Understanding the effects of one's actions upon hidden objects and the development of search behaviour in 7-month-old infants.

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Research Highlights

● We suggest that infants younger than eight months old do not search for hidden objects because they do not yet understand how their own actions can bring about the reappearance of these objects.

● This hypothesis was tested by giving seven-month-old infants a training experience of rotating a turntable to cause the reappearance of a hidden toy, and comparing their search behaviour on a different task before and after training.

● Infants showed improved search following training, and the degree of this improvement correlated with the number of successful interactions with the turntable.

● A control group who learnt the same actions to rotate the turntable to bring a *visible* toy into reach did not show this improvement.

Abstract

Infants' understanding of how their actions affect the visibility of hidden objects may be a crucial aspect of the development of search behaviour. To investigate this possibility, 7-month-old infants took part in a two-day training study. At the start of the first session, and at the end of the second, all infants performed a search task with a hiding-well. On both days, infants had an additional training experience. The "Agency group" learnt to spin a turntable to reveal a hidden toy, whilst the "Means-End" group learnt the same means-end motor action, but the toy was always visible. The Agency group showed greater improvement on the hiding-well search task following their training experience. We suggest that the Agency group's turntable experience was effective because it provided the experience of bringing objects back into visibility by one's actions. Further, the performance of the Agency group demonstrates generalised transfer of learning across situations with both different motor actions and stimuli in infants as young as 7 months.

Introduction

It is well known that infants do not search for completely-occluded objects until around 8-9 months of age, despite having the motor skill to do so (Piaget, 1954). However, infants as young as 3 months, or younger, appear to display knowledge of the continued existence of hidden objects in a variety of looking-time tasks (*e.g.* Baillargeon, 1987a; Baillargeon & DeVos, 1991; Newcombe, Huttenlocher & Learmonth, 1999; Wilcox & Schweinle, 2002). The apparent discrepancy between performance on looking-time and search tasks has been called the "Paradox of Object Permanence" (Meltzoff & Moore, 1998). Why are infants younger than 8 months unable to use the representational information that appears to be available to them on looking-time tasks to search for hidden objects?

There have been a number of attempts to resolve this paradox. Some have claimed that young infants do not have the means-end capacity to organise intentional search (Bower & Wishart, 1972; Baillargeon, Spelke & Wasserman, 1985; Diamond, 1991). Alternatively, the "graded representations" view holds that these infants are only able to form 'weak' representations of hidden objects, capable of informing looking behaviour, but not search (Munakata, McClelland, Johnson & Siegler, 1997). Such explanations are not without their challenges. Seven-month-old infants can perform means-end action sequences to bring an object within reach as long as they can see the object (Munakata *et al.*, 1997; Shinskey & Munakata, 2001; Shinskey, Bogartz & Piorier, 2000), suggesting a lack of means-end planning is not sufficient explanation of the failure to search at this age. The graded representations view, conversely, must explain why search tasks require some property of representation to be stronger or more precise than that needed for looking-time tasks. With a number of looking-time tasks showing an impressive level of precision and strength in a variety of properties of infant representations (*e.g.* Baillargeon, 1986; Luo, Baillargeon, Brueckner, & Munakata, 2003), the unresolved issue is why this level would not also be sufficient to support search behaviour.

This paper explores a novel resolution to the paradox. A fundamental cleft between the demands of looking-time tasks and those of search tasks is that in the latter the infant is active and in the former she is passive. In looking-time tasks infants may be required to form representations of hidden objects, and form expectations about those objects, but they are never required *to predict what the effects of their own actions will be upon the objects that they are representing*. In search-based tasks infants must be active; in order to intentionally search they must be able to predict that their actions will bring the hidden object back into perception (Russell, 1999). Plausibly, infants might be able to form representations of hidden objects, but not understand that they themselves are capable of acting on the basis of these representations so as to bring currently invisible objects into view. It is the development of this form of 'insight into agency' that may cause the emergence of intentional search at 8 months.

