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Location matters: Why target location impacts performance in orientation tasks

GLENN GUNZELMANN
Air Force Research Laboratory, Mesa, Arizona

and

JOHN R. ANDERSON
Carnegie Mellon University, Pittsburgh, Pennsylvania

This research explores human performance in a spatial orientation task. In three experiments, participants saw a target highlighted in a visual scene and were asked to locate it on a map of the space. Across all of the experiments, the target's location in the visual scene influenced the participants' response times. Generally, response times increased when the target was located farther away from the viewer, when the target was farther to one side or the other, and when more distractors were nearby. However, there were important exceptions to these findings, suggesting that participants encode the location of a target hierarchically, using different features of the space depending on the target's particular location. We conclude that participants perform such tasks by extracting a description from the egocentric view and then transforming that description to allow them to find the target on the map.

In visual perception, spatial information is represented relative to the viewer's location and orientation (the direction the viewer is facing; Klatzky, 1998; Tversky, 2003). That is, the locations of objects within the space can be encoded in terms of their egocentric distance and egocentric bearing. Egocentric distance is simply the distance from the viewer to the object, whereas egocentric bearing is a measure of the angle to the object, relative to the direction the viewer is facing. An object directly in front of the viewer has an egocentric bearing of 0º, whereas an object directly to one side or the other has an egocentric bearing of 90º. As experience is gained with a space, individuals can store representations of this information, which can be used to facilitate navigation.

Many species exhibit behavioral evidence that they store cognitive representations of space, but humans have developed the ability to create and use external representations to guide spatial reasoning and decision making, with or without any direct experience in the space. Although external representations of space can also assume different forms, the most familiar is a standard map, which provides an allocentric frame of reference for locating objects within the space. In other words, maps indicate the locations of objects in the space in a way that is not directly linked to the position of the viewer. Instead, they impose reference frames that are based on an origin and orientation external to the viewer. For instance, on most maps, the orientation is based on cardinal directions, with north at the top. Understanding the cognitive mechanisms that are involved in using such external aids effectively is one of the goals of this research.

Encoding Spatial Information

Before it is possible to use maps to guide navigational decision making, it is necessary to know one's current position and orientation in the space. The viewer can accomplish this by accurately extracting spatial information from the visual scene that can be perceived. Although the locations of objects in an allocentric frame of reference could be derived from a visual scene, researchers have generally taken the view that object locations are encoded egocentrically, using a coordinate system defined by the major axes of the body (up/down, front/back, and left/right; Easton & Sholl, 1995; Franklin & Tversky, 1990; Sholl & Nolin, 1997; Tversky, 2003). The major shortfall of egocentric representations is that they are inherently unstable, because the reference frame changes continuously as the viewer moves or rotates in the space (Klatzky, 1998). Thus, transformations may be needed to make use of information that has been encoded in this manner.

In Tversky's (Franklin & Tversky, 1990; Tversky, 2003) *spatial framework theory*, the difficulty of locating objects in space depends on where they are relative to the viewer. According to Tversky, this is because there are differences in the saliency of the major axes, based on asymmetries

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relative to the body and the physics of the world. Symmetry on axes makes it more difficult to accurately encode the correct direction to the object in the space. Asymmetries provide additional cues that facilitate encoding. In this theoretical perspective, an item's position relative to the up/down axis is easiest to encode because it is asymmetric with respect to both the body (head vs. feet) and the world (as a function of gravity). The front/back axis is asymmetric with respect to the body but symmetric in terms of the physics of the world. The left–right axis is symmetric with respect to both the body and the physics of the world, making it the most difficult to disentangle in spatial tasks. This provides an explanation for why *left–right confusion* frequently arises in spatial tasks (Gunzelmann & Anderson, 2002; Gunzelmann, Anderson, & Douglass, 2004; Sholl & Egeth, 1981).

