REPORT

Reorientation by geometric and landmark information in environments of different size

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Abstract

It has been found that disoriented children could use geometric information in combination with landmark information to reorient themselves in large but not in small experimental spaces. We tested domestic chicks in the same task and found that they were able to conjoin geometric and nongeometric (landmark) information to reorient themselves in both the large and the small space used. Moreover, chicks reoriented immediately when displaced from a large to a small experimental space and vice versa, suggesting that they used the relative metrics of the environment. However, when tested with a transformation (affine transformation) that alters the geometric relations between the target and the shape of the environment, chicks tended to make more errors based on geometric information when tested in the small than in the large space. These findings suggest that the reliance of the use of geometric information on the spatial scale of the environment is not restricted to the human species.

Introduction

For successful navigation animals must determine the appropriate direction to travel (see Gallistel, 1990; Sholl, 1995). To this end they can use self-referencing systems such as path integration, allowing them to represent their own changing locations by integrating information about position, direction and speed. However, these sorts of self-referencing systems are subject to cumulative errors (Gallistel, 1990). Therefore, animals need external referencing systems based on landmarks or environmental geometry. The type of information used by external referencing systems can be probed by preventing use of self-referencing systems by disorienting the animals (e.g. by rotation), so that they need to rely on external cues to reorient.

In the earliest reorientation studies, rats were shown the location of a food reward in a corner of a rectangular room (120 × 60 cm) with several visual and olfactory cues (Cheng, 1986); the rats were removed from the room, passively disoriented and then returned to the room and allowed to search for food. Results showed that rats searched equally at the target corner and at the corner located at a 180° rotation from the target, i.e. a location which had the same geometric relationship to the shape of the environment as the target location (Fig. 1). Surprisingly, rats did not make any use of the nongeometric cues (visual and olfactory) to distinguish between the two geometrically equivalent locations. A series of studies demonstrated that children (18- to 24-month-olds), like rats, reorient using the geometric features of the environment while ignoring salient nongeometric features (Hermer and Spelke, 1994, 1996). Children and adults were tested in a rectangular room (4 × 6 ft) with either all white walls or three white walls and one blue wall. In the all-white-wall condition, where there were only geometric cues available, both children and adults searched equally for an out-of-sight toy in the correct and in the geometrically equivalent corners. In the blue-wall condition, however, adults readily used the presence of the blue wall to search only in the correct corner, whereas children performed like rats, systematically confusing the two geometrically equivalent corners.

Spelke and co-workers suggested that these results indicate that children must possess some sort of innate ‘geometric module’ and that with development of spatial language the module may be overridden to allow for the conjoining of geometric and nongeometric information.
landmark cues, e.g. in reference memory tasks but not in
rats can, in some circumstances, integrate geometric and
Hauser, 2001). Second, it has become apparent that even
Blanc & Vauclair, 2001; tamarins: Deipolyi, Santos &
Heth, 1998; mammals: rhesus monkeys: Gouteux, Thinus-
Zanforlin & Pasti, 1990; pigeons: Kelly, Spetch &
Salas & Thinus-Blanc, 2004; birds: chicks: Vallortigara,
2002, 2003; goldfish (Xenotoca eiseni) duplicated the procedure used with chil-
dren and failed to reveal any difference between conjoint
goal was hidden at a fixed location relative to an array of
landmarks. On array expansion/contraction tests,
several species have been shown to search at locations
that maintained the approximate training vector (distance
and direction) from individual landmarks (e.g. gerbils: Collett, Cartwright & Smith, 1986; pigeons: Spetch, Cheng, MacDonald, Linkenhoker, Kelly & Doerkson, 1997). However, when trained with continuous surfaces
instead of discrete landmarks animals seem to show
relational rather than absolute encoding during expan-
sion/contraction tests (chicks: Tommasi, Vallortigara &
Zanforlin, 1997; Tommasi & Vallortigara, 2000, 2001;
pigeons: Gray, Spetch, Kelly & Nguyen, 2004). It could be
that orientation on the basis of distances from surfaces
or the geometric arrangements of walls may promote
different encoding strategies than orientation based on