This explanation supports the prediction that *with additional experience of how their actions can render an occluded object visible again,* infants might be encouraged to search for completely-occluded objects. The present training study tests this prediction. Training studies can provide infants with experiences they might otherwise not encounter, leading to changes in proximal and distal cognitive processes. For example, giving pre-reaching infants experience of actively producing object-directed reaches has been found to change and benefit infant manual and visual exploration of objects and people (*e.g.* Needham, Barrett & Peterman, 2002; Libertus & Needham, 2010, 2011), causal understanding (Rakison & Krogh, 2011) and understanding of other agent's goal-directed actions (*e.g.* Sommerville, Woodward, & Needham, 2005). Active training in older infants with tool-use has also been found to facilitate understanding of other agent's tool-use actions (Sommerville, Hildebrand, & Crane, 2008). Finally, attentional training using a gaze-contingent paradigm has shown distal transfer to spontaneous looking behaviour in free play (Wass, Porayska-Pomsta & Johnson, 2011). The present study is, we believe, the first to use an active training paradigm with infants in relation to searching for hidden objects.

Training studies raise the question of what the appropriate amount of training is to give to infants. The amount of training in past studies has ranged from only 3 minutes of training in one single session (*e.g.* Gerson & Woodward, 2014) to 10 minutes per day for 2 weeks (*e.g.* Needham *et al.*, 2002). The appropriate amount of training to give will vary according to the age of participants and type of training used. Infants in the present study were aged between 6 and 8 months. At this age one would expect infants to be on the threshold of being able to search for hidden objects, and thus may be most sensitive to the effects of additional experience of affecting the reappearance of hidden objects. However, infants of this age appear to show marked practice effects on search tasks within a single session (Shinskey & Munakata, 2005). Infants were therefore seen on two consecutive days, so that pre- and post-tests of searching ability would not be within the same session. Piloting had also found that infants tended to become fussy after several repeated training trials in a single session. By splitting the study across two days, it was hoped that practice effects and drop-outs due to fussiness might be reduced.

At the start of the first day, and the end of the second, all infants performed two trials of a search task, recovering a toy hidden under a cloth in a hiding-well. Between these pre- and post- training blocks, infants experienced different training tasks according to their group. An “Agency” group played with a turntable, across the diameter of which was an opaque screen. After seeing a new toy placed on the other side of the screen, these infants could learn that rotating the turntable would render this toy visible again. Infants experienced eight trials overall of this training, with four trials on each day. The total number of training trials was therefore similar to that used in Sommerville *et al.* (2008), where infants learnt to use a tool to retrieve a (visible) toy.

Our explanation of the paradox of object permanence predicts that experiencing how their actions with the turntable affect the reappearance of the toy would lead the Agency group to improve on the hiding-well search task. The toy, the method of hiding, and the motor action required to retrieve the toy in the search task were all different from those used when playing with the turntable. Any improvement seen in this group might be interpreted as a generalisation of the ‘insight into agency’ gained through their experiences with the turntable, as opposed to specific stimuli or motor learning effects.

Our key question is whether the experience of *rendering hidden objects visible again* will lead to generalised search improvement. A “Means-End” control group were therefore given the experience of the same type of turntable task as the Agency group, but with a *transparent* screen across the turntable instead. These infants learnt to perform the same means-end motor action as the Agency group to bring a toy within reach. They did not, however, receive any experience of how their own actions brought objects back into visibility. Our comparison was, then, in terms of whether the action taken caused an object to become visible. We did not ask whether this becoming-visible was having an effect in and of itself. In order to answer this question it would have been necessary to include a group of infants who simply watched the experimenter performing the actions (as in Gerson & Woodward, 2014), thereby resulting in a 2X2 (active/passive X become-visible/remain-visible) design. We will discuss the possible role of becoming-visible *per se* in light of our data below.

Method

Participants

Forty four full-term infants aged 6-8 months were assigned to two groups: the Agency group (*N* = 22, 11 boys, *M* age = 7m 0d, *SD* = 12d, Range: 6m 4d – 7m 28d) and the Means-End group (*N* = 22, 10 boys, *M* age = 7m 3d, *SD* = 12d, Range: 6m 9d – 7m 26d). Participants were recruited from the Cambridge area. Whilst no formal measures of socioeconomic status were taken, infants predominantly came from middle-class households. An additional 13 infants were tested but did not contribute usable data due to fussiness (*N* = 9), recording equipment failure (*N* = 2), non-attendance on the second day (*N* = 1) and apparatus failure (*N* = 1).

Test Environment and Apparatus

Infants were tested either in an experimental room in the lab or in their home, with the location being kept constant across both days. The number of infants seen at home was equal across the two groups (Agency group = 14/22; Means-End group = 14/22). Infants sat in their care-giver's lap at a table, with the table-top level with the infant’s navel. The experimenter timed events using a stopwatch. A single video camera recorded the procedure.

