Human Spatial Reorientation using Dual Task Paradigms

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Abstract

After disorientation, human adults reorient within a symmetric geometric environment using featural information as well as the shape of the surrounding space, whereas children younger than 6 years do not. The hypothesis that use of features is due to language has been supported by findings that human adults behave like children when reorienting while performing a linguistic shadowing task (Hermer-Vazquez, Spelke, & Katsnelson, 1999). In this study we conducted a replication of the Hermer-Vazquez et al. (1999) Experiment 1, together with a condition involving more explicit information regarding the nature of the task. In this study, we also added a condition involving a spatial secondary task. Successful reorientation was more common in the explicit condition than in the exact replication, although above chance even in the latter. Reorientation was lowest for participants performing the spatial secondary task. These results provide evidence against the idea that language is necessary to overcome the encapsulation found among children and rats when trying to integrate geometric and featural information.

Keywords: Spatial cognition; navigation; modularity.

Introduction

To functionally navigate through the environment, humans and animals rely on two systems of spatial adaptation: the egocentric "dead reckoning" system, whereby the organism uses the location of the self as the key to spatial orientation, and the allocentric system, whereby the surrounding environment provides landmarks for the organism to measure distance and direction to code location (Newcombe, 2002). The allocentric system itself can be further reduced to two types of spatial information by distinguishing between geometric and nongeometric information. 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.

Cheng (1986) examined how disoriented rats utilized geometric and featural information to reorient themselves and find food, which was hidden in one corner of a rectangular enclosure. Rats can no longer use dead reckoning once disoriented and must rely on their allocentric spatial system. Cheng found that the rats searched for the food at the geometrically equivalent corners in the rectangular room, suggesting that rats encode the geometric properties of the space and handedness (short versus long walls to the left or right in the rectangle); however, the rats did not use other kinds of featural information, such as a colored wall or patterned corners, which would allow them to distinguish the correct corner.

Hermer and Spelke (1994, 1996) found similar results using human children, 18 to 24 months. Based on these results, the geometric module hypothesis was proposed, suggesting that the geometric coding abilities of rats and children are encapsulated. Hermer-Vazquez, Spelke, and Katsnelson (1999) extended the geometric module hypothesis by claiming that the module is only seen among humans in children, due to their lack of a developed spatial language. Replicating the Cheng orientation task with human adults, Hermer-Vazquez et al. found that adults show no encapsulation, in that they use both the geometry of a room and the featural landmark cue of a colored wall to successfully reorient in a rectangular enclosure. They proposed that acquiring language, specifically production of the spatial terms "left" and "right", may be necessary and sufficient for integrating geometric and featural information.

Applying a selective interference design to further probe the necessity of language, Hermer-Vazquez et al. (1999) found that adults simultaneously performing a verbal shadowing task behave like children and rats, searching between two geometrically equivalent corners when reorienting in a rectangular room with one colored wall. However, when adults performed the reorientation task while simultaneously performing a nonverbal rhythm-clapping task, they successfully integrated the information from the two domains. These results support their conclusion that language is necessary for the integration of geometric and featural spatial information, allowing adults to overcome the encapsulation of the geometric module.

Evidence Against the Geometric Module

Recent animal research has cast doubt on the existence of a geometric module by examining various species capable of integrating geometric information along with featural landmarks to locate hidden objects. Additionally, these results raise more questions for the *language modulated* geometric module hypothesis, in that these nonhuman species definitely do not have linguistic capabilities to integrate the two forms of spatial information.

Vallortigara, Zanforlin and Pasti (1990) have found such evidence in experiments with chickens, Kelly, Spetch and Heth (1998) found no encapsulation in pigeons, and Sovrano, Bisazza and Vallortigara (2002) found evidence that fish are capable of integrating featural landmarks with geometric information to find an exit in a small tank within a larger fish tank. Similarly, Gouteux, Thinus-Blanc, and Vauclair (2001) found that monkeys showed no encapsulation of geometric information either, as they used a colored wall to reorient and find a reward after disorientation in a rectangular room.

Hermer-Vazquez, Moffet, and Munkholm (2001) have suggested that these results from non-human studies might be a reflection of the extensive training typically found when working with animals. However, doubts concerning the geometric module hypothesis have also emerged within the human research area. Learmonth, Newcombe, and Huttenlocher (2001) replicated Hermer and Spelke (1994, 1996), finding that disoriented children divide their searches between two geometrically equivalent corners of a featureless rectangular room. However, by increasing the area of the room four times that of the original Hermer and Spelke room, children between 17 and 24 months do use featural landmarks in addition to the shape of the room to successfully find the hidden toy.