(Spex: 2003; Wang and Spelke, 2002). The hypothesis
is sustained by data showing that children who already
possess spatial language abilities (Hermer-Vasquez,
Moffet & Munkholm, 2001) can conjoin geometric and
nongeometric information in the blue-wall task. Indeed,
the ability to correctly orient in the blue-wall task
(Hermer & Spelke, 1994) correlated with the ability of
children to produce and use phrases involving ‘left’ and
‘right’ when describing the locations of hidden objects
(MacWhinney, 1991). The developmental time course of
the ability to conjoin geometric and nongeometric informa-
tion thus suggests that language acquired by children
(starting at 2–3 years of age) would allow them to per-
form as well as adults (at about 5–7 years of age) (see
Hermer-Vasquez et al., 2001).

However, some novel findings have been reported
recently, changing our views on the abilities of human
and non-human animals to conjoin geometric and featur-
al information to reorient themselves. First, it has been
shown that many non-linguistic animals can, unlike rats,
integrate the two sources of information (fish: redtail
splitfins (Xenotoca eiseni): Sovrano, Bisazza & Vallortigara,
2002, 2003; goldfish (Carassius auratus): Vargas, Lopez,
Salas & Thinus-Blanc, 2004; birds: chicks: Vallortigara,
Zanforlin & Pasti, 1990; pigeons: Kelly, Spetch &
Heth, 1998; mammals: rhesus monkeys: Gouteux, Thinus-
Blanc & Vauclair, 2001; tamarins: Deipolyi, Santos &
Hauser, 2001). Second, it has become apparent that even
rats can, in some circumstances, integrate geometric and
landmark cues, e.g. in reference memory tasks but not in
working memory tasks (Cheng, 1986), in escape tasks
but not in search tasks (Golob & Taube, 2002). Third,
and most importantly for the present paper, it has been
recently shown that the spatial scale of the environment
in which the children are tested can also play a crucial
role in the ability to conjoin geometric and landmark
information. Learmonth, Newcombe and Huttenlocher
(2001) and Learmonth, Nadel and Newcombe (2002)
replicated the original finding of Hermer and Spelke
(1994) with 5-year-old children, concluding that they fail
to conjoin geometric and landmark information in a
small room (4 × 6 ft), but demonstrated that the same
children succeeded in a large room (4 × 12 ft).

Little is known on the comparative side about the
effects of spatial scale on reorientation. A very recent
study (Sovrano, Bisazza & Vallortigara, 2005) carried
out with redtail splitfins (a species of goodeid fish,
Xenotoca eiseni) replicated the procedure used with chil-
dren and failed to reveal any difference between conjoint
goal was hidden at a fixed location relative to an array of
landmarks. On array expansion/contraction tests,
several species have been shown to search at locations
that maintained the approximate training vector (distance
and direction) from individual landmarks (e.g. gerbils: Collett, Cartwright & Smith, 1986; pigeons: Spetch, Cheng, MacDonald, Linkenhoker, Kelly & Doerkson, 1997). However, when trained with continuous surfaces
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Figure 1  Schematic representation of the geometrical
information which is available in a rectangular-shaped
environment. The target (filled dot) stands in the same
geometric relation to the shape of the environment as its
rotational equivalent (open dot). Metric information (i.e.
distinction between a short and a long wall) together with sense
(i.e. distinction between left and right) suffices to distinguish
between locations A-C and locations B-D, but not to distinguish
between A and C (or between B and D).

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discrete local landmarks (see for reviews Vallortigara, 2004, 2005). However, little research has been done on this issue using the rectangular-cage task. The issue can be addressed through size transformation tests which preserve shape but alter absolute metrics. Work carried out with pigeons (Kelly & Spetch, 2001) showed that these animals encoded the relative geometry of the enclosure; however, pigeons were tested in a rectangular enclosure without any nongeometric cues available.

