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A Matter of Trust: When Landmarks and Geometry Are Used During Reorientation

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Abstract

The size of the experimental enclosure used in a reorientation paradigm appears to have a profound effect on very young children (Learmonth, Newcombe, & Huttenlocher, 2001; Learmonth, Nadel, & Newcombe, 2002) and non-human species (Sovrano, Bisazza, & Vallortigara, 2005; Sovrano, & Vallortigara, 2006; Vallortigara, Feruglio, & Sovrano, 2005). Greater preference has been found for geometric information when reorienting in smaller environments than in larger spaces once geometric and featural cues are placed in conflict (Chiandetti, Regolin, Sovrano & Vallortigara, in press; Sovrano, Bisazza, & Vallortigara, 2007; Sovrano & Vallortigara, 2006). We present two studies suggesting that: (a) when a landmark is placed in conflict with the geometry of an experimental space, adults favor geometric information only in a small room and favor featural information in a larger room, and (b) training in a large room increases use of features in a small room. These results provide evidence that the supposed dominance of geometric information in guiding reorientation is limited to small, fully-enclosed spaces. Flexible reorientation, encompassing all available spatial cues, is characteristic in larger spaces or when learning history and experience have established the usefulness of features.

Key Words: navigation; reorientation; adaptive combination.

Introduction

Determining one's specific location after being disoriented is a basic adaptive challenge for all mobile organisms. The development and production of such navigational abilities often relies on an allocentric process where direction and distance are measured using various types of spatial cues such as geometric and featural information (Gallistel, 1990; Newcombe, 2002). However, there has been much debate as to how these various sources of spatial information are utilized during reorientation.

Research on human and nonhuman spatial reorientation has revealed that all varieties of species tested thus far navigate using the geometric shape of an environment following disorientation, while use of features (such as distinctive wall colors or panels) has only been found in certain circumstances, such as larger environments, when landmarks are distal, or when the feature directly marks the site of the hidden target (see Cheng & Newcombe, 2005 for a full review). Some have argued that these results suggest a modular view of reorientation, in that a mental representation of the space is formed within an encapsulated geometric module that only incorporates information about the *shape* of spaces (Cheng, 1986; Gallistel, 1990; Hermer & Spelke, 1994, 1996; Wang & Spelke, 2002; see Cheng & Newcombe, 2005 for an overview).

As an alternative to modularity, evidence within a variety of domains suggests that spatial information sources are frequently combined to determine judgments and behavior using weighting mechanisms. Within the spatial domain, methods using weighting mechanisms include Huttenlocher, Hedges and Duncan's (1991) hierarchical combination model and Hartley, Trinkler and Burgess' (2004) boundary proximity model (see Cheng et al., in press; Newcombe & Ratliff, 2007, for overviews). Such approaches can be classified as examples of the adaptive combination view, which focuses on the certainty and variability of encoding of spatial cues to determine the weight placed on that information (Newcombe & Huttenlocher, 2006). Organisms are more likely to use information that is more salient, certain and less variable, as well as information that is more familiar to the organism from prior experience. During reorientation, an adaptive combination view suggests that geometric and featural information are utilized in varying degrees at varying points in development, depending on the certainty and variance with which the two kinds of information are encoded, along with the salience of the cues, their perceived usefulness, and the organism's prior experience using the cues (Newcombe & Ratliff, 2007).

When and How Features Are Used

In contrast to evidence supporting a geometric module account of reorientation, many non-human species use features in addition to geometric information during reorientation in a wide array of circumstances. Vallortigara, Zanforlin and Pasti (1990) found that chickens used both geometry and features to reorient within a rectangular enclosure; however, this use was limited to featural cues that directly marked the target or rotationally opposite corner. Kelly, Spetch and Heth (1998) found more flexible feature use among pigeons, reorienting by both direct and indirect features in conjunction with geometry to guide searches for food. Additionally, when features were placed in conflict with the learned geometry of the space (distinct panels placed in the corners rotated to adjacent corners) the history of the pigeon's exposure to the featural cues affected their reliance on them. Pigeons trained in the presence of the feature panels primarily used this information, even in the conflicting geometric locations, whereas the pigeons trained initially with only geometry showed a mixed use of features and geometry.