As was indicated above, when sufficient information about a space is available, it is possible to navigate through it effectively. However, when multiple sources of information are used to guide actions within a space, it is necessary to establish correspondence between them. This requires that at least two relationships be identified between two views of a space (Levine, Jankovic, & Palij, 1982; Maxwell, 1975, as cited in Levine et al., 1982). First, there must be at least one point that can be reliably identified in both representations of the space, to provide a stable point of reference between them. Then, to align the orientations, either another point or a reference direction must be identified in both representations. Once correspondence has been established between the two views, other points can be linked in the two representations by locating them relative to the reference features that can be reliably identified in both views. Orientation tasks require individuals to perform this operation of bringing two representations into correspondence. This kind of task has been investigated in a variety of different situations, using an assortment of different materials, to examine many different empirical questions (e.g., Boer, 1991; Easton & Sholl, 1995; Hintzman, O'Dell, & Arndt, 1981; Kirasic, Allen, & Siegel, 1984; McNamara, 1986; Richardson, Montello, & Hegarty, 1999; Rieser, 1989; Rossano, West, Robertson, Wayne, & Chase, 1999).

A naturalistic example of an orientation task is trying to navigate through an unfamiliar town using a map. The scene that the driver can perceive through the car windshield provides an egocentric view of the space, whereas the map of the town provides a representation that uses an allocentric frame of reference. Trying to decide whether to turn right or left at an intersection in this situation requires that the information in the two views be coordinated. Although this is a fairly easy task in general, research has shown that it becomes more difficult to perform as the two views of the space become increasingly misaligned (Shepard & Hurwitz, 1984). That is, whereas maps are typically oriented using cardinal directions, with north at the top, the orientation of the egocentric view is defined by the direction the viewer is facing. The difference (in degrees) between these two orientations defines the extent to which they are misaligned, which can range from 0º (if the viewer is facing north) to 180º (if the viewer is facing south). The results from Shepard and Hurwitz show that response times (RTs) increase in a roughly linear fashion as a function of misalignment. This basic effect has been replicated in a variety of different contexts (e.g., Hintzman et al., 1981; Rieser, 1989; Shelton & McNamara, 2001; Shepard & Hurwitz, 1984), which suggests that performance on these tasks involves mental imagery and rotation, since the results mirror effects found in the mental rotation literature (e.g., Shepard & Metzler, 1971).

Current Research

The focus of much of the past research on orientation tasks has been on how misalignment impacts performance in different contexts. However, the focus of our research is on properties of the target in the egocentric view. In studies (e.g., Gunzelmann et al., 2004; Hintzman et al., 1981; Wraga, Creem, & Proffitt, 2000) in which the stimuli are systematically arrayed in a circle in front of the reviewer, an *M-shaped profile* is typically found for how the location of the target impacts difficulty. This pattern occurs when stimuli are plotted as a function of position on the circle with 0º (or 360º) being directly in front and 180º being directly opposite. Response latencies increase as the target location approaches 180º from either 0º or 360º

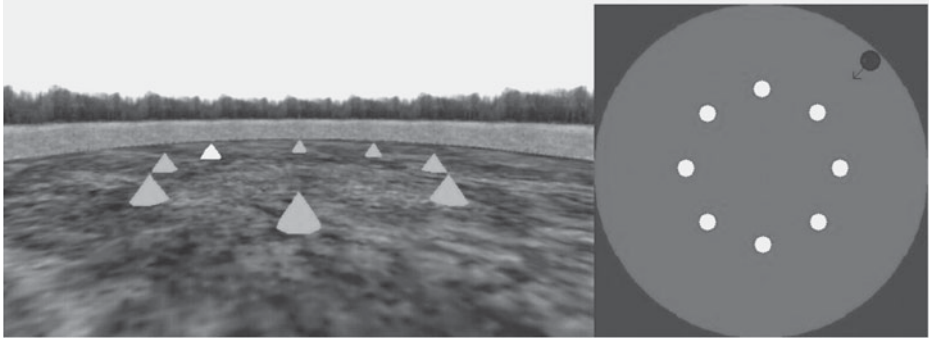

Figure 1. Sample trial for the orientation task. Participants were asked to indicate the object on the map that corresponded to the red object in the visual scene.

but dip dramatically for 180º, which is directly opposite. The goal of this research is to come to a better understanding of this effect and of other effects of how targets are displayed in an egocentric view.