In this paper we investigated the ability of young chicks to integrate geometric and landmark information in environmental spaces of different sizes. We selected chicks as models because they have been already tested in the 'geometric module' tasks (Vallortigara et al., 1990; Vallortigara, Pagni & Sovrano, 2004) and because, as a precocial species, chicks can be more conveniently tested with relatively small apparatus than adults. We were also interested in the ability of these animals to generalize reorientation responses between environments of different size. Thus, we trained chicks for reorientation in an enclosure of a certain size (either large or small) and then we tested them for their ability to reorient immediately (without any further training) when located in an enclosure of a different size (smaller or larger).

**Experiment 1**

**Methods**

**Subjects**

Subjects were 15 male domestic chicks (*Gallus gallus*) of the Hybro strain (a local variety derived from White-Leghorn), supplied from a commercial hatchery when they were only a few hours old. The animals were reared singly at a controlled temperature (30°C), with food and water ad libitum. Rearing cages, 25 cm wide × 30 cm high × 40 cm deep, were illuminated by fluorescent lamps.

**Apparatus**

The experimental apparatus consisted of two rectangular wooden enclosures (a large enclosure: 70 cm deep × 40 cm high × 35 cm wide, a small enclosure: 35 cm deep × 40 cm high × 17.5 cm wide) with three uniformly white-coloured walls and one blue wall (Fig. 2). A (cylindric) transparent plastic container (4 cm in diameter; 4 cm in height) was located in each corner (it was similar to the food container which was present in the chicks’ home-cage). Illumination was provided by a light bulb placed perpendicular to the centre of the enclosures. The upper part of the rectangular cages was covered by a one-way screen so that the animals could not use external visual stimuli as directional cues for orientation.

**Procedure**

In their second day of life chicks were accustomed to the experimental environment. During this habituation phase, chicks could freely move in the enclosure and peck at food from the feeder placed in the corner to be reinforced (see below). The habituation condition was the same as the training one, but during this phase no choice was recorded. The habituation phase ended when chicks spontaneously searched for food in the feeders placed in the corners.

On day 3 of life, about 8–10 hours before starting training, chicks were food deprived to induce the necessary level of motivation. Eight chicks were trained in the small enclosure and seven in the large enclosure. Chicks were placed in the centre of the enclosure and were trained to search for the reinforced glass container associated with a particular corner and a fixed position in the enclosure (this will be conventionally referred to as the A corner, but different animals were tested with different corners as reinforced). All four containers were filled with food, but in three containers a very fine wire net prevented the chicks from pecking the food. The same wire net was located also in the correct, reinforced container, but a small hole (1 cm in diameter) was cut into it to allow chicks access to the food. Training started on day 3 of life and consisted of three daily sessions of ten trials (inter-trial interval was 2 min),
separated by a 2-hour interval. In each trial, the chick was placed in the middle of the enclosure and allowed to approach one food container. When the food container in the correct position was chosen, the chick was allowed four–five pecks (reinforcement); after that, the chick was removed and placed in a small closed cardboard box (20 × 20 × 30 cm) outside the test-enclosure. During the inter-trial interval the small box containing the chick was rotated slowly on a rotating chair to eliminate compass or inertial information (disorientation procedure, see also Vallortigara et al., 1990). The test cage was rotated 90° as well from trial to trial. When a food container in an incorrect position was chosen, the chick was immediately removed from the test-enclosure and, after the disorientation procedure, given another trial. The learning criterion was 90% correct in a single session of ten trials. One hour after reaching the learning criterion, a control session of ten trials was given, in which all four containers were closed by the wire net (no hole was present in the correct container). This was done to check that learning was accomplished on the basis of spatial cues and not on subtle cues associated with visibility of the hole in the correct container. Three reinforced trials (in which access to food in the correct container was allowed to the chicks) were intermixed with the control trials, to avoid extinction of the searching responses (these trials were not considered in the data analysis).