Rhesus monkeys also demonstrate flexible reorientation using both room geometry (rectangular shape) and a large feature (colored wall) to locate a reward (Gouteux, Thinus-Blanc, & Vauclair, 2001). However, the monkeys only used large features to distinguish the room shape while ignoring small cues. This may be explained by cue validity, in that small objects are more likely to move and thus provide less stable landmarks than large objects. Since size often relates to weight, larger objects in the environment are viewed as heavy and harder to move, providing a more stable distant landmark. There is even some neurobiological evidence to support the importance of proximity when utilizing features, in that the head-direction cells of rats seem to depend on information from distal rather than proximal cues (Zugaro et al., 2004).

Fish have been trained to locate an exit within a small rectangular fish tank by using either featured panels in each corner or a colored wall along one side of the tank in addition to the available geometry (Sovrano, Bisazza, & Vallortigara, 2002). Interestingly, when trained in a small tank and later tested in a larger tank, fish make relatively more geometric errors, whereas fish trained in a large space then tested in a small tank rely greatly on features to reorient (Sovrano, Bisazza, & Vallortigara, 2005). Size of the enclosure also changes reorientation strategies when a feature, such as a colored wall, is shifted during testing from the learned location. When the learned geometry and feature locations are placed in conflict, fish (Sovrano, Bisazza, & Vallortigara, 2007) as well as chicks (Chiandetti, Regolin, Sovrano & Vallortigara, in press; Sovrano & Vallortigara, 2006) reorient by the geometry of a small enclosure but incorporate features to a greater extent in the larger space.

The effect of room size is seen among human children as well. Disoriented children 17 to 24 months (Learmonth, Newcombe, & Huttenlocher, 2001) and 3 to 5 years (Learmonth, Nadel, & Newcombe, 2002) used a variety of featural landmarks, including a bookcase or a colored wall, to reorient in a room larger than the original Hermer and Spelke (1994, 1996) studies. Although the larger room is four times the area of the original small room, the ratio of long to short walls remains the same as the original Hermer and Spelke room. All children in this larger room successfully used the features to reorient above chance and performance improved with increasing age. However, all children demonstrated geometric encapsulation in the small room until the age of six years.

Explaining the Room Size Effect

All of the previously reviewed studies include fully enclosed rectangular environments in which geometric information is easily encoded with great certainty and low variability. Geometric information could therefore be expected to predominate in these studies. However, when geometric information is more ambiguous, as found with a partially enclosed environment, its use in guiding reorientation is less powerful (Gouteux & Spelke, 2001; Poucet, Lenck-Santini, & Save, 2003).

The previously reviewed studies with children and nonhuman species demonstrate the profound effect of room size on determining whether features will be used during reorientation. The further away a feature is located from an organism the greater they will rely on this cue as compared to the location of a proximal feature because movement around a local area creates only small variations in the location of the distal feature but very large variations in the location of a local feature according to an adaptive combination model (Newcombe & Ratliff, 2007).

An organism's prior experience and learning history would also be predicted to greatly affect the weight given to featural information according to an adaptive combination model. Striking evidence for this idea was recently reported when wild-caught mountain chickadees, having spent little to no time in enclosed rectangular environments, showed a dominant use of features overshadowing geometry during reorientation (Gray, Bloomfield, Ferrey, Spetch & Sturdy, 2005). The chickadees also used geometry to a reduced degree when it is the only information available as compared to other studied organisms. Similarly, fish that have been raised in circular tanks reorient more by featural information than geometry as compared to fish raised in rectangular tanks (Brown, Spetch, & Hurd, in press).