Figures 1 and 2 show the apparatus. The hiding-well was a 20cm x 20cm x 7cm blue wooden block with a 6cm deep, 8cm diameter cylindrical yellow cavity in the centre of the top surface. A 14cm x 14cm green cloth covered the cavity, secured along the edge facing the infant. Toys used with the well were: A 7cm rubber duck; a 7cm diameter plastic ball; and an 8cm rubber starfish.

The turntable was 49cm in diameter, standing 7cm high, made from blue Perspex. A 2.5cm high slot ran across the diameter of the turntable, into which could be inserted a

17.5cm high Perspex screen. Two screens were used; one transparent, the other yellow and opaque. Eight 7cm x 4cm Perspex 'paddles', and four yellow 7cm diameter wooden balls were positioned around the circumference to provide purchase for spinning the turntable. Toys used with the turntable were: a 10cm rubber crocodile; a 12cm bear-shaped rattle; and a 9cm plastic three-key ring.

Figure 1. Hiding-well and toys as used in the search task.

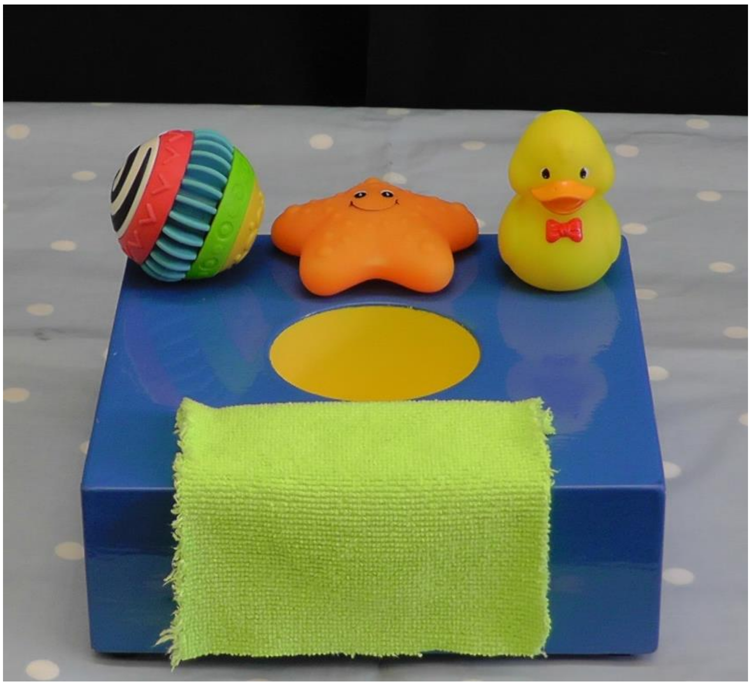
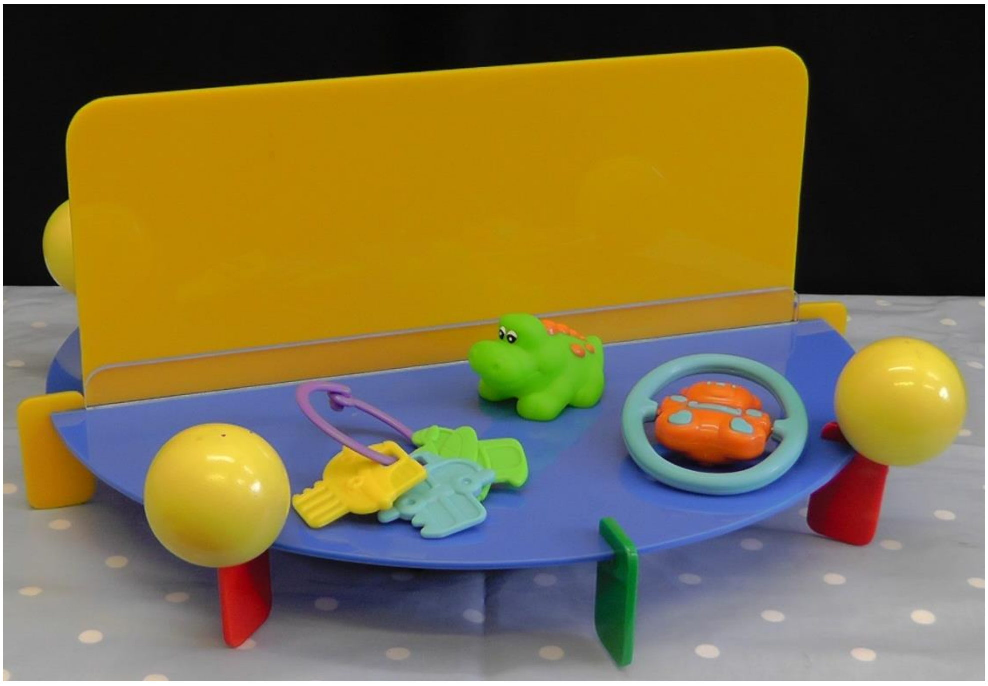


Figure 2. Turntable and toys, with opaque screen, as used in Agency group. Means-End group used the same turntable and toys, with a transparent screen (not shown).