Our task required participants to integrate egocentric visual information with an allocentric map of the space to make their responses. In each trial, the participants were presented with a visual scene that showed a circular space containing a number of objects. One of the objects in the visual scene was highlighted in red to identify it as the target (it is white in the sample trial shown in Figure 1). In conjunction with the visual scene, a map of the space was presented, showing the locations of each of the objects in the space, as well as the location and orientation of the viewer. Using this information, the participants were asked to indicate the object on the map that corresponded to the target identified in the visual scene. The visual scenes used in this research were computer-generated graphic portrayals of the space, with realistic 3-D properties to enhance the ecological validity of the task. A sample trial from Experiment 1 is presented in Figure 1.

The first experiment reported here provided a replication of the results when the target was one of a number of objects arranged in a circle in front of the viewer. By replicating the M-shaped profiles, this experiment established that participants perform this task in a way similar to that in past research. The second experiment extended the results of Experiment 1 by examining human performance on the orientation task when the space was less well organized. By using the same target locations, while varying the locations of the distractors on each trial, it was possible to see whether the results that typically have been obtained depend on the orderly layout of objects in the space. Finally, in Experiment 3, the results were extended further by introducing more variation in the location of the target in the space. This final experiment defined the target's location by explicitly manipulating the egocentric distance and bearing of the target. Although these factors should be important influences on performance in orientation tasks, they have not been studied in this context in the past. This seems to have been due to the tendency to use tasks such as the one shown in Figure 1, in which the objects have been carefully arranged in some predetermined manner in the space. The results of the experiments, therefore, provided a progressively more detailed examination of how a target's location influences human performance on spatial orientation tasks.

In addition to the target's location, the experiments presented here examined the influence of other objects in the space on performance in orientation tasks. In particular, how is performance affected by having objects placed near the target? Although the impact of distractors is well documented in visual search tasks (e.g., Neisser, 1963), the impact on performance in orientation tasks has not been shown. Although placing more distractors in the vicinity of the target provides a richer context for describing the target's location, it also creates a situation in which a more detailed description is needed to uniquely define the target's location. As a result, we expect that RTs will tend to increase as the number of nearby distractors increases. This hypothesis was tested in the second and third experiments below. Finally, this research should replicate the finding that misalignment impacts performance on orientation tasks. In line with previous research in this area, RTs should increase as misalignment increases.

EXPERIMENT 1

To establish the relationship between the stimuli used in this research and those in previous efforts in this area, Experiment 1 provided a replication of previous studies in our task environment (Figure 1). In particular, the space contained eight objects, spaced at 45º intervals around a circle in front of the viewer. Although the exact stimuli used may be different, this arrangement matched the general form of the stimuli that have typically been used in studies that have reported M-shaped profiles (e.g., Gunzelmann et al., 2004; Hintzman et al., 1981; Wraga et al., 2000). The visual scene incorporated 3-D characteristics to give the sense of a real space. The map showed the eight individual objects, as well as the location of the viewer. The participants were asked to identify which of the objects on the map corresponded to the red one in the visual scene (it is white in Figure 1). The data from this experiment should replicate two major findings from the literature: the effect of misalignment and the M-shaped profile relating target location to performance.

Method

Participants. The participants in this experiment were 13 individuals recruited from a campus e-mail b-board at Carnegie Mellon University. The participants' mean age was 24 years. There were 7 males and 6 females in the sample, and each participant was paid $8 for participating in the 1-h experiment.

Materials. In order to develop convincing visual scenes with 3-D properties, the commercial game Unreal Tournament (2001) was used to create the stimuli. The Unreal Tournament development environment allows users to create their own 3-D worlds. Although the usual intent is to create levels for multiplayer games, in this case it was used to create a carefully defined space to present to the participants in the experiment. The space consisted of a circular area with a circle of eight evenly spaced objects within it (Figure 1). The map presented to the participants showed the eight objects in the space, as well as the viewer's location. The viewer was always located in one of eight positions on the edge of the space, with two objects straight ahead (one nearby and one farther away). For each trial, one of the objects was colored red in the egocentric view. So, there were 64 possible trials in this task (eight possible target locations crossed with eight possible viewer orientations, or misalignments).