These findings, in addition to those previously reviewed, support the adaptive combination view that cue validity, strength of encoding, and prior experiences, such as rearing environments and training history, play an important role in affecting the utilization of features and geometry during reorientation. Geometry is not dominant over featural information as a rule, but rather, the use of such spatial cues depends on the weights associated with them. By placing geometric information in conflict with features in Experiment 1, we examine to what degree geometric and featural information guides adult human reorientation in two different sized environments. We expect that the adults will rely on the geometric information to a greater degree in the smaller environment, with increased use of features in the larger enclosure, due their history with the usefulness of distal versus proximal landmarks.

Learning history and prior experience appear to affect the use of features. If featural information is indeed utilized to a lesser degree in the small room than in the larger room of Experiment 1, would manipulating learning experience affect this difference as predicted by the adaptive combination model? Specifically, we wanted to know whether training in the large room would increase use of features during testing in the small room. We consider these possibilities in Experiment 2 by again placing geometric information in conflict with features in both a large and small environment after training in the opposite sized room.

Experiment 1

In this study, we placed geometric and featural information in conflict with each other within a learned environment.

Participants were trained with a location memory task in either a small, fully enclosed rectangular space or a larger rectangular room, four times the area of the small one. However, the ratio of long to short walls remained constant across room sizes, providing equivalent geometric information in both environments. Each room had a stable featural landmark on the wall during training that was moved, out of sight of the participants, to the adjacent wall prior to testing. We expected adults to reorient in a more geometrically driven manner in the small room, while showing greater dependence on feature location in the larger room. Increased feature driven searches in the large room would cast doubt on the modular viewpoint that geometric information dominates spatial reorientation as a rule.

Method

Participants. Thirty-two college undergraduates at Temple University were recruited from introductory psychology classes and given course credit. Six males and 10 females were randomly assigned to the small room, and seven males and nine females were randomly assigned to the larger room.

Apparatus and materials. Participants were tested in either a small rectangular enclosure (four ft. by six ft.) or a larger enclosure (eight ft. by 12 ft.). Thus the area of the larger room is four times that of the small room, but the ratio of long to short walls remains the same. The smaller "room" consisted of a frame with white fabric covering the four walls and the ceiling, and four 25-W lights attached at the top of each corner to illuminate the room and avoid any directional light cues. The larger "room" consisted of white fabric affixed to the ceiling of the experiment room and two symmetric overhead lights illuminating the room without giving any directional light cues. In both "rooms" one of the short walls served as a door and was sealed with Velcro when closed to retain the symmetry of the room. The featural landmark used for both rooms was a moveable piece of brightly colored, patterned fabric, which stands out from the all-white background but is flush with the wall. Identical plastic containers in each corner served as potential hiding places for the target object. Participants listened to white noise through headphones to prevent any sound cues during the task. A key chain with four keys attached served as the target search object.

Design and Procedures. Participants were randomly assigned to either the small or larger room. Participants then received four training trials with the stable landmark feature to familiarize them with the spatial layout of the room. The training trials consisted of the experimenter showing the participant the target item (keys) while standing in the middle of the room. The experimenter then hid the keys in one corner that was either directly marked by the feature (the feature was located at the hiding corner) or indirectly marked by the feature (the feature was located in the middle of the wall, adjacent to the hiding corner) (see Figure 1). Feature location was counterbalanced and matched across conditions, so that an equal number of participants received direct or indirect trials for each room size.

The experimenter instructed the participants to spin slowly in place (at least 10 full rotations) and change directions upon cue. The experimenter walked around the participant at varying speeds as to not provide a landmark cue as well. The participant then stopped spinning and faced the predetermined direction. The target was hidden in the same corner for each of the training trials within subjects. The facing position of the participants and the hiding corner for each participant was counterbalanced in each condition and matched across conditions, so that an equal number of trials ended with subjects facing each wall and the object being hidden in each corner between subjects. After disorientation, the experimenter asked the participant, "Where did I hide the keys?" noting any pauses longer than 5s and telling them to "point" if they hesitated.