Procedure

On the first day, all infants ‘warmed-up’ by playing with three linking rings. Infants then performed two trials of the search task. The experimenter placed the hiding-well within reach of the infant, with the cover pulled down so that the cavity was visible, and the infant was allowed to select a toy (from the duck, ball or starfish) to play with. This single toy was used on both trials.

For each trial, as the care-giver restrained the infant's arms, the experimenter drew the infant’s attention to the toy, placed it in the cavity, and pulled the cloth over the cavity. The experimenter then gave a verbal signal for the care-giver to release the infant’s arms, and the infant was allowed to search for the toy. After 45s, if the infant hadn't revealed the toy the experimenter pulled back the cloth and handed the infant the toy.

After the two search trials, the turntable was then placed in front of the infant, with no screen inserted. The experimenter demonstrated to the infant how to spin the turntable, and played a nursery rhyme through a speaker underneath the table whenever the turntable moved. The infants were then allowed to spin the turntable themselves, and whenever they successfully rotated it the experimenter activated the music. This familiarisation game continued for approximately 5min, or until the infant twice successfully rotated the turntable through 90 degrees unaided.

After the familiarisation game, training with the turntable began. One of two different screens was installed across the turntable. For the Agency group the screen was opaque, and for the Means-End group the screen was transparent. A new toy was selected by the infant (from the crocodile, rattle or key ring), and placed on the turntable. The experimenter first demonstrated three times rotating the turntable through 360 degrees, showing the effect this had on the toy’s location. The infant then performed four “turntable trials” of rotating the turntable themselves to bring the toy back within reach (and back within sight for the Agency group). Training with the turntable lasted approximately 5 minutes on each day.

For each trial, the toy was placed on the side of the turntable nearest the infant, the infant's arms were restrained and the turntable rotated 180 degrees. The experimenter then gave the care-giver the signal to release the infant's arms. After 30s, if the infant had failed to bring the toy within reach, the experimenter would draw attention to the toy (temporarily lifting the screen if necessary for the Agency group). If after another 30s the infant still was not engaging in any actions to retrieve the toy, the experimenter rotated the turntable for the infant. The toy was changed if the infant still showed no interest in it. Infants who failed to rotate the turntable therefore still received the same passive visual experience of seeing the toy being brought back into reach (and in the case of the Agency group, back into visibility) as those infants who did rotate the turntable.

On the second day all infants first played the turntable familiarisation game. Training with the turntable was then performed in the same manner as on the previous day. The experimenter installed the same screen as on the previous day, demonstrated three times rotating the screen through 360 degrees and the infants performed four turntable trials. Finally, all infants performed two trials of the search task, using the same toy as on the first day.

Scoring

In order to assess improvement in search task performance, and to assess how this might relate to performance during turntable training, an independent observer, blind to the day and (for search task trials) group assignment scored all video records of the search task and turntable trials. Trials were scored dichotomously as to whether infants successfully searched for the toy or, in the case of the turntable trials, brought the toy back within reach.

Infants on the search task were categorised as to whether they searched on zero, one or both of the trials on each day, and thus could be further categorised into those infants displaying less, more, or the same search performance on day-two compared to day-one. For performance on the turntable training infants were given a score out-of-8 for the number of trials on which they retrieved the toy across the two days.

In assessing the success of such searching and means-end retrieval actions, it has been noted that actions should only be considered as successful if they could be judged to have been performed with the expectation that the action would result in being able to retrieve the toy (*e.g.* Willatts, 1984; Moore & Meltzoff 1999, 2008). We measured this expectation by considering the gaze direction of the infants as they revealed the toy (or rotated the turntable through 90 degrees for the turntable trials), and whether they then made a reach for it. Actions where infants revealed the toy without looking towards it, or where they did not then reach for the toy, were judged to be accidental, and not successful search. Search task trials were therefore only considered successful if all three of the following were met:

1) The infant moved the cloth to reveal the toy such that he/she could make a direct manual reach for it.
2) At the point that the toy was revealed the infant was looking at the location of the toy.
3) The infant made a reach directed at the toy that successfully contacted it.

