Brief article

Children reorient using the left/right sense of coloured landmarks at 18–24 months ☆

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Abstract

In previous studies, children disoriented in small enclosures used room shape, but not wall colours, to find hidden objects. Their reorientation was said to depend solely on a "geometric module" informationally encapsulated with respect to colour. We argue that previous studies did not fully evaluate children's use of colour owing to a bias in the enclosures' design. In this study, disoriented 18–24 month olds searched for toys in small square enclosures with two blue and two white walls. Children successfully reoriented using wall colour. This shows that they can make location judgments based on the left/right sense of the colours of adjoining landmarks. Performance was no different when symmetric colourful shapes were added to walls, but improved with asymmetric shapes which could be used without left/right judgments. The relatively poor use of colour in previous studies may be explained partly by a bias in their design, and partly by children's limited ability to discriminate the left/right sense of nongeometric features.
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1. Introduction

A cognitive function is modular in the strong sense if it shows informational encapsulation, processing only a subset of the information represented by the organism (Fodor, 1983, 2001). Hermer and Spelke (1994, 1996) argued that children's failures to use wall colours to reorient inside small enclosures provide evidence that their reorientation depends only on a modular process encapsulated with respect to colour. We report that, when the design is changed to remove a bias towards solutions based on geometry, 18–24 month olds successfully use wall colours to reorient.

In Hermer and Spelke's (1994, 1996) task, based on a rodent paradigm (Cheng, 1986), children saw a toy hidden in one corner of a rectangular enclosure, were disoriented by turning, and prompted to find it. Deprived of their sense of orientation, they had to rely on visual cues. With all white walls (Fig. 1a), correct corner "*C*" is indistinguishable from its rotational equivalent "*R*", as both have a longer wall on the left. A disoriented subject sensitive to this "geometric" cue would, at best, divide her searches between these corners. Hermer and Spelke found that like rats, 18–24 month old children were sensitive to room geometry. With one distinctively coloured wall (Fig. 1b), the enclosure is no longer ambiguous. However, like rats, 18–24 month old children still confused "*C*" and "*R*" corners, searching by geometry but not colour. Hermer and Spelke (1994, 1996) proposed that children's reorientation depends on a "geometric module" encapsulated with respect to colour.

These studies have generated a considerable literature (reviewed by Cheng & Newcombe, 2005). The ability of adults and older children to solve the task was first proposed to depend on spatial language (Hermer-Vazquez, Moffet, & Munkholm, 2001; Hermer-Vazquez, Spelke, & Katsnelson, 1999), but its solution by animals including pigeons (Kelly, Spetch, & Heth, 1998), fish (Sovrano, Bisazza, & Vallortigara, 2002), and rhesus monkeys (Gouteux, Thinus-Blanc, & Vauclair, 2001) argues against this. Specific effects of verbal interference have also not been replicated (Hupbach, Hardt, Nadel, & Bohbot, in press; Ratliff & Newcombe, 2005).

Failures to use wall colour were confirmed to persist to age 5 years (Learmonth, Nadel, & Newcombe, 2002), however 18–24 month olds *do* use colour when the dimensions of the original enclosure are doubled (Learmonth et al., 2002; Learmonth, New-
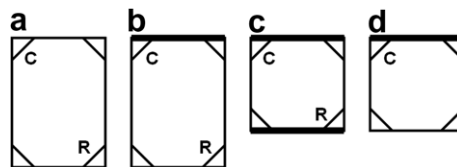
Fig. 1. Enclosure layouts. In these examples the toy is hidden in the top left corner. (a) Rectangular room with four white walls. All corners are equivalent in colour. *R* is equivalent in geometry to the correct corner *C*. (b) Rectangular room with one coloured wall. *R* is equivalent in geometry, but not colour, to *C*. (c) Square room with two coloured walls. All corners are equivalent in geometry, and *R* is equivalent in colour to *C*. This design, used in the present studies, provides a correct analogy with (a). (d) Square room with one coloured wall. No corner exactly matches *C* in colour. This does not provide a correct analogy with (a).

combe, & Huttenlocher, 2001), a result which questions whether their reorientation is necessarily encapsulated with respect to colour. More recently, based on studies using circular enclosures with distinctively coloured containers, Lee, Shusterman, and Spelke (2006) argued that reorientation by geometry is supplemented by an associative process which can use colour information, but only as a direct and not an indirect landmark.