After the four training trials, the participants were instructed that the test trials would consist of the same task and they must remember, "the keys will be in the same place as they were during training, but you will not see me hide them this time." All participants were led outside the room and asked to draw a sketch of the enclosure to establish encoding of the geometry and features. While the participant waited outside the room, the experimenter moved the feature from its trained position to the next adjacent clockwise corner (direct) or middle panel (indirect). After the short break, the experimenter blindfolded the participant and led them back into the middle of the room. The participant then performed the same disorientation procedure previously described. Once the participant stopped spinning and took off the blindfold, they pointed to a corner, indicating where they thought the target object was located. No feedback was given on whether they were correct or incorrect. The experimenter then asked which corner they would pick for their second choice. The experimenter recorded the first and second choices as the landmark corner (L), a geometrically appropriate corner (G), or the error corner (E) as shown in Figure 1. Another test trial of the same procedure was then performed with the feature location in the same shifted position as test trial 1.

Following the test trials, participants were de-briefed about the purpose of the experiment and asked about what strategy, if any, they used to reorient. We calculated for each participant a proportion of search trials at landmark (L) and combined geometric (G+G) corners for each trial. We used single sample *t* tests (all two-tailed unless specified otherwise) to examine crucial contrasts in landmark and geometric search performance between the two room sizes.

Results

Figures 1a and 1b present the mean proportion of landmark and geometric first searches during trial 1.

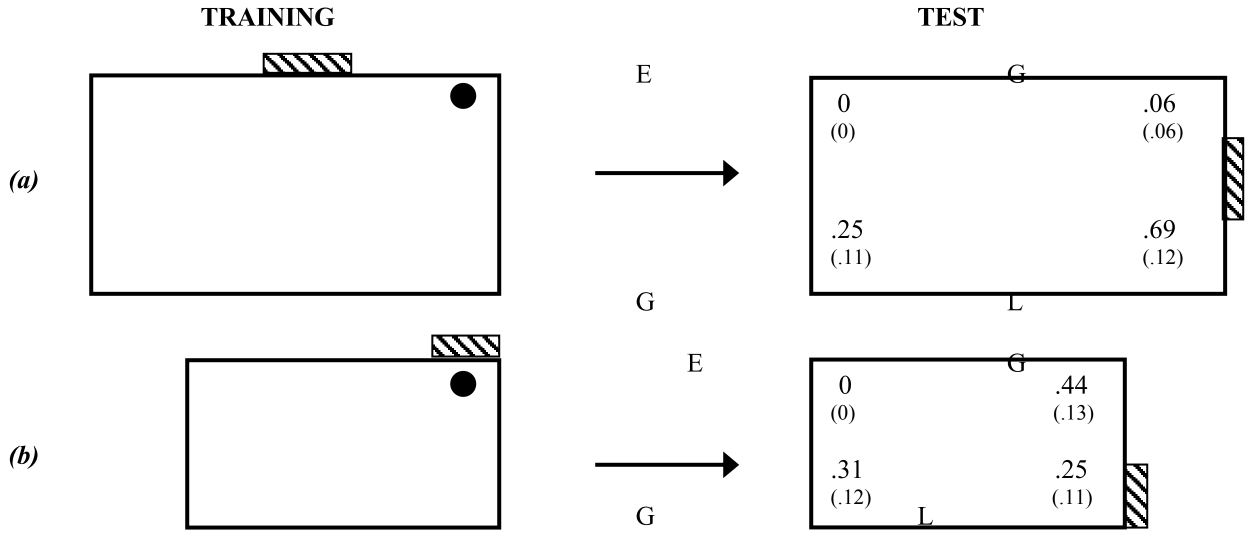

Figure 1. Adults received four trials with a stable target and were tested in either (a) a large or (b) a small rectangular room. Mean proportions (with standard errors) of first searches after the landmark shift are presented on the right (G=geometric corner, L=landmark corner, E=error corner). Feature location was counterbalanced across all participants in both room sizes, but for space concerns we present two examples here by either marking the target directly (bottom) or indirectly (top).