Turntable trials were scored similarly, with trials only considered successful if all three of the following were met:

1) The infant rotated the turntable through 90 degrees.
2) As the turntable was rotated through 90 degrees, the infant was either looking at the

location of the toy or monitoring the turntable as he/she rotated it.

3) The infant made a reach directed at the toy that successfully contacted it.

For both the search task and the turntable trials, scoring began from when the infant's arms were released. For the search task, only actions performed within 45s were scored. For turntable trials, if the experimenter had to turn the turntable to bring the toy in reach for the infant, no subsequent actions were scored.

In addition to the independent observer, the first author also scored 100 of each of these trials (38% of search task and 28% of turntable trials). The kappa values for agreement between experimenter and observer were .86 and .84 for the search task and turntable trials respectively.

Results

Table 1 details the distribution of infants within each group successfully searching on zero, one or both of the search trials on each day. There was no significant difference in distribution between the two groups on day-one, $X^2(2, N = 44) = 2.48$, $p = .29$. On day-two, however, there was a difference in distributions, $p = .017$ (as a cell had an expected value < 5 , Fisher's Exact Test[1] was used), with the Agency group having more infants searching on both trials, and less searching on zero trials compared to the Means-End group.

[1] Where F.E.T. has been used with 2 x 3 tables, the Freeman-Halton extension (Freeman & Halton, 1951) has been used.

Table 1. Distribution of infants in each group according to the number of successful search trials achieved on each day.

		Number of infants searching on 0, 1 or 2 trials		
		0	1	2
Day-One	Agency	**9**	**9**	**4**
	Means-End	**9**	**5**	**8**
Day-Two	Agency	**0**	**7**	**15**
	Means-End	**7**	**6**	**9**

To assess the improvement on the search task from day-one to day-two, infants in each group were classified as to whether they searched on fewer, more, or the same number of trials on day-two compared to day-one. Table 2 details the distribution of this classification for each group. Sign-tests indicated that infants in the Agency group tended to search more on day-two than day-one $p < .001$, whereas the Means-End group did not, $p = 1.0$. The distribution of infants searching less, more or the same was different between the Agency group and Means-End group, $p = .022$ (Fisher's Exact Test), with more infants searching more on day-two, in the Agency group compared to the Means-End group. Thus greater improvement appeared to be shown in the Agency group than the Means-End group.

This difference in distribution of improvement on the search task did not appear to be driven by a ceiling effect in the Means-End group caused by this group having more infants searching on both trials on day-one compared to the Agency group. Even after excluding all infants who searched on both trials on day-one (see Table 2), the difference in the distributions was still significant, $p = 0.037$ (Fisher's Exact Test).

Table 2. Distribution of infants in each group searching on fewer, the same, or more trials on day-two compared to day-one. The numbers given in brackets are the frequencies once infants who searched on both trials on day-one are excluded.

	Less Search	Same Search	More Search
Agency	**1** *(0)*	**5** *(2)*	**16**
Means-End	**6** *(2)*	**9** *(5)*	**7**

Considering now performance on the turntable tasks, there was no difference in the number of successful trials performed across the two days between the Agency (*M* = 4.41, *S.D.* = 2.48) and Means-End (*M* = 4.36, *S.D.* = 2.15) groups, $t(42) = .06$, $p = .95$. To assess the relationship between performance on the turntable tasks and improvement on the search task, the categories of 'less', 'same' and 'more' search in Table 2 were assumed to be ordinal (with 'less search' ranked as the lowest category, and 'more search' the highest). To make this assumption, those infants who searched on *both* trials on *both* days (and were thus ranked in the middle 'same search' category, despite showing maximal performance) were excluded (Agency = 3, Means-End = 4 infants). Further, due to the uneven distribution of the Agency group across these three categories, the 'more search' category was split in two: search on *one* more trial (Agency = 11, Means-End = 4 infants), and search on *two* more trials (Agency = 5, Means-End = 3 infants) on day-two compared to day-one. This created four ranked categories of improvement overall.