Procedure. The participants first read a brief description of the task and were asked to complete a sample trial to make sure that they understood it. The experimental procedure was then explained to them. The participants made their responses by using the number pad on the right portion of the keyboard. Responses were spatially mapped to the object locations on the map. So, if the target was the bottommost item on the map (as it is in the sample trial in Figure 1), the correct response was "2" on the number pad. Each participant completed four blocks of trials. Each block included all of the 64 possible trials and incorporated a dropout procedure. If the participants made an error on any of the trials, it was repeated later in the

Table 1
Proportion of Errors as a Function of Target Location and Misalignment in Experiment 1

Viewer's Position (Misalignment)	Target Location				
	Bottom	Near	Middle	Far	Top
Bottom (0º)	.00	.02	.02	.01	.04
To the side					
Near (45º)	.04	.07	.06	.07	.04
Middle (90º)	.08	.06	.08	.07	.04
Far (135º)	.04	.12	.05	.08	.00
Top (180º)	.04	.21	.05	.11	.04

block until they got it correct, with the constraint that the same trial was never presented twice in a row. The participants were told about the dropout procedure before they began the experiment, and they received feedback on their responses for each trial.

Results

The data from this experiment show a pattern that is very similar to that in the results of other research in this and related areas (e.g., Boer, 1991; Hintzman, et al., 1981; Jolicœur, 1988). First, the participants were quite accurate, overall, in this experiment (94%). However, the errors that they made were informative about the sources of difficulty in the task. These data are presented in Table 1 and are averaged over left and right target locations and misalignments. They show that very few errors were made when the target was in line with the viewer (a target at the bottom or top of the circle in the visual scene). It is also the case that fewer errors were made when the two views were aligned (when the viewer was at the bottom) than when the two views were misaligned. These data correspond well with those in previous research in this area (e.g., Gugerty, deBoom, Jenkins, & Morley, 2000; Hintzman et al., 1981). In addition, although there is not a close correspondence of the error data to the RT data ($r = .13$), the same trends are present, suggesting that the results were not due to a speed–accuracy trade-off.

The RT data, presented in Figure 2, include only the RTs for correct trials. A close look at those data reveals that there is substantial left–right symmetry in the RT patterns produced by the participants. To evaluate the influence of the left–right axis on performance, the data were analyzed using a four-way ANOVA for repeated measures, using the direction (left or right) and distance (near, middle, or far) of the target and the direction (left or right) and the degree (45º, 90º, or 135º) of misalignment as the factors (note that this analysis ignores trials in which the target location was in line with the viewer and trials in which the misalignment was 0º or 180º). For all analyses in this article, p values are Greenhouse–Geisser adjusted, where appropriate. On the basis of this analysis, the side on which the target was located did not significantly impact performance [$F(1,12) = 0.66$, $MS_e = 1.12$ sec^2, $p > .43$]. The same is true for misalignment [$F(1,12) = 2.29$, $MS_e = 2.65$ sec^2, $p > .15$]. In addition, none of the interactions in this analysis involving either the side of the target or the direction of the misalignment was significant ($p > .15$). As a result, the trend analyses presented below are conducted with data that are averaged over the left–right deviations for both factors, to best evaluate the nature of their influences on performance. To analyze the overall effects of the factors, a two-way ANOVA for repeated measures was conducted on the RT data, using the location of the target and the degree of misalignment as the factors (8×8).

For the solid line in Figure 2, the x-axis indicates the position of the target relative to the viewer in the visual scene. On this line, the first point represents trials in which the target was located in the closest position, directly in