There was no effect of gender, $F(1,24) = 0.43$, $p = .52$, or feature location, $F(1,24) = 2.08$, $p = .16$, on either landmark or geometric searches. However, room size had a significant effect on whether participants chose landmark or geometrically appropriate corners, $F(1,24) = 6.19$, $p = .02$. Participants in the small room first searched at the geometric corners where the target was located during the training session significantly more often than did those in the larger room, $t(30) = 2.67$, $p < .01$ (one-tailed). The opposite response strategy was found for the participants in the larger room, who first searched the corner relative to where the landmark was now located, significantly more often than did the participants in the small room, $t(30) = 2.67$, $p < .01$ (one-tailed).

Room size had a profound effect on participants' initial search strategies. Participants searched the geometrically appropriate corners from the training layout significantly more often in the small enclosure than in the larger space. However, participants used the location of the featural landmark to reorient, despite its shifted location from the trained layout, in the larger room as compared to the small room. The feature was not serving as a direct beacon in this case either, as there were no differences in search behavior for participants using the feature that directly marked the target or those who used the feature in an indirect manner.

Experiment 2

In order to examine the effects of learning history on adult spatial reorientation, we replicated Experiment 1 but switched room size between training and testing. Hence, half the participants were trained in the larger room and tested using the shifted landmark in the small room and vice versa for the other half of participants. Finding that learning history can increase the use of features in the small room among reorienting adults would support an adaptive combination view of explaining human reorientation based on cue weighting rather than the existence of a geometric module.

Method

Participants. Thirty-two Temple undergraduates were recruited as previously described and randomly assigned to two groups, with six males and 10 females in each group.

Apparatus, Design and Procedures. Participants were randomly assigned to the large or small room for the training session and followed the same reorientation procedure in Experiment 1. Following training, participants were then given the test trials in the opposite size room. As such, half of the participants learned the spatial layout of the small space and experienced the landmark shift in the larger room, whereas the other half received training in the larger room and were tested in the small room (see Figure 2). The experimenter recorded the participants' searches and analyzed the data as described in Experiment 1.

Results

Figures 2a and 2b present the mean proportion of landmark and geometric first searches during trial 1.

There were no effects of feature location, gender, or room size on either landmark or geometric searches (all F's $< .13$, p's $> .72$). All participants used the same search strategy with no differences between the larger and small rooms, $F(1,28) = .35$, $p = .56$. That is, participants initially searched based on the location of the *feature* significantly more than the geometry, even after the landmark location shifted from the trained layout with respect to the geometry of the room,