In the Agency group, there was a monotonic relationship, measured by Spearman's Rank, between the number of successful turntable trials achieved, and improvement category, ρ (19) = .55, $p = .014$. This suggests that more success on the turntable trials tended to result in more improvement on the search task. This relationship was not seen in the Means-End group, ρ (18) = -.15, $p = .57$. These two correlations were significantly different from each other, $Z = 2.14$, $p = .032$[2].

[2] Difference in correlations was assessed using the Fisher r-to-z transformation with the untransformed Spearman's ρ values, following Myers and Sirois (2004).

Discussion

We asked whether giving infants the experience of how their actions can render an occluded object visible again would improve their performance on a search task. Our results suggested that it did. Following training on their turntable task across two days, the Agency group improved on the search task, and showed greater improvement than did the Means-End control group. The different turntable tasks required the same actions and means-end planning to rotate the turntable to bring the toy within reach. The improvement seen in the Agency group cannot therefore be fully explained by the learning of some action incidentally useful across both tasks, or due to simply learning to perform a means-end action *per se*.

Regarding performance on the turntable task, the two groups showed nearly equal levels of performance, as measured by number of successful retrievals of the toy. Given this, the improvement of the Agency group on the search task cannot be explained by their turntable task eliciting some higher behavioural activation than that of the Means-End group. Furthermore, it was only within the Agency group that performance on their turntable task correlated with improvement on the search task. This would suggest that the Agency group transferred learning from their successful interactions with objects during their turntable task to the search task in a way that the Means-End group did not.

We suggested that search tasks require the understanding that one’s actions have the potential to bring a hidden object back into visibility. We would argue that the improvement of the Agency group on the search task reflects the transfer of this understanding from the turntable task to the search task. This supports our claim that the “Paradox of Object Permanence” is a result of younger infants lacking such an understanding. There are two issues to be considered with regards to this claim.

First, one might consider a potential alternative explanation of the Agency group’s improvement to be that they simply learnt passively from the perceptual experience of seeing toys disappear and reappear on the turntable task: this experience may have been sufficient to encourage search behaviour. In response, we would argue that the correlation within the Agency group between successful performance with the turntable and improvement on the search task suggests there is more than just passive learning about disappearance and reappearance taking place. It is important to note that even if an infant failed to reveal the toy themselves on turntable trials, *they nonetheless saw the toy being revealed again by the experimenter on two occasions* (once halfway through the trial, and again at the end of the trial). Thus infants in the Agency group who *failed* to reveal the toy themselves on turntable task trials passively viewed at least the same number of disappearance and reappearance events as infants who successfully revealed the toy. Given that experience of disappearance and reappearance of the toy is invariant to performance on the turntable task, a passive learning account would struggle to explain the correlation within the Agency group between the number of successful turntable trials and degree of improvement on the search task. We believe our claim that infants are learning from their own actions involving revealing hidden objects provides a satisfying account of the data. Indeed, where recent training studies have attempted to control for the effects of learning from passive perceptual experience, it has been found that it is the active experience of generating the perceptual experience oneself that drives the training effects (*e.g.* Libertus & Needham, 2014; Gerson & Woodward, 2014).

Second, there might be said to be some ambiguity over the object-directedness of the improved search behaviour seen in the Agency group. All of the search task trials involved some object being hidden in the hiding-well. It is therefore not entirely clear whether the infants in the Agency group transferred learning about how their actions could reveal a hidden *object*, or instead about how their actions could reveal the hidden *spatial layout* behind an occluder. This could be disambiguated by having search task trials in which no object is hidden in the hiding-well. If infants in the Agency group were learning from their turntable task experiences how their actions can specifically reveal hidden objects, then one would not expect infants to show increased searching behaviours with the hiding-well when no object is hidden within it. If infants did, however, show an increase in search behaviours on such no-search trials then this would suggest that infants are learning from the turntable task how to reveal a hidden spatial layout behind an occluder, irrespective of whether there are any objects within the hidden layout.

Finally, the transfer of learning seen in the Agency group, however it is to be characterised, seems to exemplify a powerful learning mechanism. These infants appear to have generalised their learning about their interactions with hidden objects across different stimuli, methods of hiding and retrieval actions. Whilst studies have found action generalisation across different stimuli in infants (*e.g.* Greco, Hayne & Rovee-Collier, 1990; Chen, Sanchez & Campbell,1997; Learmonth, Lamberth & Rovee-Collier, 2004), we believe this is the first demonstration of generalised transfer of learning across situations with both different motor actions and stimuli in infants as young as 7 months. We would encourage further exploration of the nature and robustness of such transfer in infants at this age.

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