The present study addresses a bias in the original enclosure's design. In those studies, a geometry only condition (all white walls; Fig. 1a) was compared with geometry plus colour (one blue wall; Fig. 1b). Evidence that children did not use colour came from the latter condition. However the design was unbalanced with respect to the number of solutions supported by wall geometry and wall colour, and there was no control "colour only" condition.

A colour only test providing a valid analogy with geometry only would correspond to the enclosure with all white walls, but reverse the status of colour and geometry. In that space (Fig. 1a), all corners were equivalent in colour, while opposite pairs were equivalent in geometry. In the present study, therefore, all corners were equivalent in geometry, and opposite pairs were equivalent in colour. In this layout (Fig. 1c), participants using colour can always locate a corner matching the target within 90° of whichever direction they are facing, as they can using geometry in Fig. 1a.

Given intrinsic differences between the information provided by wall colours and wall lengths, the information available in the present design is not necessarily equivalent to the previous "geometry only" test in terms of available distal and proximal cues (see Section 5). The sense in which the present design provides a correct analogy with that test is in matching the number of solutions available with respect to the colour cue.

In square enclosures with this design (two coloured walls), rats (McGregor, Hayward, Pearce, & Good, 2004) used colour. Chicks used colour in square enclosures with different coloured features at each corner (Vallortigara, Pagni, & Sovrano, 2004). Children have been tested in square enclosures with one coloured wall; 18–24 month olds failed to use colour (Wang, Hermer, & Spelke, 1999), while 5–6 year olds succeeded (Hermer-Vazquez et al., 2001). However these tests of colour use were not comparable with the geometry only test, as the correct corner *C* had no exact colour equivalent (Fig. 1d).

In the literature, nongeometric cues including colour, pattern, and – in rodent studies – odour – are termed "features" (Cheng, 1986). We tested whether children's searches at corners specified by colourful features were above chance with the design shown in Fig. 1c. We further predicted that richer colour and pattern features would be used more reliably, and that performance would be best with features useable without left/right judgments.

2. Method

2.1. Design and participants

Children aged 18–24 months were tested on one of four conditions (Fig. 2). In baseline condition "plain", the only orienting cues were blue and white coloured
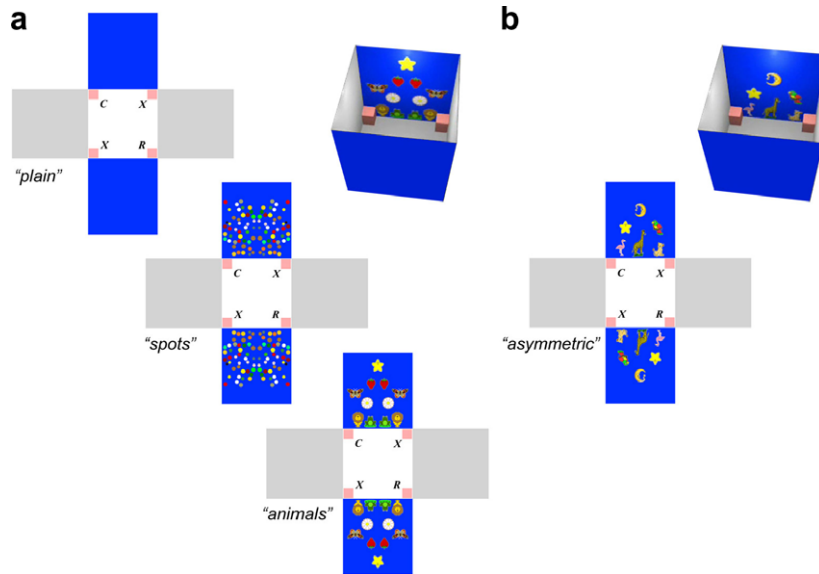
Fig. 2. (a) Layouts for the symmetric "plain", "spots", and "animals" conditions, and 3D view ("animals" condition). In this example the top left corner is the correct hiding place (*C*). Adjacent corners *X* differ in blue-white and animal or spot left/right sense. The rotational equivalent *R* is visually identical. For any feature to be useful, participants have to discriminate whether the hiding place was to its left or right. (b) Layout and 3D view for the "asymmetric" condition, in which visual features are useful even without a left/right judgment. In this example, *C* and *R* corners are close to flamingos, whereas *X* corners are close to lions.