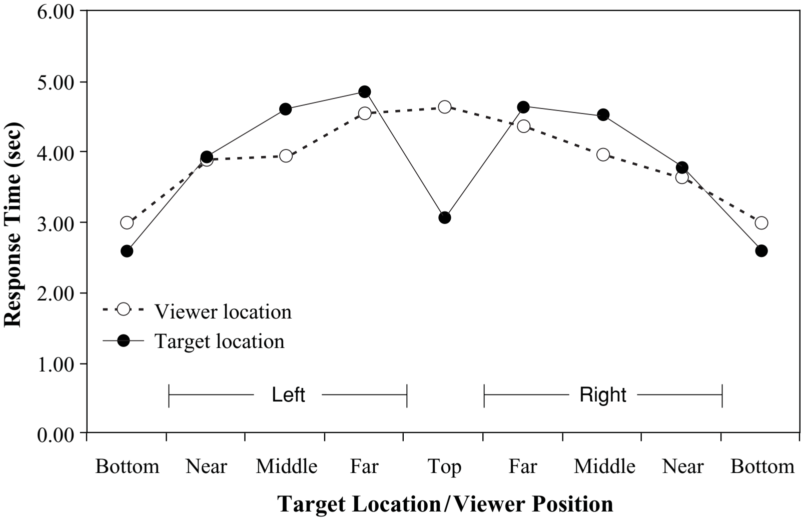

Figure 2. Response times (in seconds) as a function of the position of the target in the visual scene and the viewer's location (misalignment) on the map.

front of the viewer. The remaining points show the data for the other target locations, moving around the circle in a clockwise direction (the first point is replicated at the end for symmetry). The participants showed relatively short RTs when the target was in line with their viewpoint (an egocentric bearing of 0º). Also, RTs increased as they got farther from the viewer on the left or right of the visual scene. These two effects create the M-shaped profile that was discussed above.

The effect of the target's location in the visual scene had a significant effect on performance [$F(7,84) = 18.66$, $MS_e = 3.74$ sec^2, $p < .001$]. Previous research has demonstrated that special-case strategies tend to be used by participants when the target is located directly in front of the viewer (Gunzelmann & Anderson, 2002; Gunzelmann et al., 2004). Basically, participants are able to encode these target locations with simple verbal labels, such as *right in front of me* or *directly across from me*, thereby simplifying the process of locating the target on the map. When these "special cases" are ignored, the trend in the data is that the participants took longer to respond when the target was farther from the viewer. This linear trend was significant [$F(1,24) = 20.34$, $MS_e = 0.25$ sec^2, $p < .001$], and the quadratic trend was not [$F(1,24) = 2.34$, $MS_e = 0.25$ sec^2, $p > .14$]. These data provide some initial evidence that the target's location in the visual scene influences difficulty, even ignoring instances in which special-case strategies may be driving performance.

The dashed line in Figure 2 shows the impact of misalignment on performance, with the *x*-axis denoting the viewer's location on the map. As the viewer was located farther from the bottom of the map, misalignment increased. As Figure 2 illustrates, RTs increased as this misalignment increased. This effect was significant [$F(7,84) = 8.65$, $MS_e = 3.41$ sec^2, $p < .001$]. Although some previous research has shown evidence for unusually good performance on trials in which misalignment was maximal (e.g., Gugerty et al., 2000; Hintzman et al., 1981), this has not been universally found (Presson, 1982; Wraga et al., 2000) and has typically been limited to accuracy measures (e.g., Gunzelmann et al., 2004; Wraga et al., 2000). In this study, no participants reported using a different strategy for these trials, and there was not significant evidence of a nonlinearity in the data. That is, the impact of misalignment had a strong linear component [$F(1,48) = 62.23$, $MS_e = 0.33$ sec^2, $p < .001$], but the quadratic trend was not significant [$F(1,48) = 2.15$, $MS_e = 0.33$ sec^2, $p > .15$, averaging over left and right viewer locations]. These findings support the conclusion that the participants interacting with our 3-D task environment found the task more difficult as misalignment increased, in line with previous research.

