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Is language necessary for human spatial reorientation? Reconsidering evidence from dual task paradigms ☆

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Abstract

Being able to reorient to the spatial environment after disorientation is a basic adaptive challenge. There is clear evidence that reorientation uses geometric information about the shape of the surrounding space. However, there has been controversy concerning whether use of geometry is a modular function, and whether use of features is dependent on human language. A key argument for the role of language comes from shadowing findings where adults engaged in a linguistic task during reorientation ignored a colored wall feature and only used geometric information to reorient [Hermer-Vazquez, L., Spelke, E., & Katsnelson, A. (1999). Sources of flexibility in human cognition: Dual task studies of space and language. *Cognitive Psychology*, 39, 3–36]. We report three studies showing: (a) that the results of Hermer–Vazques et al. [Hermer-Vazquez, L., Spelke, E., & Katsnelson, A. (1999). Sources of flexibility in human cognition: Dual task studies of space and language. *Cognitive Psychology*, 39, 3–36] are obtained in incidental learning but not with explicit instructions, (b) that a spatial task impedes use of features at least as much as a verbal shadowing task, and (c) that neither secondary task impedes use of features in a room larger than that used by Hermer–Vazquez et al. These results suggest that language is not necessary for successful use of features in reorientation. In fact, whether or not there is an encapsulated geometric module is currently unsettled. The current findings support an alternative to modularity; the *adaptive combination* view hypothesizes that geometric and featural information are utilized in varying degrees, dependent upon the certainty and variance with which the two kinds of information are encoded, along with their salience and perceived usefulness.

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1. Introduction

In order to survive, humans and all other mobile animals must be able to locate desirable objects in their surrounding environment, and avoid areas of danger. Spatial orientation and navigation abilities seem to rely on two major coding systems: a self-based "dead reckoning" system that tracks the location of the self in relation to the environment as the self moves, and an environment-based allocentric system, in which location is coded in terms of the surroundings (Gallistel, 1990; Newcombe, 2002; Sholl, 1992). These systems are complementary, with the dead reckoning system proving vital when landmarks are lacking, as in the dark or on the open ocean. However, the allocentric system is required for avoiding the inevitable drift that occurs in dead reckoning, created by the concatenation of small errors in judging distance and the angles of turns. This environment-centered spatial orientation system is further distinguished by its utilization of two types of spatial information: geometric and nongeometric. The shape of a landmark is typically regarded as geometric information, while all other characteristics of the landmark, such as color, texture, and size, are regarded as nongeometric or featural information.

A unique situation occurs when a mobile creature has lost the ability to use the dead reckoning system, due, for example, to rapid and erratic turns or (in humans) passive underground travel as by subway. In this case, environmental information is clearly required to re-establish orientation. However, interestingly, not all environmental information appears to be created equal for disoriented animals. Cheng (1986) examined how rats searched for previously located food hidden in one corner of a rectangular enclosure after a disorientation procedure of removing and replacing the rat in a different position. He found that rats searched the geometrically equivalent corners in an unfeatured enclosure, that is, they systematically chose the correct corner and the corner diagonally opposite in a featureless rectangular environment, showing that they encoded the geometric properties of the space including metric and sense information (length of short versus long walls and left-right relationships, respectively). Further, Cheng found that when he added features that would allow the rats to distinguish between the two geometrically equivalent corners, such as walls differing in shade or patterned corners, the rats continued to divide their search evenly between the two geometrically equivalent corners when the correct location changed across trials. However, when the correct location remained constant, the rats did learn to use the features but only in the case of a direct cue at the correct location. Once the distinguishing feature at the target location was removed, the rats did not use the remaining cues in surrounding corners, reverting to a more geometric reorientation strategy. That is, geometric information was seemingly always used to reorient, whereas featural information was secondary and had limited use among disoriented rats.

From these data, the proposition of a geometric module designated for spatial orientation emerged (Cheng 1986; Cheng & Gallistel, 1984). Such a module would serve to process the geometric properties of an organism's surroundings, determined by metric and sense information, in order to guide spatial navigation. The module is encapsulated, in

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Fodor's (1983) sense, in that geometric information is the *only* source utilized for spatial representations and subsequent navigation. Even though nongeometric information may allow one to correctly identify a specific location, such as using a colored wall to distinguish between two geometrically correct corners in a rectangular enclosure, this information is not considered during reorientation within a modular view. Gallistel (1990) argued that the existence of such an encapsulated module might be adaptive because geometry is often preserved when features change, e.g., when the shape of a river bank is maintained despite changes in the muddiness of the water.

Hermer and Spelke (1994, 1996) examined the possible existence of a geometric module in humans. They found that human children, when asked to search for a toy that they had watched the experimenter hide in one corner of a rectangular room, behaved much like Cheng's rats. After being spun in circles with their eyes closed to become disoriented, children as young as 18 months searched for a hidden toy in the two geometrically equivalent corners of an unfeatured room, suggesting a remarkable sensitivity to relative length and sense of the walls. However, children until the age of 6 years did not use nongeometric information, such as colored walls, even when given the opportunity.

One explanation for this shift in use of features between the age of 5 and 6 years is that children then become able to use the linguistic terms "right" and "left". In support of this idea, Hermer-Vazquez, Moffet, and Munkholm (2001) found a correlation between use of these terms and use of features in the reorientation task. However, correlational evidence is inherently weak, being subject to third variable problems. More striking evidence for the role of language in the ability to overcome an inherently modular cognitive architecture was reported by Hermer-Vazquez, Spelke, and Katsnelson (1999). They found that adults simultaneously performing a verbal shadowing task while also searching for objects following disorientation behave like children and rats, failing to use a colored wall to constrain searches in a rectangular room. The participants did, however, use the colored wall while simultaneously performing a nonverbal rhythm-clapping task, suggesting that it was language rather than simple cognitive overload that impeded the ability to use featural information. These results have seemed to provide strong support for the conclusion that language is necessary for allowing adults to overcome the encapsulation of the geometric module.

More recently, however, there have been questions concerning the proposed modular architecture and about the necessity of language for supporting spatial reorientation across various species. First, studies with non-human (and hence non-linguistic) animals have cast doubt on these two related ideas, by showing that features are sometimes used as well as geometry in the reorientation task (Chiandetti, Regolin, Sovrano, & Vallortigara, 2007; Sovrano & Vallortigara, 2006; Vallortigara, Zanforlin, & Pasti, 1990 for chickens; Kelly, Spetch, & Heth, 1998 for pigeons; Gouteux, Thinus-Blanc, & Vauclair, 2001 for monkeys; Sovrano, Bisazza, & Vallortigara, 2002, 2003, 2005, 2007, for fish). However, while these findings from animal research might seem to provide strong evidence against the geometric module hypothesis, particularly against the idea that language is necessary to integrate geometric and nongeometric information, Sovrano et al. (2003) point out that though some nonverbal animals are successful in completing these spatial tasks, this does not necessarily mean that they use the same mechanisms to perform the tasks that humans would use. Similarly, Hermer-Vazquez al. (2001) have suggested that these results from non-human studies might be a reflection of the extensive training typically found when working with animals. Thus, direct evidence from humans is necessary to support this argument. Not only is evidence from humans warranted in order to understand how and under what circumstances different spatial cues are utilized, such evidence would verify if indeed human and non-human reorientation systems are homologous.