walls. In an "animals" condition, flat pictures of colourful animals and shapes were added. In a "spots" condition, the same colours were added in an abstract pattern. Added shapes were the same on opposite walls, symmetrical about the centre of each wall, and symmetrical about their own midlines. Because of these symmetries, associating the target box with distinctive visual features would not suffice to solve the task, but features were only useful combined with judgments of left/right sense. In a final "asymmetric" condition (Fig. 2b), *C* and *R* corners could be discriminated from the others without left/right judgments, as features near *C* and *R* differed from those near *X*.

For each child one randomly selected corner was the hiding place throughout. Walls faced following disorientation were randomly determined so that all were faced approximately equal numbers of times. Participants were tested for a maximum 8 trials. Of 88, 7 would not do the task, 8 completed fewer than four valid trials, and 5 were excluded because of a procedural error (e.g., they did not become disoriented); 68 who completed at least four trials were analysed: 16 in condition "plain" (9 male, mean age 21.6, s.d. 1.7 months), 18 in "animals" (10 male, mean age 21.1, s.d. 1.1 months), 17 in "spots" (8 male, mean age 21.6, s.d. 1.3 months), and 17 in "asymmetric" (8 male, mean age 21.6, s.d. 1.7 months). Parents gave informed consent, and the study followed Ethics committee guidelines.

3. Apparatus

The enclosure was square with sides 1.69 and height 1.85 meters, made of fabric stretched over a metal frame. The floor area, 2.85 m², was similar to Hermer and Spelke's, 2.23 m². Pairs of opposite walls were white and blue, with laminated card shapes added for three conditions (see Fig. 2). The ceiling was white fabric, and the floor unpatterned linoleum. Pink cardboard boxes with removable lids, base 22×22 cm, height 30 cm, stood in each corner. A 25 Watt light was at the top centre of each wall. The hiding object was a toy. Participants entered and exited through one of the walls, resealed for testing. An overhead speaker played waterfall and bird noises to mask external sound. An overhead camera monitored the experiment.

3.1. Procedure

Parent and child entered the enclosure, while the experimenter observed from outside on a monitor. Children played with the toy for a minute to acclimatise. In conditions with added features, parents were asked to point these out. On each trial, the parent hid the toy in a predetermined corner, ensuring the child had seen it. Children were encouraged to help hide the toy. The parent lifted the child and turned her slowly in the centre to induce disorientation. Vision was blocked in one of two ways: either the parent covered the child's eyes and executed at least four full turns, or the experimenter turned all lights off for 20 s while parent and child turned. After disorientation the parent put the child down in the centre of the enclosure, stood back, and encouraged her to find the toy without giving gestural or verbal cues to its location. The first box searched was recorded, scored C (correct), R (rotational equivalent), or X (neither); see Fig. 2. Each child's number of searches was converted to a proportion of all her trials.

