-object/lids-only) and two between-subjects variables (cover type and order of task blocks) was conducted on the number of reaches to B on A-trials. There were no significant main effects and the interaction between task type and cover group ($F=2.81$; $df=1,17$; $p=0.1$) was not significant either.

Discussion

These results demonstrate that strong spatial cues allow infants to update the location in which they search for a hidden object, even if there is a large number of trials at A. Also, a significant difference is revealed between performance on AB tasks, with and without a hidden toy. The presence of strong spatial cues seems to tease out this difference as there were no extra B-trial errors at all in a 'hidden-object' task, while A-not-B errors did occur significantly in a 'lids-only' task. Our prediction that spatial cues would reduce error in a 'hidden-object' task has thus been supported. Spatial cues did not however reduce the error in the 'lids-only' task, in fact the presence of 'different' covers encouraged significantly more extra B-trial errors, than if 'same' covers were used. This is an interesting finding that we will unpack later in this discussion. Our results provide overall support for Munakata's (1997) hypothesis, which suggests that infants represent lids differently when there are hidden toys beneath in the AB task. It seems that even though the error can occur without the presence of a hidden toy, there is more to explain than just infants' perseverant responses to visual targets.

While our results support Munakata's (1997) proposal that hidden objects and lids only are represented differently by infants performing the AB task, they are not fully in concordance with Munakata's (1998) PDP model of the error. This PDP model proposes that distinct covers reduce the error on B-trials by weakening the infants attention to the A-trials, thus producing a smaller than usual pre-potent response to A. As 'lids-only' trials are suggested to produce weaker weight changes than 'hidden-object' trials, the model predicts that error would be reduced on B-trials in a 'lids-only' task also. This prediction is not borne out by the results reported above, as 'different' covers are shown to encourage *more* perseverant errors in a 'lids-only' task.

Munakata's (1998) account of the error bears a resemblance to a more recent dynamical systems account of the error (Thelen, Schöner, Scheier and Smith; in press), in which hidden objects are described in the model as a transient salient cue for picking up a lid. In this way any difference in performance between 'hidden-object' and 'lids-only' tasks is explained by suggesting that infants are drawn towards the strong transient input of a toy on B-trials[7]. Our results demonstrate that when 'different' covers are present, accuracy on B-trials is significantly greater in a 'hidden-object' task than in a 'lids-only' task, whereas on A-trials there is no such difference; the means are 3.0 and 3.1 respectively. Also, no significant difference is found between the number of reaches to B on A-trials in a 'lids-only' task and a 'hidden-object' task. We cannot derive any strong conclusions from these null findings, but it does seem that hidden objects have their effect on the task mainly during B-trials. This is in line with the model of Thelen et al (in press) which predicts that when salient transient cues are strong enough at B on B-trials they will overcome any memory that they have already set up at A on A-trials. Thus, in explaining our results the dynamical systems account would suggest that the inclusion of distinctive lids allows the salient transient cue (the toy) to cue more reaches to B on B-trials. Whereas, without the salient transient cue of a toy, the infants are less likely to overcome the memory they have already set up at A on A-trials. However, Thelen et al (in press), like Munakata (1998) describe the role of distinctive targets to be in inducing more spontaneous reaches to B on A-trials, thus increasing the likelihood of a reach to B on B-trials. Firstly, there is no evidence above to suggest that reaches on A-trials are affected by distinctive covers in this way, and secondly this position cannot explain why distinctive covers might *strengthen* perseveration in a 'lids-only' task, as is found here.