The day after the chicks had reached the learning criterion, chicks trained in the large enclosure were tested in the small enclosure and chicks trained in the small enclosure were tested in the large enclosure. (At test, chicks of this strain are about 12.5 cm in length, 6.5 cm in size and 12 cm in height; their weight is about 98.5 g).

During this test phase the chicks were given ten test trials in the absence of food reinforcement (i.e. in which access to food was prevented by the wire net in all four containers). Choices for the four corners were recorded. A choice was considered valid when the chick approached a container entering with its head in an arc of circle area of 8 cm in diameter centred on each corner, irrespective of emission of pecking responses (this was done by looking at the chick’s behaviour on a TV monitor with a superimposed transparent grid). Soon after an approach response the chick was removed from the test-enclosure and, after the disorientation procedure, given another trial. Only first choices were considered. (An extinction procedure with recording of only the first responses is usually preferred in these tasks to avoid both learning effects associated with repeated unsuccessful trials and decrease of motivation, see e.g. Gouteux et al., 2001; Kelly et al., 1998).

Results

There were no differences in the number of trials and errors needed to reach the learning criterion between chicks trained in the small (Means with SEMs: Trials: 71.25 ± 5.15; Errors: 26.125 ± 2.48) and in the large (Trials: 80.0 ± 5.77; Errors: 32.714 ± 3.36) enclosure (respectively, U = 15, n1 = 7, n2 = 8 p > .05; U = 19, n1 = 7, n2 = 8, p > .05, two-tailed Mann-Whitney U-test). The control session confirmed that chicks’ learning was not based on visual characteristics of the food containers and did not reveal any difference associated with the size of the enclosure (mean with SEM percentages of correct choices: large enclosure: 92.86 ± 2.86; small enclosure: 86.25 ± 3.24, U = 16.5, p > .05, two-tailed Mann-Whitney U-test).

Mean percentages of choices for the four corners during test are shown in Figure 3. As can be seen chicks clearly chose the correct (A) corner both in the transfer from a large to a small enclosure and in the transfer from a small to a large enclosure. No differences in the choices for corner A were apparent between the two test conditions (U = 21, p > .05, two-tailed Mann-Whitney U-test). Both in the large and in the small enclosure choices for the correct corner A were significantly higher than choices for the geometrically equivalent corner C (small to large enclosure: T = 0, n = 8, p = .01; large to small enclosure: T = 0, n = 7, p = .02, two-tailed Wilcoxon signed ranks test). There were no differences between choices for the corners B, C and D (small to large: Fr = 0.18, n = 8, k = 3, p > .05, Friedman test; large to small: Fr = 1.5, n = 7, k = 3, p > .05, Friedman test).

The results thus showed that (1) chicks can learn to conjoin geometric and featural information to reorient themselves in both the large and the small enclosure, and (2) transfer occurs very easily both from the large to the small enclosure and from the small to the large enclosure.

Experiment 2

Research on spatial reorientation in animals has made use of two types of landmark information in the rectangular test cage, a blue wall (as in Experiment 1, see Fig. 2) or a distinctive panel located in each of the four corners of the enclosure. Although both types of stimuli provided nongeometric cues for orientation, panels would allow an animal to learn to locate the correct corner using only featural information provided by the panel itself, whereas with the blue wall conjoining of geometric and featural information is needed to disentangle between two geometrically equivalent locations. In the second experiment we used panels at the corners (see Fig. 4)
instead of a blue wall with two aims. First, we wanted to check whether any difference in learning between the large and the small enclosure could be observed in this case. Second, we introduced a geometrical transformation in the spatial arrangement of the panels (the so-called ‘affine transformation’) that puts in contrast geometric and nongeometric information. In the affine transformation, each panel is moved one corner overall in a clockwise or counterclockwise direction. Hence the correct panel is located in a novel and geometrically incorrect location. We wanted to know whether any difference between the large and the small experimental space could be observed in this condition of competing information.

**Methods**

**Subjects**

Subjects were 21 naïve male domestic chicks reared in the same conditions as in Experiment 1.