4. Results

Children in the analysis completed 4–8 (median 6) trials. Fig. 3 shows mean proportions of searches at different corners for each condition. To test whether search at feature correct corners was above chance, $C + R$ searches were compared with 0.5 on one-tailed one sample *t*-tests. In the "plain" enclosure the rate was 0.61, significantly above chance ($t(15) = 2.23$, $p < 0.025$). In the "spots" enclosure the rate, 0.58, did not differ from chance ($t(16) = 1.30$, $p > 0.1$). In the "animals" enclosure the rate was 0.64, significantly above chance ($t(17) = 2.74$, $p < 0.01$). In the "asymmetric" enclosure the rate, 0.73, was also significantly above chance ($t(16) = 3.84$, $p < 0.001$).

Counter to our prediction, differences in performance across the three symmetric conditions were minor (see Fig. 3). An ANOVA found no difference between these ($F(2) = 0.37$, $p > 0.6$). However as predicted, performance was higher for the asymmetric condition, which could be solved without left/right judgments. A one-tailed *t*-test comparing it with the three symmetric conditions, collapsed for analysis as they showed no difference, found the asymmetric $C + R$ rate significantly higher ($t(66) = 1.90$, $p < 0.04$).

Plain

C			X
0.32			
(0.04)			
		0.28	
		(0.05)	
X			R

Spots

C			X
0.25			
(0.06)			
		0.32	
		(0.07)	
X			R

Animals

C			X
0.35			
(0.04)			
		0.29	
		(0.04)	
X			R

Asymmetric

C			X
0.36			
(0.06)			
		0.37	
		(0.05)	
X			R

X   = 0.39 (0.05)
C+R = 0.61 (0.05) *

X   = 0.42 (0.06)
C+R = 0.58 (0.06) n.s.

X   = 0.36 (0.05)
C+R = 0.64 (0.05) *

X   = 0.27 (0.06)
C+R = 0.73 (0.06) *

Fig. 3. Mean proportions of searches at the correct (*C*) corner, its visually matching rotational equivalent (*R*), and the visually different *X* corners. Standard errors are in brackets. *C* + *R* searches combined are "feature correct". *, rate above chance (0.5) on one-sample *t*-test; n.s., not significant.

C and *R* rates were compared to check that feature correct searches were not due to incomplete disorientation or uncontrolled visual cues. There was no evidence that children could distinguish *C* and *R* corners, which did not differ in search rates on paired *t*-tests in any condition. In "plain", $t(15) = 0.56$, $p > 0.5$; in "spots", $t(16) = 0.21$, $p > 0.2$; in "animals", $t(17) = 0.88$, $p > 0.3$; in "asymmetric", $t(16) = 0.08$, $p > 0.9$. Further, searches at the "*R*" corner alone – which would not be predicted either by incomplete disorientation, uncontrolled cues, or cueing by parents (who did not normally become disoriented, so perceived "*R*" as an 'incorrect' corner) were above chance on one-tailed *t*-tests for all three symmetric conditions considered together; $t(50) = 1.70$, $p < 0.05$, and for the asymmetric condition; $t(16) = 2.61$, $p < 0.01$.

In many previous studies children had four trials, whereas here they completed up to 8. To confirm that use of colour did not depend on these additional trials, the analysis was repeated with each child's first four trials only. As in the main analysis, searches at feature correct corners were above chance on "plain", "animals", and "asymmetric" conditions ($p < 0.04$; $p < 0.03$; $p < 0.001$), while *C* and *R* rates did not differ significantly.

5. Discussion

In small spaces, 18–24 month olds reoriented using coloured features in layouts providing a correct analogy with previous tests of geometry. Along with findings that children use colour in larger enclosures (Learmonth et al., 2002), and that geometry and colour use emerge at the same age in rhombic spaces (Hupbach & Nadel, 2005), these results argue against the thesis that children's reorientation depends solely on a "geometric module" impenetrable to colour.

In a circular space, smaller colour cues (distinctive hiding containers), were used as direct, but not as indirect landmarks by four-year-olds (Lee et al., 2006). The authors argued that reorientation by geometry is supplemented by an associative process which can use nongeometric information such as colour, but only as a direct

landmark that exactly coincides with the hiding place. By contrast, the present results show that young children can also use the colours of adjoining walls. These potentially provide an indirect landmark (''right of the blue wall'', as well as a more direct landmark (''the 'blue-on-the-left, white-on-the-right' corner''). However, in both these cases, use of colour cues in the present study depended on correct left/ right sense judgments, rather than just homing in on a distinctive container as in the Lee et al. study.