Alternatives to a Module

Two possible alternative explanations may account for the results supporting the encapsulation found among humans. In the Hermer-Vazquez et al. study (1999), adults were informed prior to the disorientation procedure that, "you will see something happening that you should try to notice," and they would be asked about what they saw. The vague instructions given to the adults may account for their lack of use of features. When given explicit instructions prior to the reorientation task, we hypothesize that adult participants will search the correct corner at greater than chance levels *even while* engaged in verbal shadowing.

Another possible explanation for these results is that the verbal shadowing task used by Hermer-Vazquez et al. (1999) disrupts the ability to use featural landmarks by not only interfering with the linguistic process, but also with a nonlinguistic spatial system (Newcombe, in press). The nonverbal shadowing condition of a rhythm-clapping task used by Hermer-Vazquez et al. (1999) was not an appropriate control to the verbal shadowing task (Newcombe, in press). A nonverbal *spatial* task should be utilized to examine if it interferes with the integration of geometric and featural information in the reorientation task.

Experiment 1

To examine the role of explicit directions and language in spatial processing, a replication of the Hermer-Vazquez, Spelke, and Katsnelson (1999) Experiment 1 was performed. In addition to the replication, another condition was added where participants were given additional instructions about the nature of the search task and a practice trial prior to performing the reorientation task. In both conditions, participants performed a reorientation task within a rectangular enclosure, while either simultaneously engaged in a secondary verbal shadowing task or no secondary task. Searches were assessed in each session to determine if participants successfully found the target object in the correct corner in the explicit directions condition significantly more than in the replication condition. These search results would cast doubt on the hypothesis that the verbal shadowing task alone hinders adult spatial capabilities of integrating geometric and featural information.

Method

Participants. Thirty-eight college undergraduates at Temple University were recruited from introductory psychology classes and given course credit. Seven males and 12 females were randomly assigned to the replication condition. 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. Five males and 14 females were randomly assigned to the explicit direction condition. 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 but were included in the data set, after data-analysis confirmed no significant differences in the findings when they were or were not excluded.

Apparatus and materials. Participants were tested in a small rectangular enclosure with short sides four feet in length and long sides six feet in length (1.92 x 1.23 x 1.92m) 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. 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 a tape recording of the experimenter reading political articles. During the nonshadowing 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.

Design and Procedures. Participants were randomly assigned to one of two conditions. For each condition, participants completed four search trials in the room with one blue wall while verbally shadowing, four trials in the one blue wall room without the secondary task, and four trials in the all white room to confirm disorientation in the space. The hiding corner 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.

One condition was a replication 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. Participants were then trained to perform a verbal shadowing task. 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 participant began continuously shadowing, and the experimenter led the participant into the smaller testing room to begin the reorientation task. They stopped shadowing once four search trials were completed in the blue wall room. Participants completed the 12 search trials in the fixed order as per Hermer-Vazquez et al. (1999): four search trials in the blue wall room while shadowing, four trials in the blue wall room with no secondary task, and four trials in the white room.

In 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 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. Then open your eyes and try to find the object." The participant was also given one practice trial in the blue wall room without a secondary task. Additionally, the order of the search trials was counterbalanced, so that within the condition there were approximately equivalent numbers of participants completing each of the six combinations of room orders. The participant was trained to perform the verbal shadowing task (as previously described) just prior to the four search trials in the blue wall room with the secondary task.

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 or 30s, and changing directions twice. While the participant rotated, the experimenter also walked around the subject at varying speeds as to not provide a landmark cue. The participant was then stopped facing the appropriate predetermined direction by the experimenter. The participant opened his or her eyes and the experimenter asked, "Where did I hide the keys?" As in Experiment 1, by Hermer-Vazquez et al. (1999), participants either pointed to a corner, or the experimenter told them to "point" if they hesitated. Four search trials were given in each of the three environments with a 1-min break between each environment.

The experimenter recorded which corner the participant first indicated the target object was hidden as shown in figure 1 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). To compare across all four search trials in each environment, we calculated for each participant a percentage of search trials at correct (C), geometrically appropriate (C+R), and landmark appropriate corners (C+N) according to Hermer-Vazquez et al. (1999). We initially compared the search rates to chance levels (chance = .25 for correct search; chance = .5 for geometrically appropriate, as well as landmark appropriate searches). We also performed ANOVAs to compare overall search performance between the three different environments, with follow-up contrasts on specific comparisons.

Figure 1: Room diagram with one blue wall (C=correct corner, R=reversal corner, N=near error, F=far error).

Results

Figures 2a and 2b present the mean number of searches in each environment for the two conditions.

Participants in both conditions searched the geometrically appropriate corners at equivalent rates across room environments, F (1, 26) = 0.26, p = .61. Participants in the explicit directions condition showed significantly greater landmark-appropriate search rates averaging across the three room types than the replication participants, $F(1, 26) = 11.63$, $p = .001$. The participants in the explicit condition also showed significantly greater searches in the correct corner across room environments than participants in the replication condition, $F(1, 26) = 12.50$, $p < .001$.