**Apparatus**

The experimental apparatus was the same as in Experiment 1. This time, however, four different cardboard panels (20 × 4.5 cm) were placed, one for each corner, in the test-enclosure (Fig. 4). The panels differed from each other in colour, brightness and texture; one panel was yellow with brown diagonal stripes; the second panel had green and white vertical stripes (0.5 cm large); the third panel had orange and black horizontal stripes (1.5 cm) and the fourth was light-blue with eight violet discs (each 1 cm in diameter). A different positive panel (i.e. the one that indicated the corner with the food) was used for different chicks (thus, for each panel there were 3 ± 1 chicks in each condition trained with that panel as reinforced).
Procedure

Training was the same as in Experiment 1. Ten chicks were trained in the small enclosure and 11 in the large enclosure. Twenty-four hours after chicks had reached the learning criterion, the chicks were presented, within the same experimental space, with a different arrangement of panels, corresponding to an affine transformation (Fig. 5). All other procedures were the same as in Experiment 1.

Results

There were no differences in the number of trials and errors needed to reach the learning criterion between chicks trained in the small (Trials: 66.36 ± 3.38; Errors: 20.5 ± 1.28) and in the large (Trials: 59.00 ± 2.33; Errors: 24.0 ± 1.19) enclosure (respectively, U = 33.5, n1 = 10, n2 = 11, p > .05; U = 28, n1 = 10, n2 = 11, p > .05, two-tailed Mann-Whitney U-test). Also, no differences were apparent in the control session (mean percentages of correct trials with SEM were: large enclosure: 93.63 ± 2.44; small enclosure: 90.00 ± 2.58; U = 41, n1 = 10, n2 = 11, p > .05, two-tailed Mann-Whitney U-test).

Mean percentages of choices for the four corners during the affine transformation test are shown in Figure 5. Choices for the correct panel (located at test in the wrong position, B) were higher in the large enclosure than in the small enclosure (U = 1, n1 = 10, n2 = 11, p < .02, two-tailed Mann-Whitney U-test). Such a difference was largely due to the fact that chicks tested in the large enclosure showed more ‘geometric’ errors (i.e. choices for the corners A and C) than chicks tested in the small enclosure (AC large enclosure vs. AC small enclosure; U = 1, n1 = 10, n2 = 11, p < .02, two-tailed Mann-Whitney U-test). There were no differences between choices for the corner A and the corner C in either the large (T = 15, p = .2, two-tailed Wilcoxon signed ranks test) or the small (T = 15, n = 10, p > .05, two-tailed Wilcoxon signed ranks test) enclosure.

Results thus showed that (1) there were no differences in reorientation during training with panels between the large and the small enclosure; (2) when faced with contradictory featural and geometric information, chicks rely more on geometry when tested in the large enclosure and rely more on local features when tested in the small enclosure.

Discussion

The experiments with chicks revealed both differences and similarities with respect to the results obtained with...
human infants. Unlike toddlers, chicks conjoined geometric and featural information to reorient themselves in both a large and a small experimental space (Experiment 1). Considering the range of experimental spaces used (even in previously published work in the same species, i.e. Vallortigara et al., 1990 (rectangular cage: $124 \times 60$ cm), Vallortigara et al., 2004 (rectangular cage: $70 \times 35$ cm), it seems clear that species differences do exist with respect to the degree of informational encapsulation of the geometric module: chicks (as well as pigeons, redtail splitfins fish and monkeys) seem to behave quite differently from rats and human infants (see, for discussions, Carruthers, 2002; Cheng & Newcombe, 2005; Newcombe, 2005; Vallortigara & Sovrano, 2002). As in toddlers, however, the reliance on geometric information in chicks seems to depend critically on the size of the experimental space. Interestingly, however, in chicks the effect only emerged when geometric and featural information provided contradictory information (Experiment 2). This suggests that encoding of both types of information occurs whatever the size of the experimental space, but that the use (or the primacy in the use) of geometric and nongeometric information varies depending on the scale of the experimental space.