In a series of studies, Learmonth, Newcombe, and Huttenlocher (2001) found that children as young as 18 months do use featural landmarks in addition to the shape of the room to successfully reorient and find a hidden toy. Learmonth et al. replicated Hermer and Spelke (1994, 1996) finding that disoriented children use geometric information to search at the two geometrically equivalent corners of a featureless rectangular room, using an area four times that of the original Hermer and Spelke studies. However, when features were added to the larger room, such as a door to the room on one long wall and a recessed bookcase on the other long wall, children between 18 and 24 months used these landmarks, in addition to the shape of the room, in their search for the toy. Further experiments established that children could successfully reorient using a single landmark (including a colored wall) as well, suggesting that human children can integrate geometric and nongeometric information to successfully complete these spatial tasks prior to acquiring spatial language.

A key factor leading to the difference in results was the size of the room (Learmonth, Nadel, & Newcombe, 2002). Hermer and Spelke had used a very small room, but more distal features are more valuable spatial cues and hence might be more likely to be used (Nadel & Hupbach, 2006; see also Wang & Spelke, 2002). Further evidence of the importance of distal versus proximal landmarks on influence of feature use is found in recent work with non-human animals. Fish make relatively more geometric errors when reorienting in a small tank and rely more on features when reorienting in a large tank (Sovrano et al., 2007). Similarly, when faced with conflicting geometric and featural cues from a learned spatial representation, chicks (Chiandetti et al., 2007; Sovrano & Vallortigara, 2006; Vallortigara, Feruglio, & Sovrano, 2005) and fish (Sovrano et al., 2007) rely on geometry to reorient in a small enclosure but use features to a greater extent in a larger environment. 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).

Although it is interesting and important for the understanding of spatial development to answer the question of why young children use features in addition to geometry in the larger room but not the small room, these results still provide evidence that children and even non-human animals are *not limited* to geometric information when reorienting in a rectangular enclosure. The finding itself, that spatial reorientation occurs in these various groups, is of vital importance to the debate on the very existence of a geometric module. Additionally, the data from very young children and non-human animals raise serious concerns for the suggestion that acquiring spatial language is essential for the ability to combine featural and geometric information.

Nevertheless, the striking data of Hermer-Vazquez et al. (1999) require explanation. Why is it that human adults required to do a verbal shadowing task (but not a control task that seemed equally attention-demanding) fail to use a feature as large as a colored wall to guide search? We suggest that there are two possible ways to explain these results. First, in the Hermer-Vazquez et al. study (1999), adults were simply informed prior to the disorientation procedure that, "you will see something happening that you should try to notice," and that they would be asked about what they saw. Following these vague instructions, and with no practice trials, the search task in a rectangular room with a blue

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wall occurred, followed by search without shadowing in that room, and by search in an all-white room. Order was not counterbalanced. It is possible that, if given a clearer idea of the demands of the reorientation task, adult participants could search the correct corner at greater than chance levels *even while* engaged in verbal shadowing. We examine this idea in Experiment 1.

Second, the verbal shadowing task used by Hermer-Vazquez et al. (1999) might disrupt the ability to use featural landmarks not (or not only) by interfering with a linguistic encoding process within a geometric module, but by interfering with a non-linguistic, non-modular spatial encoding system, whereby geometric and nongeometric information is weighted depending on the certainty and variance with which the two kinds of information are encoded and then utilized accordingly. The nonverbal rhythm-clapping task used by Hermer-Vazquez et al. (1999) might be ill-suited to examine this possibility because it involves primarily cerebellar regions of the brain (Woodruf-Pak, Papka, & Ivry, 1996) and would not be expected to engage spatial coding systems. A nonverbal *spatial* task might, however, interfere with the integration of geometric and featural information in the reorientation task (Newcombe, 2005). We look at this issue in Experiment 2.

Experiment 3 in this paper examines whether linguistic and/or spatial tasks affect the use of features to reorient in a larger room than that used in the Hermer-Vazquez studies. One potential way to explain the fact that successful use of features begins earlier in larger rooms would be to postulate that the mechanisms needed to combine features and geometry differ as a function of the size of the space. In particular, perhaps language is helpful (if not absolutely necessary) in the smaller room, but not essential in the larger one. We consider these possibilities in Experiment 3.

2. Experiment 1

One condition of this experiment was a straightforward replication of Hermer-Vazquez et al. (1999) basic paradigm (their Experiment 1) in which participants received vague task instructions, no practice trial and a fixed order of conditions beginning with shadowing in the presence of the colored wall. In a second condition, participants were given additional instructions about the nature of the search task, performed a practice trial prior to performing the reorientation task, and then completed the three blocks of trials in a counterbalanced order. Successful search in this second condition would cast doubt on the hypothesis that language is essential to integration of geometric and featural information.

2.1. Method

2.1.1. Participants

Two groups of college undergraduates at Temple University were tested. All participants were recruited from introductory psychology classes and were given course credit. Nineteen participants were randomly assigned to each group for a total of 38. For the first condition (replication of Hermer-Vazquez et al., 1999) there were seven males and 12 females. One participant was omitted from the original sample and replaced according to the criteria set by Hermer-Vazquez et al. (1999) because she maintained her sense of orientation despite the disorientation procedure, as indicated by perfect search performance in the white room. For the explicit direction condition, there were five males and 14 females. One participant was omitted from the original sample and replaced because he could not perform the verbal shadowing task. Three participants in each condition had four pauses greater than 2 s, which might suggest that they were not devoting sufficient attention to verbal shadowing. They are in the data set reported below, because the findings remain the same when they are excluded.

2.1.2. Apparatus and materials

Participants were tested in a small rectangular enclosure, as used by Hermer-Vazquez et al. (1999), with short sides four feet in length and long sides six feet in length (1.92 × 1.23 × 1.92 m) located within a larger experiment room with no windows or sources of outside noise. The smaller "room" was constructed 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 of the enclosure to illuminate the room and avoid any directional light cues. One of the short walls drew back as a curtain to permit entry into the room and was sealed with Velcro when it was closed to retain the symmetry of the room. A blue sheet of fabric was affixed with Velcro to one short wall, opposite the entrance, during the featural landmark conditions, so that it covered the wall completely. Identical plastic containers, used as potential hiding places for the target object, were affixed to each of the corners of the room. During the shadowing session, a portable cassette player with headphones was used to play the tape recording of the experimenter reading political articles. During the non-shadowing conditions, the participants listened to white noise through the headphones to prevent any sound cues in maintaining orientation. A key chain with four keys attached served as the search target object.