Our explanation of the above results appeals to differing motivations of the infants in the separate task conditions. This explanation suggests that these differences between 'hidden-object' and 'lids-only' tasks are brought out when strong spatial cues are introduced to disambiguate the hiding places and allow infants to base their actions upon more salient visual targets. In the 'hidden-object' task the spatial disambiguation decreases infants' perseveration to A by providing a reference with which to update their representations of the spatiotemporal identity of the hidden object. However, spatial disambiguation has a different effect in a 'lids-only' task. The presence of 'different' covers produces an increase in the number of perseverant responses to A on B-trials. Why might this be?: If an infant is searching for a toy, spatial disambiguation may permit her to follow and locate this object when allowed to search. However, if the infant is less motivated to follow any change of location (in this case the change being which lid the experimenter waves), any perseverant habit that he is led into may be strengthened by the salient spatial cues[8]. Considering the two tasks, the goals should be much clearer in the 'hidden-object' version, in which there is only one correct response for finding the toy, compared to the 'lids-only' version in which a response to any lid might be thought of as correct. Indeed, when observing the infants' responses to the tasks it seems apparent that there is much less of an inclination to respond accurately when no object is hidden. This conclusion is supported by the significant difference in accuracy between all trials (A- and B-) involving 'lids-only', and all trials involving a 'hidden-object'. The number of infants who dropped out when the 'lids-only' task occurred in the second block tells a similar story.

Our explanation does not exclude perseverant motor habits from having a role in the A-not-B error. However, it does suggest that, in order to understand the reasons behind the 'hidden-object' A-not-B error, we have to consider why infants fail to find the object they are looking for, rather than just: why they fall back on a perseverant response, and how that perseverant response is established. When distinctive covers are used, the 'lids-only' task allows a perseverant motor response to be set up with little distraction, while in the 'hidden-object' task infants successfully update the location of an object which infants searching under same covers were unable to find. A failure to update the object's location leads these infants to search for a solution in a perseverant response. As distinguishing the covers reduces the error in a 'hidden-object' task, it would seem that the main problem that infants face in following the transplantation of the toy on B-trials is solved by clarifying the spatial framework within which the toy is hidden, providing salient landmark cues with which to identify the location of the object.

A word or two is needed to explain why we have made certain decisions in our method. There have been various differences between the method used in our study and those used by Smith et al (1999), and Munakata (1997). Footnotes 2, and 3 show that our procedure attempts as much as possible to reduce the opportunities for distracting the infant from searching for the hidden object. Infants are familiarised to the hiding apparatus before testing occurs, and every attempt is made to interest the infants in searching for the hidden object, rather than in the action of reaching itself. Some might criticise us for muddying the issue, when what is needed to solve the problem of why the A-not-B error occurs, is a standardised approach to methodology. However, our suspicion is that a dynamical systems account will be able to explain all findings in terms of motor-history and specific transient input as long as the hidden object is given a subsidiary role and the task situation itself is emphasised. If the hidden object is given more importance relative to the other apparatus, and the task demands, infants will have more desire to actively search for it when it is introduced. Our prediction is that under such circumstances the pattern of results will demonstrate a reduced role of motor history in the production or reduction of the A-not-B error.

To conclude, Piaget's (1954) original explanation of the A-not-B error was concerned with how infants' 'object-concepts' are limited. The dynamic systems account of the error favours a description in terms of the motor-habits that infants set up towards visual targets (Smith et al, 1995, 1999). The results of the current investigation demonstrate a difference in infants' responses in 'hidden-object' and 'lids-only' versions of the task suggesting that their representations of hidden objects do matter. While a more recent dynamical systems model of the error predicts some of our findings (Thelen et al, in press), it describes all successes and failures as being due to the strength of motor history relative to specific input. The authors provide an alternative interpretation which better fits the results found here, explaining successes and failures as being due to the differing motivations of the infants in different tasks. We would suggest that although 'lids-only' and 'hidden-object' versions of the AB task both produce perseverant responses, the reasons behind failure to respond to the B-location are different in the two tasks. In the case of 'lids-only' this is likely to be due to low motivation to change, while failures in a 'hidden-object' task are probably due to an inability to update search in terms of the location of a hidden object in external space.