Finally, the data for the interaction between target location and misalignment show that there was less of an impact of misalignment when the target was in line with the viewpoint (the nearest and farthest target locations). Figure 3 shows this effect, averaging over left and right locations for both target location and misalignment, to simplify the figure. Although the impact of misalignment was diminished when the target was located in the bottom or top position in the visual scene, the interaction was not significant in the RT data [$F(49,588) = 1.65$, $MS_e = 1.44$ sec^2, $p > .14$]. To more closely examine this interaction, however, it is possible to compare the slopes of the two effects, using a repeated measures ANOVA. For this analysis, a best-fitting line was estimated for each participant for the misalignment effect when the target was in line with the viewer and when it was not. The slopes of

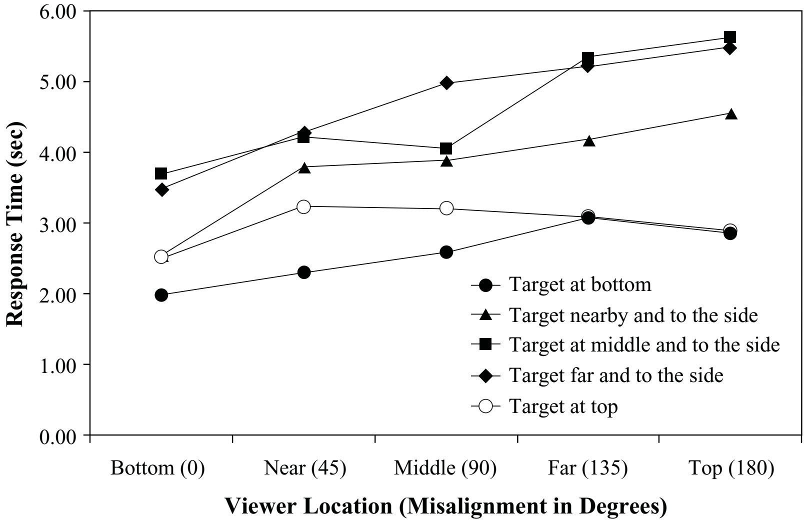

Figure 3. Response times (in seconds) as a function of the interaction of the target's position in the visual scene and the viewer's location (misalignment) on the map. The data are averaged over left and right locations for both the target's position and the viewer's location.

these best-fitting lines were used in the analysis, showing a significant difference between those two situations [$F(1,12) = 10.34$, $MS_e = 0.06$ sec^2, $p < .01$], with the slope of the misalignment effect being smaller when the target had an egocentric bearing of 0º (top or bottom) than for other bearings. The difference was quite substantial in this comparison: an average of 157 msec (SE = 78.92 msec) versus 476 msec (SE = 78.06 msec) per 45º increase in misalignment, respectively.

One final point is worth mentioning. The participants in this study used the number pad on the keyboard to make their responses. This raises the possibility that the motor movements required for making those keypresses influenced the data. Whereas these responses were balanced across levels of both misalignment and target location, this issue could have impacted the interaction of the two factors. To evaluate this possibility, the data were analyzed as a function of the response that was required. When this was done, no significant difference was indicated [$F(7,84) = 1.73$, $MS_e = 0.29$ sec^2, $p > .15$]. This further supports the conclusion that the differences reflect the cognitive requirements for doing the task. In the remaining experiments, the participants made their responses by clicking on the appropriate object, eliminating this factor as a possible influence.

Discussion

This experiment showed a pattern of data similar to that found in previous research on orientation tasks (e.g., Boer, 1991; Gugerty et al., 2000; Hintzman et al., 1981). This suggests that the participants performed the task in a similar manner. First, as the misalignment between the two views of the space increased, RTs and error rates increased as well. This result relates to the difficulty of establishing correspondence between the two views of space. In addition, this research replicated previous research showing that targets with an egocentric bearing of 0º are easier to locate than other targets in the space. The finding that the impact of misalignment was diminished in these cases suggests that the impact of misalignment may depend on the difficulty of describing the location of the target.

Finally, the results of this experiment indicate that as the target is located farther from the viewer on one side or the other, RTs increase, showing that the target's distance from the viewer may be a factor in the difficulty of this task. However, previous research has identified particular strategies that participants may use to do this task (Gunzelmann & Anderson, 2002; Gunzelmann et al., 2004). Those strategies predict this effect, but they depend on the regular arrangement of the objects in the space. In general, the results provide evidence that that the target's location relative to the axes of the body may influence how its location is encoded. The following experiments, however, showed that this is not the only important factor. Experiments 2 and 3 explored the impact of target location in more detail, to demonstrate that similar results are found when the objects in the space are not arranged in such a regular manner. We will use the results from those experiments to develop a more general understanding of the basic phenomena.