2.1.3. Design and procedure

Participants were randomly assigned to one of two conditions. One condition replicated the procedure of Experiment 1 by Hermer-Vazquez et al. (1999). Before the experiment began, participants were instructed, "You will see something happening that you should try to notice," and were informed that they would be asked about what they saw. Participants were also instructed to allow themselves to become disoriented in the room instead of trying to maintain their orientation. For the other condition, subjects were given more explicit instructions as to the nature of the search task. Before the experiment began, participants were instructed, "This is a visual search task. I will hide an object in a corner of the room and then you will spin around in place with your eyes closed. Allow yourself to become disoriented in the room rather than trying to maintain your orientation. When I tap you on the shoulder you may open your eyes and point to where you think the object was hidden."

Immediately after receiving instructions, participants in the replication condition were trained to perform the same verbal shadowing task used by Hermer-Vazquez et al. (1999), which served as a difficult secondary task and an effective form of interference. While seated at a desk, participants listened through headphones to a tape recording of the experimenter reading political articles. Participants were trained to repeat the verbal material as they heard it, word by word, instead of waiting for larger phrases. An experimenter timed their performance until they were fluent enough to shadow for 2 continuous minutes without pausing for more than 2 s at any time. Once this criterion had been reached, the replication participants began continuously shadowing, and the experimenter led each participant into the smaller testing room to begin the reorientation task.

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For both conditions, the reorientation task consisted of participants being shown the target item (keys) while standing in the middle of a rectangular enclosure. The keys were then hidden in the predetermined corner of the room by the experimenter and the participant was cued to close their eyes. The experimenter disoriented the participants by spinning them around in circles, at least 10 full rotations, while also changing the direction of rotation. During disorientation, the experimenter walked around the subject at varying speeds as to not provide a landmark cue. The participant was then stopped facing the predetermined direction by the experimenter. The hiding corner of the target and facing position of the participants were 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. After disorientation, the experimenter cued the participant to open his or her eyes by tapping them on the shoulder and asked them, "Where did I hide the keys?" As in Hermer-Vazquez et al. (1999) Experiment 1, participants either pointed to a corner, or the experimenter told them to "point" if they hesitated.

For both conditions, the reorientation task was given four times in each of three different environments for a total of 12 search trials. For the replication condition, the twelve searches were given in a fixed order as per Hermer-Vazquez et al. (1999): four search trials in the blue wall room while shadowing, followed by four trials in the blue wall room with no secondary task, and lastly, four trials in the all-white room with no secondary task, with a 1-min break between each room environment for all participants. The order of the search trials was counterbalanced for participants who received the explicit directions, so that within the condition there were approximately equivalent numbers of participants completing each of the six combinations of room orders (blue room with shadowing task, blue room with no secondary task and white room with no secondary task). Verbal shadowing training (as previously described) occurred just prior to the four search trials in the blue wall room with the secondary task during the explicit condition. Additionally, these participants were given one practice trial in the blue wall room without a secondary task prior to the reorientation task.

2.1.4. Scoring

The experimenter recorded which corner the participant first indicated the target object was hidden by coding it as either the correct corner (C), the rotational equivalent corner based on the shape of the room (R), the nearest error corner to the correct location (N), or the farthest error corner (F) as shown in Fig. 1.

2.2. Results

Fig. 2 presents the mean proportion of searches in each of the three task environments for each of the two conditions[1], (a) replication of Hermer-Vazquez et al. (1999) and (b) explicit directions given prior to the reorientation task along with a counterbalanced room order. We began the data analysis by calculating for each participant a percentage of search trials at correct (C), geometrically appropriate (C+R), and landmark appropriate corners (C+N), as done by Hermer-Vazquez et al. (1999). We then compared these per-

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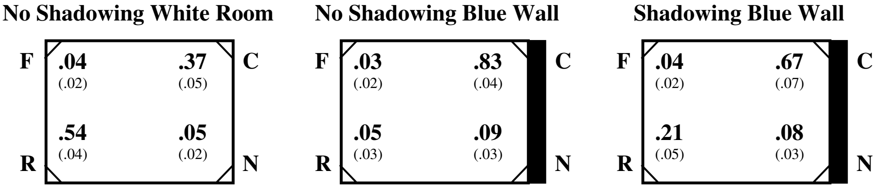
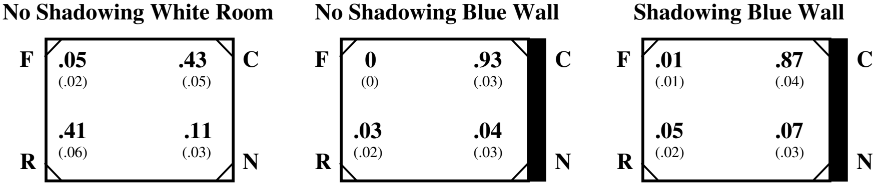
[1] There were no significant differences between across trial and first search trial means in Experiment 1 (all p's > .05). Therefore, only mean proportions are reported.

Fig. 1. Diagram of the rectangular enclosure with one blue wall and the corner categories.

(a) replication condition



(b) explicit condition



*correct corner (C) was not always located along the blue wall. The hiding corner was counterbalanced in each condition and matched across trials, so that the target was hidden in each corner an equal number of times.

Fig. 2. Proportion of searches at each corner (with standard errors) in Experiment 1 for the three room environments in the two conditions with verbal shadowing, (a) replication in fixed order and (b) directions, one practice trial and counterbalanced room order.

centage scores of accuracy to chance in each of the six conditions using one-tailed single sample t tests, with chance being 50% for C+R and C+N and 25% for C. Subsequently, we used a priori comparisons to examine crucial contrasts in search performance in the three different environments for the two conditions.

2.2.1. Comparisons to chance

2.2.1.1. White room with no secondary task. Adults disoriented in the all white room used the shape of the room to reorient, searching with high and equal frequency at the correct and rotationally equivalent corners. In both the replication and explicit directions conditions, participants directed their searches at the geometrically appropriate corners, C and R, at levels greater than chance (replication, $t(18) = 14.35$, $p < .001$; explicit directions, $t(18) = 9.99$, $p < .001$). The participants did not show any landmark-appropriate searches in either condition, because there were no landmarks, (replication, $t(18) = 1.68$, $p < .11$; explicit directions, $t(18) = 0.59$, $p < .56$). Participants in both conditions searched the correct location at above chance levels because they were using the shape of the room to guide searches (replication, $t(18) = 2.46$, $p < .01$; explicit directions, $t(18) = 3.99$, $p < .001$). These results are analogous to those of Hermer-Vazquez et al. (1999).