Footnotes

[1] Munakata (1997) did not introduce a toy until the B-trials, whereas our procedure involves hiding a toy throughout all of the 'hidden-object' trials.

[2] This also differs from Munakata's (1997) method, in which the experimenter passed the toy to the child each time, in order to equate the amount of motor history given to A, between subjects. However, it was found difficult to get the infants interested enough in searching for the toy, unless they were allowed to retrieve it for themselves.

[3] This again differs from Munakata's (1997) method in that she did not cover the B-well at all during pre-trials. When piloting the study it was found that the introduction of the B-lid acted as a distracter on A-trials, especially when it was a novel, 'different' lid.

[4] While there were some significant effects of Gender, and A-well side, these did not reduce the significance of the effects quoted above. There was also a significant effect of lid orientation ('different' cover group only). This had no affect on the significance of effects of task variable, and the trial variable, calculated from only the different covers condition of the data set. Thus, the variables; gender, A-well side, and lid orientation were excluded from the analysis.

[5] The number of reaches to A recorded in Table 3 include those made on pre-trials and the obligatory A-trials.

[6] The average number of trials to A before B in each condition was: i) 'different' covers, 'hidden-object' task: M=6.8, N=14, SD=1.0. ii) 'different' covers, 'lids-only' task: M=6.8, N=11, SD=0.9. iii) 'same' covers, 'hidden-object' task: M=6.5, N=13, SD=0.8. iv) 'same' covers, 'lids-only' task: M=7.1, N=11, SD=0.9.

[7] According to Thelen et al's (in press) account the specific input of a toy has a non-linear effect on B-trials; if it is strong enough it will overcome the memory it has already set up at A during A-trials.

[8] Thanks are due to an anonymous reviewer who pointed out that this particular effect of ‘different’ covers may be in encouraging a simple landmark-honing strategy, rather than in disambiguating one particular location in space.

Acknowledgements

We would like to thank Jordy Kaufman, Linda Smith, and an anonymous reviewer for their helpful comments on an earlier version of this manuscript. We also thank David Popplewell and Todd Bailey for their help with the data analyses.

References

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

Bremner, J.G. (1985). Object tracking and search in infancy: A review of data and a theoretical evaluation. *Developmental Review*, **5**, 371-396.

Bremner, J.G., and Bryant, P.E. (1977). Place versus response as the basis of spatial errors made by young infants. *Journal of Experimental Child Psychology*, **23**, 162-71.

Butterworth, G. (1977). Object disappearance and error in Piaget's stage IV task. *Journal of Experimental Child Psychology*, **23**, 391-401.

Butterworth, G., Jarrett, N., and Hicks, L. (1982). Spatiotemporal identity in infancy: Perceptual competence or conceptual deficit? *Developmental Psychology*, **18**, 435-49.

Cummings, E.M., and Bjork, E.L. (1983). Search behaviour on multi-choice hiding tasks: evidence for an objective conception of space in infancy. *International Journal of Behavioural Development,* **6**, 71-87.

Diamond, A. (1985). Development of the ability to use recall to guide action, as indicated by infants' performance on AB. *Child Development*, **55**, 868-883.

Harris, P.L. (1989). Object permanence in infancy. In A. Slater and G. Bremner (Eds.), *Infant Development*, pp. 103-112. Hove: Lawrence Erlbaum Associates, Inc.

Marcovitch, S., and Zelazo, P.D. (1999). The A-not-B error: results from a logistic meta-analysis. *Child Development,* **70**, 1297-1313.

Munakata, Y. (1997). Perseverative reaching in infancy: The roles of hidden toys and motor history in the AB task. *Infant Behaviour and Development*, **20**, 405-416.

Munakata, Y. (1998). Infant perseveration and implications for object permanence theories: A PDP model of the AB task. *Developmental Science,* **1**, 161-211.

Newcombe, N., Huttenlocher, J., Learmonth, A., and Wiley, J. (1997). Infants' coding of location in continuous space. Paper presented at the Society for Research in Child Development, Washington, DC: USA.