Why would making two solutions available enable children to use wall colour? Presumably, disorientation sets the directional sense (heading) to a random direction. For reorientation heading has to be readjusted using visual information. In the rectangular room with one blue wall, finding a geometrically correct corner would never entail a reorientation of more than 90°, whereas finding one matching in colour would entail reorientations of over 90° approximately half the time. If children tended not to make reorientations of more than 90° (as rodents may not; Etienne, Teroni, Hurni, & Portenier, 1990), this could explain their disregard of colour in the original task, and their use of it in the present, where a reorientation of 90° or less always suffices to locate a colour-correct corner.

Additional symmetric features produced no improvement on the ''plain'' baseline. However performance improved with asymmetric features, which could potentially act as beacons to the correct box without a left/right judgment. This suggests that children's reorientation is not limited by the visual information distinguishing the different walls, but by their ability to discriminate the left/right sense of wall features with respect to corners. Children's sense judgments may be better for walls' lengths than for their features: in our ''plain'' condition participants discriminated whether corners were left or right of a blue wall on 61% of trials, whereas in previous geometry only tests, they discriminated whether corners were left or right of a longer wall on over 75% (Hermer & Spelke, 1994, 1996). When walls were manipulated to pit the sense of colours and lengths against each other (Sovrano & Vallortigara, 2006), chicks maintained wall length (geometric) sense in small spaces, but wall colour sense in larger spaces. Their preferences changed with enclosure size, perhaps because, when near the target corner, wall length is harder to judge in a large than a small enclosure. This could explain why children's preference for using geometry decreases with enclosure size.

Although these results show that children can reorient using colour, their favoured use of geometry in small spaces still needs explanation. Children reorient in a square enclosure containing a single geometric cue but not a single colour cue (Wang et al., 1999). It is unlikely that reorientation depends on an innately specified geometric module plus later developing language, see Section 1 and Cheng & Newcombe (2005). An alternative framework, consistent with findings that colour and geometry use change according to several factors, is ''adaptive combination'' (Newcombe & Ratliff, in press), which proposes that cues are combined by a weighting process shaped by learning about their reliability and adaptive value. Cheng (2005a) proposes that searches in fish are best explained by their matching as many cues as possible, but also argues that geometric computation could be modular even if geometry and features are stored together (Cheng, 2005b). Coding geometry is

likely to depend on specialised kinds of computation, encoding shape in terms of principal axes or medial or symmetry axes (Cheng & Gallistel, 2005), and/or boundary distances, consistent with neurophysiological recordings from rodent hippocampus (O'Keefe & Burgess, 1996) and human behavioural data (Hartley, Trinkler, & Burgess, 2004). Consistent with hippocampal involvement in geometric computation, hippocampal lesioned rats do not reorient by geometry in rectangular enclosures, but do reorient by opposite coloured walls in square enclosures like those used here (McGregor et al., 2004). Although geometry may indeed be computed by a specialised process, the present results show that such a process is not the only one available to young children for reorientation. Children can also reorient by making left/right judgments about colour cues.

There may be a general explanation for children's relatively poorer use of colour. Initial results from a desktop search task requiring memory for colours and actions but not reorientation or geometry use show that 18–24 month olds are poor at using colours alone as cues, and particularly likely to be mistaken on colours when they have to be combined in memory with actions (Nardini, Braddick, & Atkinson, 2006). This raises the possibility that "disregard of colour" is a common developmental phenomenon linked to development of separate visual streams for recognition and action (Milner & Goodale, 1995), which may develop unevenly (Gunn et al., 2002) and be poorly integrated in development (Mareschal & Johnson, 2003).

Acknowledgments

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