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2.2.1.2. Blue room with no secondary task. When disoriented in the blue wall room, but not required to verbally shadow, participants in both conditions combined the geometric information given by the shape of the room with the additional landmark information given by the blue wall to reorient and successfully find the target object. In both conditions, nonshadowing participants searched the geometrically appropriate corners at above-chance levels, (replication, $t(18) = 10.88$, $p < .001$; explicit directions, $t(18) = 16.01$, $p < .001$). Both groups of participants also showed a significant effect of using the blue wall, searching at above-chance rates in the landmark appropriate corners, (replication, $t(18) = 12.61$, $p < .001$; explicit directions, $t(18) = 26.19$, $p < .001$). Together, these effects produced a significant tendency to search at the correct corner, (replication, $t(18) = 15.04$, $p < .001$; explicit directions, $t(18) = 21.23$, $p < .001$). These results are again similar to those of Hermer-Vazquez et al. (1999).

2.2.1.3. Blue room with verbal shadowing task. In both conditions, shadowing participants showed a significant effect of room shape by searching at the geometrically appropriate corners (replication, $t(18) = 10.88$, $p < .001$; explicit directions, $t(18) = 12.61$, $p < .001$). Also, participants in both conditions searched the landmark appropriate corners at above chance levels, (replication, $t(18) = 3.78$, $p = .001$; explicit directions, $t(18) = 16.73$, $p < .001$). The significant effects of room shape and the blue wall landmark led to a combined effect of searching the correct corner significantly more than chance for both conditions, (replication, $t(18) = 6.10$, $p < .001$; explicit directions, $\mathrm{t}(18) = 17.63$, $p < .001$). Thus, participants in both conditions were able to combine geometric and landmark information in order to locate the target object in the blue wall room, even while engaged in verbal shadowing. That is, the result in the replication condition differs from the data of Hermer-Vazquez et al. (1999) because our participants but not theirs used the colored wall at above-chance levels.

2.2.2. Comparing across conditions

Although participants in the replication condition used the blue wall at above chance levels even while verbally shadowing, their ability to use the landmark was significantly reduced compared to the no-shadowing condition, $t(18) = 2.47$, $p < .01$. By contrast, no significant differences were found between shadowing and nonshadowing participants for the explicit directions condition (all p's $> .05$). In addition, participants in the explicit directions condition used the blue wall in conjunction with the room shape to search the correct corner significantly more often than participants in the replication paradigm, $t(36) = 2.55$, $p < .01$. A further examination of the order in which the shadowing trials were presented within the explicit condition (where there was counterbalancing) revealed no significant effect of room order on correct search performance, $F(2, 18) = 0.23$, $p > .05$.

2.3. Discussion

The data in Experiment 1 confirm the Hermer–Vazquez et al. finding that verbal shadowing has a reliable interference effect on use of a feature to reorient, although the present interference effect is not as large as the one they reported (i.e., we found a reliable decrement but not to chance performance). However, we also found that simply giving participants explicit information as to the nature of the task and a practice trial was sufficient to remove the adverse effect of linguistic shadowing. Clearer instructions alone seem to have enabled adults to successfully reorient using the colored wall in conjunction with the shape of the room. Similarly, Nardini (2006) performed a replication of the Hermer–Vazquez et al. task except that he gave very clear instructions as to what would happen during the task before the experiment began. He found no effect of shadowing on adults' ability to use a colored wall to reorient. The results from Experiment 1 along with those of Nardini (2006), cast doubt on the hypothesis that language is required to integrate geometric and featural information, because simply giving information about the nature of the task should not be sufficient to change performance if language is absolutely required.

It may be that participants in the replication condition have little idea what the experimenter wants them to do other than to continue verbal shadowing, and do not attach much importance to the keys. After all, the experimenter is doing other actions as well, any one of which might be what the participant is supposed to notice and retain. It might be suggested that, on subsequent trials, participants should start to get the idea that they should remember where the keys are, in which case performance should improve over trials. However, they may also think that the experimenter wants them to attend to varying events from trial to trial, in which case it might take more than four trials for them to learn that the location of the keys is always crucial.

It is also possible that the adults in the explicit condition realized they needed to create a short verbal description to cue them to the hiding place that could be repeated during some of the pauses during the shadowing task. However, this scenario seems unlikely due to the difficulty in obtaining participants who were even able to perform the shadowing task with the current pausing criterion (six of the 38 included participants had pauses greater than the 2 second criterion). The shadowing tape itself had to be slowed from a normal speaking rate in order to obtain participants who met the shadowing criterion. In addition, we note that explicit instructions are more analogous to procedures with young children and even with non-human animals. Previous studies have given children explicit instructions as well as corrected practice trials (Learmonth et al., 2001, 2002) and extensive training for several days or weeks is common among non-human animal studies, suggesting explicit task knowledge rather than incidental learning in these cases.

In summary, the data from Experiment 1 suggest that linguistic interference is not necessary to encode and use features to reorient. They are, however, consistent with the weaker hypothesis that language is needed in order to notice and retain featural information when learning is incidental and testing is unexpected, and it might be argued that, in the real world, the need for reorientation may be unexpected (as, for example, following a fall). Thus, in Experiment 2, we investigated whether nonlinguistic concurrent tasks might have an effect on incidental encoding of features for reorientation.

3. Experiment 2

In order to examine the effects of interference tasks on incidental learning among adults, we again replicated the reorientation task used by Hermer-Vazquez et al. (1999). However, we substituted a different nonverbal shadowing task. The nonverbal rhythm-shadowing condition they used may be an inappropriate control for the verbal shadowing task because keeping a rhythm involves primarily cerebellar regions of the brain, and hence would not be expected to be centrally involved with spatial information integration (Woodruf-Pak et al., 1996). Experiment 2 examines how a nonverbal *spatial* task interferes with the integration of geometric and featural information during the reorientation task. If the nonverbal spatial interference does indeed disrupt the integration process in adults, further evidence would be provided that the acquisition and use of spatial language is not necessary for use of features in reorientation tasks.

3.1. Method

3.1.1. Participants

Two groups of college undergraduates at Temple University were recruited as previously described. Sixteen participants were randomly assigned to each group for a total of 32, consisting of five males and 11 females for each condition. One participant was omitted from the original sample and replaced because he maintained his sense of orientation despite the disorientation procedure, as indicated by perfect search performance in the all white room. One participant was omitted from the original sample and replaced because he could not perform the visualizing task.