Piaget, J. (1954). *The construction of reality in the child* (trans. M. Cook). New York: Basic Books.

Smith, L.B., McLin, D., Titzer, R., and Thelen, E. (1995). The task dynamics of the A-not-B error. Paper presented at the Society for Research in Child Development, Washington, DC: USA.

Smith, L.B., Thelen, E., Titzer, R., and McLin, D. (1999). Knowing in the context of acting: The task dynamics of the A-not-B error. *Psychological Review*, **106**, 235-260.

Thelen, E., Schöner, G., Scheier, C., and Smith, L.B. (in press). The dynamics of embodiment: A field theory of infant perseverative reaching. *Behavioural and Brain Sciences*.

Table 1: Between-subjects counterbalanced conditions.

Cover Group	Task Order	Lid Orientation	A-well side Order
Same	Hidden-object (1) -Lids-only (2)	-------	Left (1)-Right (2)
			Right (1)-Left (2)
	Lids-only (1) -Hidden-object (2)	-------	Left (1)-Right (2)
			Right (1)-Left (2)
Different	Hidden-object (1) -Lids-only (2)	SLid Left -CLid Right	Left (1)-Right (2)
			Right (1)-Left (2)
		CLid Left -SLid Left	Left (1)-Right (2)
			Right (1)-Left (2)
	Lids-only (1) -Hidden-object (2)	SLid Left -CLid Right	Left (1)-Right (2)
			Right (1)-Left (2)
		CLid Left -SLid Left	Left (1)-Right (2)
			Right (1)-Left (2)

Table 2: Mean accuracy score (out of 4) on A- and B-trials for different tasks across both cover groups.

	Task			
	Hidden-object		Lids-only	
Cover Group	A-trials	B-trials	A-trials	B-trials
Same	M = 3.7	M = 1.6	M = 3.1	M = 1.6
	N = 13	N = 13	N = 11	N = 11
	SD = 0.8	SD = 1.8	SD = 1.3	SD = 1.7
Different	M = 3.0	M = 3.0	M = 3.1	M = 0.8
	N = 14	N = 14	N = 11	N = 11
	SD = 1.1	SD = 1.2	SD = 1.0	SD = 1.0

Table 3: Mean number of extra B-trials needed (out of 3) before ‘B well’ was uncovered, for different tasks across both cover groups.

	Task	
Lid Group	Hidden Object	Lids Only
Same	M = 0.9 N = 13 SD = 1.3	M = 0.6 N = 11 SD = 1.0
Different	M = 0.0 N = 14 SD = 0.0	M = 1.5 N = 11 SD = 1.2

Table 4: Total number of reaches to each location on each trial and in each condition.

i) Reaches to A

	Task			
	Hidden-object		Lids-only	
Cover Group	A-trials	B-trials	A-trials	B-trials
Same	M = 6.2	M = 1.2	M = 6.0	M = 1.3
	N = 13	N = 13	N = 11	N = 11
	SD = 0.7	SD = 0.9	SD = 1.5	SD = 0.8
Different	M = 6.1	M = 0.9	M = 6.3	M = 1.9
	N = 14	N = 14	N = 11	N = 11
	SD = 1.2	SD = 0.9	SD = 1.0	SD = 0.4

ii) Reaches to B

	Task			
	Hidden-object		Lids-only	
Cover Group	A-trials	B-trials	A-trials	B-trials
Same	M = 0.8	M = 0.8	M = 2.4	M = 1.4
	N = 13	N = 13	N = 11	N = 11
	SD = 0.9	SD = 0.9	SD = 2.3	SD = 0.8
Different	M = 1.8	M = 1.4	M = 1.8	M = 0.7
	N = 14	N = 14	N = 11	N = 11
	SD = 2.0	SD = 0.7	SD = 2.0	SD = 0.8