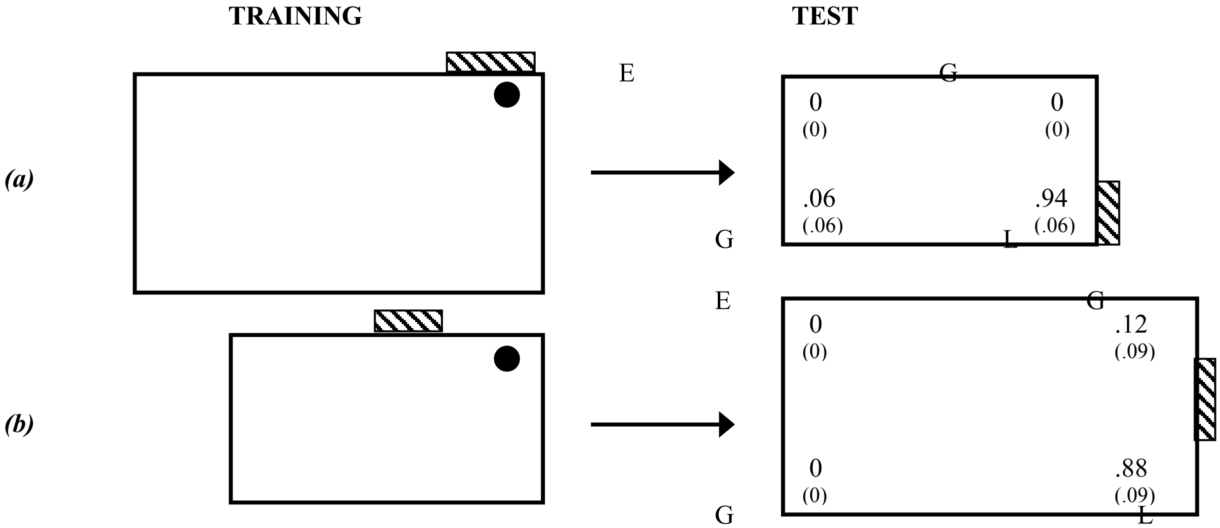

Figure 2. Adults were either (a) trained in a large room and tested in a small room, or (b) trained in a small room and tested in a large room. Mean proportions (with standard errors) of first searches after the landmark shift are presented on the right. Feature location was again counterbalanced across all participants in both room sizes using the two examples shown here by either marking the target directly (top) or indirectly (bottom).

for *both* the small, $t(15) = 4.39$, $p < .01$, and larger testing enclosures, $t(15) = 7.00$, $p < .01$. Interestingly, the participants who were trained in the larger space and subsequently tested in the small room searched at the featural corner significantly more often than the participants tested in the small room in Experiment 1, $t(30) = 4.44$, $p < .01$.

Again, use of features during reorientation was greatly increased by exposure to the larger room, whether during a brief training session or during the two test trials alone. Reorientation was dominated by the location of the feature in both small and larger rooms in this shifted landmark task. Participants initially searched for the keys according to the location of the featural landmark, ignoring the geometric information. The brief training session in the larger space is enough to shift response strategies from geometry based to feature driven in the small enclosure following landmark displacement. Perhaps even more striking is that training in the small room resulted in featural driven reorientation when testing occurred in the larger space.

One may argue these findings do not provide evidence against modularity because the geometric module may be deactivated when switching room sizes from training to testing, which leaves only the featural information to guide searches. However, this explanation is unlikely due to the fact that the ratio of long to short walls remains constant in the two testing environments, despite the size change, resulting in the same relative geometric information in both rooms. Additionally, we know that training in the small room encourages encoding of, and subsequent reorientation by, geometry over features. Therefore, finding that features guide reorientation in the larger space suggests a change in strategy relative to the change in room size, not an inactivated geometric module.

Discussion

In the present experiments we found that adults use both geometric and featural properties of environments in order to reorient and find a hidden object. By shifting a landmark's position during a reorientation task in a small versus larger space, we placed the geometric information of the learned spatial layout in conflict with the learned location of a feature within that space. In Experiment 1, we found that in pitting features against geometry, adults choose to reorient by the geometric room shape in a very small enclosure, but the feature is used to guide navigation in a larger space.

We also examined in Experiment 2 whether learning history affects the use of features in instances of competing information by training the adults in either the larger or small space and then performing the shifted landmark task in the opposite sized room. Adults reoriented strictly by the location of the feature, regardless of room size. It appears that exposure to the larger room, either during four training sessions or two test trials, drastically increases the use of features during reorientation.

Taken together, these results provide evidence against an encapsulated geometric module guiding reorientation and suggest a more flexible approach to explaining spatial navigation and development. We have shown that geometric information does not necessarily dominate over features during human reorientation. In fact, reorientation guided by featural cues is highly malleable given sufficient prior experience using the feature and the opportunity to encode the feature with low variability and high certainty, as in the case of a more distal landmark in the larger space. The present findings also correspond to the adaptive combination model predictions that feature use will increase in larger spaces due to such factors as cue validity and strength of encoding (Experiment 1) and prior experience using features as spatial cue to increase their perceived usefulness (Experiment 2). The adaptive combination approach provides an appropriate fit to the behavioral data and accounts for why some sources of information are weighted more heavily than others in determining orientation, without proposing a modular architecture.

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