3.1.2. Apparatus, design and procedure

The same replication condition from Experiment 1 was used, in which participants received vague task instructions, no practice trial and a fixed order of room environments. The second condition was the explicit directions condition used in Experiment 1, where participants were given additional instructions about the nature of the search task, one practice trial prior to performing the reorientation task, and performed the three blocks of trials in a counterbalanced order. Participants were tested in the environment previously described. The experimenter read the instructions described in Experiment 1 for either the replication or explicit condition, and then trained participants on a spatial interference task involving visual imagery based on Brooks (1968) design.

While seated at a desk, participants viewed a series of four line diagrams (block letters F, G, N, and Z). On the initial presentation of each figure, the ten intersecting points were explicitly pointed out to the participant, as well as the starting place, which was an asterisk at one corner with an arrow indicating that the points were taken in a clockwise direction from the starting place as seen in Fig. 3. Retention of each figure and the correct order of points were assessed by having the participants draw each block letter from memory, starting from the point indicated by the asterisk and continuing clockwise as originally directed by the arrow.

Once retention in memory was established, the experimenter instructed the participant to visualize the letter and categorize each intersecting point in the diagram according to one of two categories. If the experimenter said ‘‘top/bottom’’, the participant said ‘‘yes’’ for each point that was either at the most extreme top or bottom of the figure and ‘‘no’’ for all other points. If the experimenter said ‘‘outside’’, the participant said ‘‘yes’’

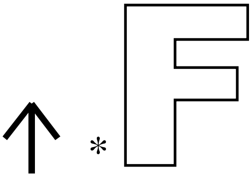


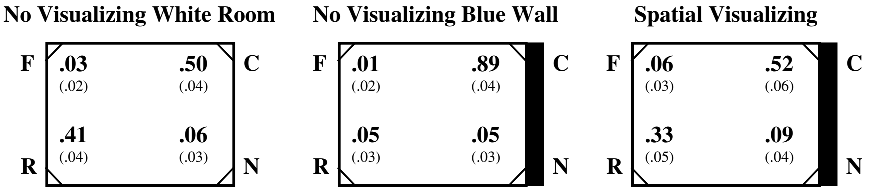
Fig. 3. Example of the block line diagram, *F*, used for the spatial interference task.

for each point that was either at the most extreme right or left side of the figure and “no” for all other points. The participant then practiced categorizing the intersecting points repeatedly for each diagram for 1 min or until reaching the criterion of not pausing for more than 2 s at any time during the responses.

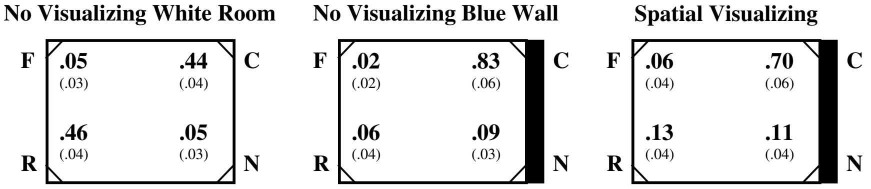
Although the response for the visualizing task is verbal, it is an exceedingly simple response, especially when compared to the verbal shadowing task. A nonverbal response of tapping or using an external device would have provided logistical problems and possible navigation impediments in the small testing environment. Additionally, Brooks (1968) found that participants responding verbally performed significantly faster than those responding through tapping, or pointing during the block letter task. These results imply that using the verbal response of “yes” or “no” while visualizing is the easiest form of the spatial task. By using the verbal output we actually decreased our chances of finding any interference effects. If such effects were to be found, they would be increased had we used a nonverbal response such as tapping, which makes the visualizing task significantly more difficult. Based on these results we trained participants to perform the block letter task using a verbal response, thus providing the maximum advantage for participants to perform the search task with the least amount of spatial interference.

Once each practice session was successfully completed for the four block letter diagrams, participants were led into the testing room with one blue wall and given the reorientation task. At the beginning of each search trial the experimenter told the participant to begin visualizing a previously trained letter and gave the category cue. Once the participant began responding “yes”/“no”, the experimenter placed the keys in the predetermined corner box and performed the disorientation procedure described in Experiment 1. During the search trials the participant listened to white noise through headphones to avoid any

(a) replication condition



(b) explicit condition



*correct corner (C) was not always located along the blue wall. The hiding corner was counterbalanced in each condition and matched across trials, so that the target was hidden in each corner an equal number of times.

Fig. 4. Proportion of searches at each corner (with standard errors) in Experiment 2 for the three room environments in the two conditions with spatial visualizing, (a) replication in fixed order and (b) directions, one practice trial and counterbalanced room order.

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sound cues. The experimenter recorded the participant's searches and analyzed the data as described in Experiment 1.

3.2. Results

Fig. 4 presents the mean proportion of searches in each of the three task environments for each of the two conditions[2], (a) replication of Hermer-Vazquez et al. (1999) and (b) additional directions and practice trial given prior to reorientation task with counterbalanced room order. We again calculated for each participant a percentage of search trials at correct (C), geometrically appropriate (C + R), and landmark appropriate corners (C + N), and then compared the percentage scores of accuracy to chance in each of the six conditions using one-tailed single sample *t* tests, with chance being 50% for C + R and C + N and 25% for C. We also used a priori comparisons to test the crucial contrasts in search performance among the three different environments between the two conditions.

3.2.1. Comparisons to chance

3.2.1.1. White room with no secondary task. As found in Experiment 1, performance in the white room showed a reliance on the shape of the space to find the correct corner, which resulted in correct searches about half of the time. Searches were at high and equal frequency at the correct and rotationally equivalent corners in both the replication and explicit conditions (replication, $t(15) = 13.00$, $p < .001$; explicit directions, $t(15) = 10.50$, $p < .001$), with no greater than chance landmark-appropriate searches in either condition across trials, (all p's > .05).

3.2.1.2. Blue room with no secondary task. Similar to the search pattern found in Experiment 1, participants in both conditions combined the geometric information with the blue wall landmark to reorient and search the correct corner when not performing the secondary spatial task. In both conditions, non-visualizing participants searched the geometrically appropriate corners significantly more than chance across trials, (replication, $t(15) = 15.65$, $p < .001$; explicit directions, $t(15) = 9.93$, $p < .001$), as well as the landmark appropriate corners, (replication, $t(15) = 12.12$, $p < .001$; explicit directions, $t(15) = 8.51$, $p < .001$).