Overall, participants in the explicit directions condition successfully used the blue wall as a landmark significantly more than the participants in the replication condition. This greater success in using the blue wall led to a higher rate of

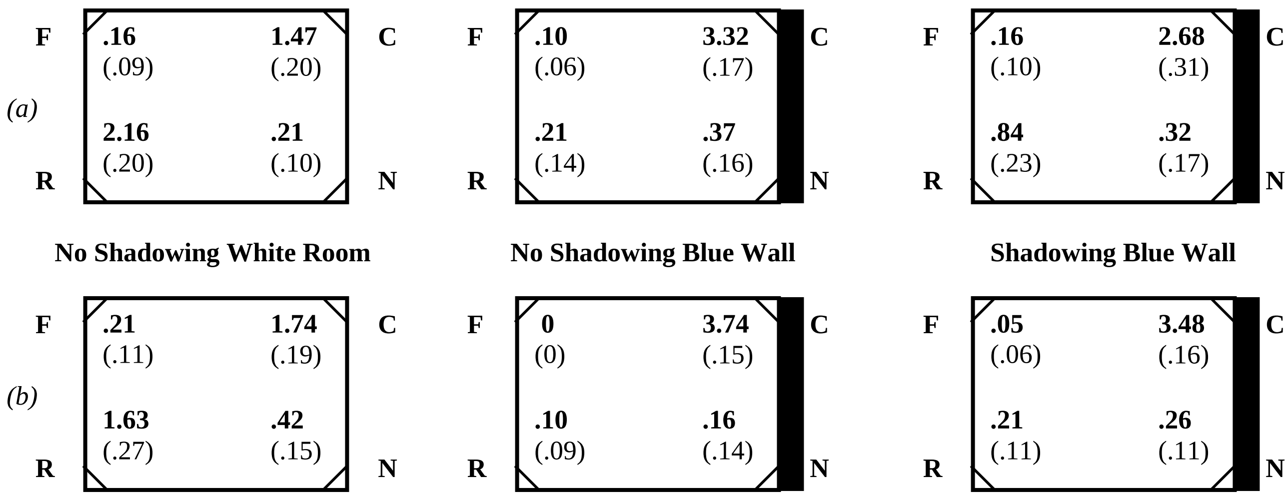

Figure 2: Mean number of searches at each corner (with standard errors in parentheses) in the three different room environments for (a) the replication condition and (b) the explicit direction condition.

correct corner searches for participants who received the explicit directions than for the replications condition participants.

Follow-up tests revealed the most crucial differences between and within the conditions. There were no significant differences found within the explicit directions condition shadowing and nonshadowing participant's search rates in the blue wall room (all *p*'s >.05). Although shadowing participants in the replication condition used the blue wall as a landmark at above chance levels, $t(18) = 3.78$, $p = .001$, their landmark appropriate search performance was significantly reduced while engaged in verbal shadowing than when no secondary task was performed, $t(36) = 2.84$, $p = .003$. This differential rate of utilizing the landmark information resulted in significant reductions in correct searches for the shadowing compared to nonshadowing participants in the replication condition, $t(36) = 2.63$, $p = .005$.

Thus a partial replication of Hermer-Vazquez et al. (1999) was found, in that shadowing participants were significantly worse at using the landmark information than the nonshadowing participants in the replication condition. Additionally, combining the geometric information with the landmark information to guide correct searching was significantly less likely when participants were engaged in verbal shadowing.

Shadowing participants in the explicit directions condition searched the correct corner significantly more than shadowing participants in the replication condition, $t(36) = 3.28$, $p < .001$. It appears that giving participants additional directions and a practice trial removes the adverse effect verbal shadowing has on combining geometric and featural information. These results cast doubt on the hypothesis that the verbal shadowing task alone hinders adult spatial capabilities of integrating both geometric and featural information.

Experiment 2

The nonverbal rhythm-shadowing condition used by Hermer-Vazquez et al. (1999) can be argued to be an inappropriate control to the verbal shadowing task. The rhythm-clapping task, which involves more cerebellar regions of the brain, would not be expected to be intrinsically involved with spatial information integration (Woodruf-Pak, Papka, & Ivry, 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 against the hypothesis of a geometric module overcome solely through the acquisition of spatial language.

Method

Participants. Sixteen Temple University undergraduates, five males and 11 females, were recruited as previously described. 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.

Apparatus, Design and Procedures. Participants were tested in the environment described in Experiment 1. The experimenter read the instructions described in Experiment 1 for the replication condition to the participants, and then trained them to perform a spatial interference task involving visual imagery based on a task designed by Brooks (1968).

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

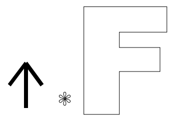

Figure 3: Line diagram used for spatial interference task.