In a species of fish (redtail splitfins, Xenotoca eiseni) a somewhat similar effect was observed, but only during transfer tests: animals tended to make relatively more errors based on geometric information when transfer occurred from a small to a large space, and to make relatively more errors based on landmark information when transfer occurred from a large to a small space (see Introduction; Sovrano et al., 2005). Such an effect was not observed in chicks. We are not aware of any study in which transfer tests or affine transformation tests were performed in human infants using experimental spaces of different sizes, but the issue is worth checking.

Though certainly not as dramatic as that observed directly in the basic blue-wall task by Learmonth et al. (2002), there seems to be evidence that geometric information is relatively more important in small spaces and/or that featural information is relatively more important in large spaces (or some combination of both) even in non-human species. Based on the results with the blue-wall task, it has been suggested that the size of the nongeometric cue may be crucial, because in the blue-wall task the change in size of the enclosure is also accompanied by a change in absolute size of the blue wall itself (Shusterman & Spelke, in press). This would be in agreement with Gouteux et al.’s (2001) finding that rhesus monkeys could learn to reorient by using a large red square on the wall as nongeometric cue but not by using a small red square. However, the results of Experiment 2 suggest that the distance, rather than the size, of the nongeometric cue may be important: the size of the panels was the same in the large and small enclosures in Experiment 2.

A reasonable explanation for the results of Experiment 2 is to assume that the chicks attempt to match all cues (geometric and featural cues) whenever possible. Geometric cues apply to the overall shape, but featural cues are local in character. At least, the featural cues near the target are most important (and there are data in support of this claim; Cheng, 1986). In the small enclosure, the cue in the other corner along the short wall is near. Let us assume that the chick takes in the target cue and its nearest neighbour along the short wall in the small space. In the large enclosure, distances are doubled, and the chick cares only about the short wall of the target feature. If such an assumption is correct, then what the cue shuffling in Experiment 2 does is to change the nature of the target feature somewhat in the small space, but not at all in a large space. Changing the featural cues degrades the use of featural cues. This is a reasonable assumption since Kelly et al. (1998) found rotational errors with degraded featural cues in several manipulations in pigeons. (Rotational errors arise from using geometric and not featural cues.) Therefore, chicks in the small space use geometric cues more compared with chicks in the large space. One difficulty with this hypothesis is that it assumes that the animals encode the feature in the corner and the more distant feature near the corner. However, previous studies, using similar sizes, found that neither rats (Cheng, 1986) nor chicks (Vallortigara et al., 1990) showed evidence of encoding the distant features within a geometric enclosure. Pigeons, in contrast, demonstrated the ability to use the distant features to correctly locate the positive corner (Kelly et al., 1998). Of course, it is quite possible that chicks would behave like pigeons but only in small spaces.

Further research thus seems necessary, but nonetheless for the moment it could be reasonably argued that animals are likely to be ‘prepared’ to treat nongeometric features as orienting cues (landmarks) only when they are perceived as far away, but not when they are perceived in close proximity (the effects of the size of the nongeometric cues observed in other tasks by Gouteux et al., 2001, may be explained with the same logic, assuming absolute size of a stimulus to be used by animals as a rough estimate of its proximity).

The size of the experimental space used in reorientation tasks thus seems to be important for animals. Very likely this could be accounted for in terms of a preference to use distal rather than proximal cues as landmarks. In this vein, Nadel and Hupbach (2005) suggested that the size of the organism can also make a contribution, and that this could explain the developmental pattern observed
in humans. In the small room, a blue wall that cannot be more than 6 feet away is not treated as a landmark by children; in the large room, the same blue wall, which can now be up to 12 feet away, is treated as a landmark (see Learmonth et al., 2002).

In conclusion, although the size of the environment may affect the primacy in the use of geometry or landmark information, both types of information seem to be actually encoded and used in conjunction in animals’ reorientation.

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