3.2.1.3. Blue room with spatial visualizing task. In both conditions, visualizing participants searched at the geometrically appropriate corners at levels significantly greater than chance (replication, $t(15) = 6.21$, $p < .001$; explicit directions, $t(15) = 5.18$, $p < .001$), as well as the landmark appropriate corners, (replication, $t(15) = 2.15$, $p = .02$; explicit directions, $t(15) = 6.46$, $p < .001$). The significant effects of room shape and the blue wall landmark led to a combined effect of searching the correct corner significantly more than chance for both conditions, (replication, $t(15) = 4.26$, $p = .001$; explicit directions, $t(15) = 7.39$, $p < .001$). Again, as found in Experiment 1 for verbal shadowing, participants in both conditions were able to combine geometric and nongeometric information

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[2] There were no significant differences between across trial and first search trial means in Experiment 2 (all p's > .05). Therefore, only mean proportions are reported.

at above-chance levels in order to locate the target object in the blue wall room, even while engaged in the secondary task.

3.2.2. Comparing across conditions

In the replication condition, correct search performance in the blue wall room was better when participants were not performing the spatial task than while visualizing, $t(15) = 5.48$, $p < .01$. By contrast, when participants were given explicit directions, there were no significant differences in the blue wall room between visualizing and nonvisualizing participants' search patterns (all p's $> .05$). Thus, the spatial visualizing task significantly interfered with participants' ability to reorient when they were given vague directions as compared to those who were given informative directions, $t(30) = 2.14$, $p = .02$. The spatial visualizing task impeded performance by interfering with the ability to combine information about the room shape and the blue wall. However, once explicit information about the task was given, participants searched for the hidden target successfully, whether or not they were performing a concurrent task.

3.2.3. Comparing across experiments

Although the spatial visualizing participants in the replication condition of Experiment 2 seemed more impeded in using the blue wall as a landmark than did the verbal shadowing participants given similarly vague instructions in Experiment 1, this difference was not reliable, $t(33) = 1.64$, $p = .11$ (two-tailed). Whether or not the spatial interference task is harder (or easier) than the verbal interference task is not, however, the key issue from a theoretical point of view. The important finding is that a nonverbal secondary task can interfere with integrating geometric and nongeometric information at least as much as verbal shadowing.

3.3. Discussion

The data from Experiment 2 are strikingly similar to those from Experiment 1. In both studies, performing a concurrent task impeded the use of a feature to reorient, but only when participants had little if any idea of what they were supposed to do besides the concurrent task. The results contrast with the lack of an effect with nonverbal rhythm shadowing found by Hermer–Vazquez et al. Their failure to find an effect may well be due to the fact that rhythm tasks utilize neural structures different from those used for reorientation. Experiment 2 thus provides evidence that a suitable nonlinguistic task prevents incidental encoding of features at least as much as a linguistic interference task. Hence, Experiment 2 provides data arguing against the idea that language is required to overcome the encapsulation of a geometric module. Note, however, that this conclusion does not imply that language may not be *helpful* for the use of features in reorientation. We merely argue that language is not necessary.

It might be urged that performing our spatial task required some use of language, because participants said "yes" and "no". However, it is hard to believe that simply pronouncing these familiar words could have as large an effect as processing and repeating passages with complex vocabulary as well as complicated syntax. Supporting this idea, Hupbach, Hardt, Nadel, and Bohbot (2007) recently found similar results to ours, using a different spatial secondary task. In their study, a short tone was broadcasted by one of eight speakers attached to the ceiling of a larger square room, and participants were

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asked to point towards the speaker that currently displayed the sound while reorienting. The square room was composed of three white walls and one colored wall to serve as a landmark. Adults did not successfully reorient with respect to the sense information given by the landmark (left or right of colored wall) while they were concurrently engaged in the spatial task requiring encoding of spatial direction.

Another criticism of Experiment 2 might be that the spatial task could be more difficult than verbal shadowing. However, Experiments 1 and 2 were similar in that one (and only one) participant needed to be replaced for inability to perform the concurrent task. If anything, verbal shadowing was harder than the spatial task, in that six participants did not really meet criterion performance. Although we left them in the data set because their removal did not crucially alter the results, by doing so we maximized the verbal interference effect.

4. Experiment 3

Experiments 1 and 2 suggest that concurrent tasks, whether linguistic or spatial in nature, disrupt encoding of features in an incidental condition. These experiments were conducted in a small room, only 4 by 6 feet, in order to replicate the conditions of the previous studies. However, Learmonth et al. (2001, 2002) have found that young children are more likely to use features in a larger room. To examine whether integration of geometric and nongeometric information has different cognitive bases in rooms of different sizes, we conducted another replication of the Hermer-Vazquez et al. (1999) reorientation paradigm, this time using a room the same size as in Learmonth et al. (2001, 2002), four times the area of the Hermer–Vazquez et al. enclosure. One comparison of interest was whether adults would perform more accurately in the larger room than in the smaller room used in Experiment 1; whether larger room size improves feature use for adults has not previously been examined (Cheng & Newcombe, 2005). Additionally, participants performed either a verbal or spatial interference task to determine whether integrating spatial information has different bases in the larger room than in the smaller room. We only used incidental instructions because the first two experiments had not shown effects of a secondary task when instructions were explicit.

4.1. Method

4.1.1. Participants

Sixty-four participants were recruited at Temple University's main and satellite campuses from psychology classes or adult volunteers and were given course credit or monetary compensation. There were 12 males and 20 females randomly assigned to the spatial visualizing group and 11 males and 21 females in the verbal interference group. One participant was replaced because she could not perform the verbal task.

4.1.2. Apparatus, design and procedure

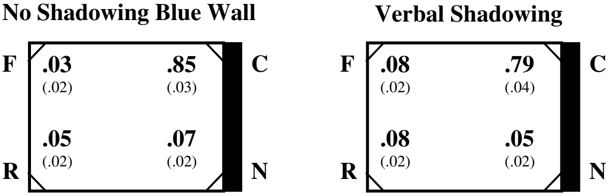
The replication procedure was used, whereby participants received vague task instructions and a fixed order of room environments. Participants were tested in a similar environment described previously except the dimensions of the space were enlarged to 8 by 12 feet. Thus the area of the room was four times that of the room used in Experiments 1 and 2, but the ratio of long to short walls remains the same. Additionally a colored sheet of fabric was affixed to one short wall to provide a featural landmark cue. After listening to instructions and training to perform either the verbal shadowing or spatial visualizing task, participants completed 8 search trials in a fixed order: four search trials in the blue wall room with a concurrent task, followed by four trials in the blue wall room with no secondary task.