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 figure 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” 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 one minute or until reaching the criterion of not pausing for more than 2s 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 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. During the search trials the participant listened to white noise through headphones to avoid any sound cues. At the beginning of each search trial the experimenter told the participant to begin visualizing the 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. After each trial, the experimenter told the participant to visualize another letter and gave the category cue until all four block letter diagrams had been visualized. The participant completed 12 search trials in the fixed order: four search trials in the blue wall room while engaging in the spatial secondary task, four trials in the blue wall room with no secondary task, and four trials in the white room.

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

Results

Figure 4 presents the mean number of searches in each room environment. As in Experiment 1, participants performed significantly better while not engaged in the secondary task in the blue wall room than when in the all white room, indicating the successful use of the blue wall as a landmark, $t(30) = 6.35$, $p < .001$. Additionally, the interference task was effective in that participants in the blue wall room performed significantly better while they were not performing the secondary task than while engaged in visualizing, $t(30) = 6.10$, $p < .001$.

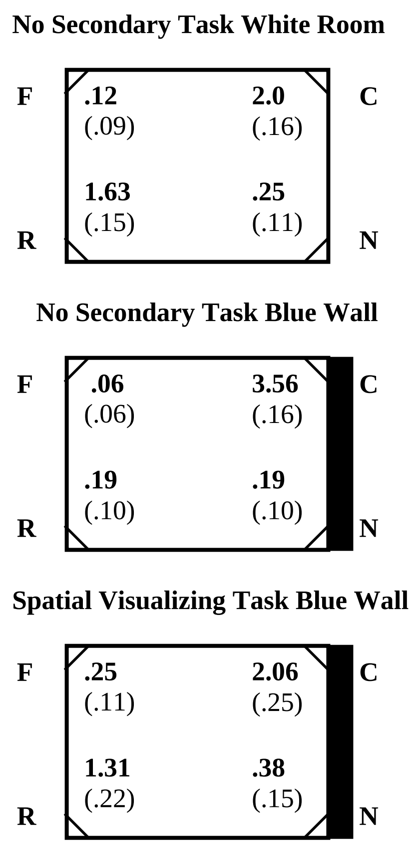

Figure 4: Mean number of searches at each corner (with standard errors in parentheses).

However, the most interesting finding is that there were no significant differences between the search rates for those in the blue room while engaged in the spatial secondary task and those in the all white room, all *t*'s < 1, all *p*'s > .30. Participants engaged in the spatial task in the blue wall room performed as if they were in the all white room.

Overall, participants successfully used the blue wall as a landmark and the shape of the room to find the target while they were not performing the secondary task. However, once participants began visualizing, their accuracy declined to the level of the all white room. Performing the spatial task significantly reduced participants' abilities to combine the geometric and featural information during reorientation.

Comparing across experiments, verbal shadowing participants in the replication condition of Experiment 1 and spatial visualizing participants in Experiment 2 both used the room shape to guide their search at equivalent rates, $t(33) = .60$, $p = .28$. However, the verbal shadowing participants in the replication condition of Experiment 1 used the blue wall as a landmark significantly more than the spatial visualizing participants in Experiment 2, $t(33) = 1.64$, $p = .05$, leading to overall higher accuracy searches, $t(33) = 1.64$, $p = .05$. The spatial secondary task interfered significantly more with the participants' abilities to use the featural information in the blue wall room than the verbal shadowing task did in Experiment 1.

Discussion

In the present experiments we found that adults used both geometric and featural properties of the surrounding environment in order to reorient themselves and find a hidden object. Once adults engaged in a secondary task of verbal shadowing or spatial visualizing while reorienting in the blue wall room, their search accuracy declined, though it was still above chance. The secondary tasks in Experiments 1 and 2 interfered with the participants' abilities to combine geometric and featural information in order to successfully reorient. However, once participants in Experiment 1 were given explicit directions as to the nature of the search task and a practice trial, they were not affected by the verbal shadowing task.

Additionally, successful reorientation was more common among the verbal shadowing participants in the replication condition of Experiment 1 than the participants engaged in spatial visualizing in Experiment 2. Participants who performed the spatial visualizing task concentrated their searches most frequently between the correct and rotationally equivalent corners, whereas verbal shadowing participants in the replication condition utilized the blue wall landmark to a higher degree.

The spatial secondary task in Experiment 2 proved to be a greater interference in adults' ability to flexibly combine geometric and featural information than the verbal shadowing task in Experiment 1. This provides evidence against the theory that acquiring spatial language is responsible for overcoming encapsulation when trying to integrate geometric and featural information. Perhaps the decline in accuracy caused by verbal shadowing disrupts the ability to use featural landmarks by interfering with a nonlinguistic spatial system, as well as the linguistic process (Newcombe, in press).

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