4.2. Results

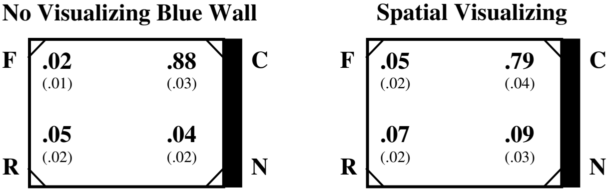
Fig. 5 presents the mean proportion of searches for the adults in the larger room while either (a) verbal shadowing or (b) spatial visualizing. We again calculated for each participant a percentage of search trials at the correct (C) corner and used a priori comparisons to test the crucial contrasts in search performance between the two groups (all *p*'s one-tailed unless otherwise noted). All comparisons to chance were significant and followed the same pattern previously reported in Experiments 1 and 2. However, the data differed from the previous experiments in that no reliable decrements were seen as a function of performance for the verbal task using the vague directions. For the verbal shadowing participants, there was no effect of shadowing versus not shadowing in the larger room, $t(31) = 1.25$, $p = .11$. However, the difference in correct searches for participants performing the spatial visualizing task compared to those not engaged in the spatial interference task in the larger room with the blue wall was marginally significant, $t(31) = 1.73$, $p = .06$.

Although, the spatial visualizing participants performed more accurately when not engaged in the spatial task in the larger room, summing across concurrent tasks there were no significant differences in correct search behavior between the spatial and verbal interference groups, $t(62) = 0.15$, $p = .44$. Thus, after receiving the same vague directions in

(*a*) verbal shadowing



(*b*) spatial visualizing



*correct corner (C) was not always located along the blue wall. The hiding corner was counterbalanced in each condition and matched across trials, so that the target was hidden in each corner an equal number of times.

Fig. 5. Proportion of searches at each corner (with standard errors) in the large room of Experiment 3 for the two interference groups, (a) verbal shadowing and (b) spatial visualizing.

both groups, there was a marginal effect of spatial interference decreasing adults' search behavior while reorienting in the larger room but no effect of verbal interference.

4.2.1. Comparing across experiments

Summing across the presence or absence of concurrent tasks, verbal shadowing participants in the large room of Experiment 3 searched the correct corner more often than shadowing participants in the small room of Experiment 1, $t(49) = 1.68$, $p = .05$. Corresponding results were found for the spatial visualizing task participants. Visualizing participants in the large room in Experiment 3 searched the correct corner more often than participants in the small room in Experiment 2, $t(46) = 4.16$, $p < .01$. Therefore, reorienting in the larger space maintains a greater use of features in combination with geometry resulting in higher accuracy, but is still vulnerable to interference, although to a lesser degree than the small room.

4.3. Discussion

There are two interesting findings from Experiment 3. First, use of features to reorient is more common in a larger than a smaller room for adults, as has been found for children and many non-human animals. This fact suggests that the room size effect does not tap any function that changes developmentally, but is instead a general fact about spatial reorientation, occurring across age (Learmonth et al., 2001, 2002) as well as across species (Chiandetti et al., 2007; Sovrano & Vallortigara, 2006; Vallortigara et al., 2005, for chicks; Sovrano et al., 2005, 2007, for fish). In recent work, we have suggested that there are several determinants of the room size effect, including whether the feature is distal or proximal and whether or not there are significant action possibilities in the space (Newcombe & Ratilff, 2007).

Second, although the verbal shadowing task did not interfere with reorientation in the larger space in an incidental learning situation, we found a marginal effect of the spatial visualizing task using a one-tailed significance test. This difference is most likely due to the natural fluctuation of correct search rates in the blue wall room with no concurrent task. It is possible that both interference tasks would approach significance by increasing the number of participants. However, our results are similar to Hupbach et al. (2007), who found that adults successfully reorient using a colored wall feature in a large square room even while engaged in a verbal shadowing task with the vague directions given by Hermer-Vazquez et al. (1999), yet a spatial task significantly interfered with feature use in a large square room. It is possible that the visualizing spatial task used here did not interfere with reorientation to the degree found by Hupbach et al. because it did not utilize spatial features within the test environment, and/or involve some sort of large-scale spatial coding (Hupbach et al., 2007). Another possible explanation is that greater attention is drawn to the hiding corner in the larger room since the experimenter must make more movements in this environment as compared to the small room, where very few movements are required to hide the target.

Alternatively, perhaps the larger room changes the formation of the spatial representation of the space in such a way that the focus of the colored wall far outweighs the demands of the secondary tasks used here. Previously reviewed findings from non-human animals suggest reorientation in the larger space is more likely to involve the use of features in addition to geometry as compared to smaller spaces, which heavily favor geometric information. Interestingly, when chicks learn a certain configuration of features placed in four corners of a rectangular enclosure and then attempt to reorient once the features have been shifted from their original locations (producing a conflict between the feature locations and their learned geometry) they follow the location of the features instead of the geometry regardless of room size during training and testing (Chiandetti et al., 2007). We hypothesize that humans would perform similarly to animals in this case, using the feature location to find a hidden object instead of focusing on the shape of the room. However, if increased attention alone was the cause for successful reorientation in the larger room, adults would likely maintain a geometric-favored search in a similar small to larger room testing scenario and only reorient using the location of the features when trained in the larger room and tested in the small room. Further examination of this issue is warranted to understand spatial orientation within different environments and to ensure if non-human animals, young children and adults perform these tasks based on similar navigational systems.

4.4. General discussion

In the present experiments we addressed whether language is necessary to use nongeometric as well as geometric information to deal with disorientation. Findings that a verbal interference task limits the ability of human adults to reorient using nongeometric features as well as geometric information have seemed to provide striking support for this hypothesis (Hermer-Vazquez et al., 1999). The present data show that the Hermer–Vazquez et al. result can be replicated, at least in part. Using their exact technique, we found that participants required to verbally shadow were less likely to use features to reorient, although not reduced to chance levels. This effect was found only when participants lacked explicit information regarding the nature of the task and only in a small room. Additionally, we found that a nonverbal spatial task also produced a similar effect. Taken together, these studies strongly suggest that language is not crucial in combining information from geometric and nongeometric sources in order to reorient, although it may sometimes be helpful.

Instead, the combination of featural and geometric information may depend on cognitive and neural mechanisms that are involved in both spatial and verbal attention and memory (Newcombe, 2005). The facts that larger rooms favor use of features and that interference effects are not observed in larger rooms to the same degree as small ones, as shown in Experiment 3, show the need to consider general cognitive factors in predicting use of features, such as the recruitment of attention, use of spatial features during secondary tasks, and differential weighting of features.

Do these studies bear on the issue of whether or not there is a geometric module? Strictly speaking, they are only relevant to the hypothesis that language is necessary to deal with encapsulation. If language is not necessary, it is possible there could still be encapsulation in some circumstances, but simply encapsulation that can also be overcome by non-linguistic means. Although we believe the results of these studies provide evidence against encapsulation and primacy of geometry, there are two aspects of the data in these experiments which might be argued to support modularity. First, features are not reliably used to reorient when participants receive vague instructions and are also doing a concurrent task, but geometry is always used. That is, it seems to take a certain degree of attention combined with attentional set to encode features, but encoding of geometry is automatic. Second, errors are always predominantly geometric rather than featural. Thus, it could be argued that geometry is used obligatorily and strongly to reorient, with featural information added in a secondary way and only in certain circumstances, and it could be further urged that this pattern of data is consistent with modularity. There is even some evidence, from avian hippocampal lesions (Tommasi, Gagliardo, Andrew, & Vallortigara, 2003) and avian visual processing (Vallortigara, Pagni, & Sovrano, 2004), to suggest separate neural substrates responsible for encoding geometric and nongeometric information.

However, whether or not primacy of geometric information implies modularity depends in part on the meaning of the word "modularity", which has been used in very different ways by different investigators (Cheng & Newcombe, 2005; Newcombe & Ratilff, 2007). Beyond terminological discussion, however, we should consider how these facts are interpreted by a non-modular conceptualization of how organisms reorient, the adaptive combination view (Newcombe & Huttenlocher, 2006; Newcombe & Ratilff, 2007). This approach is based on evidence, from a variety of domains, that information sources are frequently combined to determine judgments and behavior using weighting mechanisms. For example, judgments of an object's size can be based on information from either vision or touch; when both kinds of information are available, people combine the two sources in a fashion weighted by the variance associated with each source (Banks, 2005; Ernst & Banks, 2002). In the spatial domain, Huttenlocher, Hedges, and Duncan (1991) have proposed a hierarchical combination model, in which estimates of an object's location are based on a combination of fine-grained and categorical information. In terms of the task of re-establishing spatial orientation, an adaptive combination view suggests the possibility that geometric and featural information are utilized in varying degrees in varying situations and at varying points in development. The degree to which they are used is hypothesized to reflect the certainty and variance with which the two kinds of information are encoded, along with their salience and perceived usefulness.

Many of the paradigms used in research on the geometric module have involved situations in which geometric information could be expected to predominate because it is easily encoded with great certainty and minimum variability, and is highly salient, whereas the featural information may be encoded with more variability, or is low in salience. Specifically, a fully enclosed familiar geometric shape, such as a rectangle, is most likely encoded with great certainty with little room for variability. The greater the ratio of long to short walls within the experimental rectangular space is (and thus further from a square shape), the more likely the length of the walls will be discriminated from one another, making the geometric encoding highly reliable and salient, resulting in strong geometric reliance relative to feature use. However, if geometric sensitivity were examined in a case where the shape of the space was only suggested rather than explicitly displayed, as is true in the natural environment where fully enclosed and regular spaces are rare, it should be less dominant. There is empirical support for this idea for both rats (Benhamou & Poucet, 1998; Poucet, Lenck-Santini, & Save, 2003), and humans (Gouteux & Spelke, 2001; Gouteux, Vauclair, & Thinus-Blanc, 2001; Hupbach & Nadel, 2005; Huttenlocher & Vasilyeva, 2003; Vasilyeva, 2005).

Additionally, the adaptive combination view predicts reliance on nongeometric information will increase as features become more salient, as has been found for fish (Sovrano et al., 2005, 2007), domestic chicks (Sovrano & Vallortigara, 2006; Vallortigara et al., 2005) and children (Learmonth et al., 2001, 2002; Lee, Shusterman, & Spelke, 2006; Lourenco, Fabian, & Huttenlocher, 2007). Despite the increased use of landmarks in these cases, Lee et al. (2006) argue that when feature use is given directly at the site of the target (where the landmark serves as a beacon) children are not actually reorienting, but merely using the feature as a guide within an associative process linking landmarks directly to specific locations. However, when errors are made in environments with distinctive geometric properties (such as a rectangular enclosure) they are predominantly in the geometrically appropriate corners, suggesting a combined use of geometric and nongeometric information guiding reorientation (Learmonth et al., 2001, 2002; see Lourenco et al. (2007), for sex differences in error rates).

In addition to factors such as salience and encoding strength, the adaptive combination view also takes into account one's learning and experience as a factor in determining the weight placed on specific spatial information. A dramatic finding in support of featural use as dependent on environment and experience rather than an automatic dominance of geometric information comes from wild-caught mountain chickadees with limited experience in enclosed environments (Gray, Bloomfield, Ferrey, Spetch, & Sturdy, 2005). The chickadees show a dominant use of features overshadowing geometry in reorientation, and use geometry to a reduced degree as compared to other domesticated organisms when it is the only information available. Similarly, fish that have been raised in circular tanks use featural information to a greater degree during reorientation as compared to fish raised in rectangular tanks (Brown, Spetch, & Hurd, 2007). Thus, these studies support the adaptive combination view that prior experiences, such as rearing environments, play an important role in affecting the dominance of features and geometry during reorientation rather than an automaticity of geometry.

In relation to the findings from our present experiments, the adaptive combination view provides an alternative explanation to the geometric module theory. During reorientation in a small rectangular space with unspecific task instruction and performance of an interference task, adults certainly encode the shape of the fully enclosed rectangular room with little variability and utilize this information to a greater degree than the colored wall feature, though it is used as well. Once additional experience is given and learning occurs (as in the case of the added practice trial and instructions of Experiment 1) the initial weighting and salience of the feature is increased at least to the level of the geometric information, leading to a successful completion of the task using both features and geometry. Both a linguistic (verbal shadowing) and nonlinguistic (spatial imagery) secondary task interfere with the ability to combine different spatial cues, leaving the cue with the greatest weight as the dominant reorienting factor, which is typically geometric information in this fully-enclosed incidental learning trial scenario. In a larger room where features are more distal and perhaps more salient, humans and non-human animals both integrate features and geometric information in order to flexibly reorient and find a hidden target. However, there may be some decrements in performance while engaged in concurrent tasks in the larger room but these are significantly less than those found while reorienting in the small room. The apparent "shift" from ignoring to using nongeometric features starting at 6 years of age in children may only reflect the increased salience with which features are encoded and the benefit of experiencing in using colors and landmarks in spatial navigation during development. A similar explanation may account for the differential use of features in the larger room versus the small room among humans and non-human animals.

In summary, modular and non-modular views of reorientation are still both tenable and further studies will be required to adjudicate their relative plausibility. However, there seems to be no reason to believe that language plays a crucial role in enabling the use

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of features in reorientation. The last compelling reason to entertain this hypothesis was the verbal shadowing effect, and the present data suggest it is far less dramatic than it initially appeared to be. Thus, a challenge for a modular view is to explain how and when features are used to reorient, and when they are not.

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