EXPERIMENT 2

The results of Experiment 1 replicated previous findings, but the arrangement of the objects in the space may have influenced the results. In addition, objects in real-world spaces are typically arranged in a much less regular manner. As a result, it is not clear to what extent the findings from the task in Experiment 1 (and others like it) can be extended to naturalistic situations. The present experiment was conducted in an attempt to see whether the impact of the target's location in the visual scene would remain when the objects in the space were organized more irregularly. This was done by dividing the space into quadrants and placing the objects into the space in clusters that fell within those quadrants. The exact design of the experiment will be described below. However, a key feature of this design was that there were no trials in this experiment in which the objects fell on a circle within the space. Thus, strategies that have been reported elsewhere for circular arrays (e.g., Gunzelmann et al., 2004) could not apply. If an M-shaped profile relating target location to performance were to appear in these data, it would suggest that some more general characteristic of the task contributes to this effect.

This experiment included a manipulation of the number of objects positioned near the target as well. When objects are in groups, individuals may take a different approach to locating the correct target. The impact of this factor in this kind of task has not been examined in detail in past research. It is possible that placing a larger number of objects in the vicinity of the target will provide a large enough increase in contextual information to facilitate locating the target. However, we believe that although it may facilitate finding the area of the map where the target is located, it also will make it more difficult to identify which of the items in that area is actually the target. Consequently, as the number of local distractors increases, we expect RTs to increase. Examination of this factor should lead to a better appreciation of the processes that participants use to perform the task.

Method

Participants. The participants in this experiment were 20 individuals recruited from a campus e-mail b-board at Carnegie Mellon University. There were 12 males and 8 females, with a mean age of 21.9 years. This does not include 1 participant who was unable to complete the experiment because of technical difficulties. The participants were paid $10 for their participation in the study, which lasted about 1.5 h.

Materials. Once again, the stimuli for the visual scene were developed using the Unreal Tournament (2001) game engine. The space was the same size as the one used in Experiment 1. However, for this experiment, six unique spaces were created to present to the participants. In each space, there were 10 objects, which were positioned so that they did not create a circle of objects like the stimuli

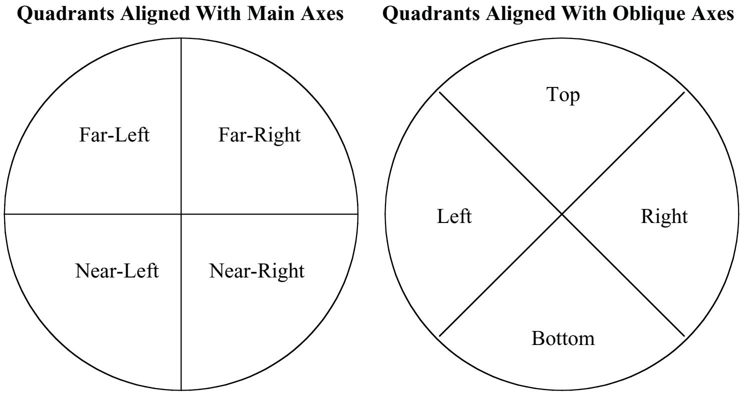

Figure 4. Organization of quadrants in Experiment 2 for both conditions. On each trial, there were 10 objects, placed in the visual scene in such a way that one quadrant contained 1 object, one quadrant contained 2 objects, one quadrant contained 3 objects, and one quadrant contained 4 objects.

used in Experiment 1. Instead, the objects were placed by dividing the space into quadrants. The individual objects were put into the space in such a way that, on each trial, one quadrant contained a single object, one quadrant contained 2 objects, one quadrant contained 3 objects, and the final quadrant contained 4 objects. Within each quadrant, the objects were placed randomly around a central point. Because of the random placement of objects, it was possible for an object to be closer to objects in a neighboring quadrant than to objects in its own quadrant. This was rare, however, and one motivation for using different maps was to offset any influence of the particular way in which the objects were arranged in the space. In addition, the six different maps corresponded to the six possible configurations of quadrants relative to each other. Finally, each map was presented in all eight 45º rotations, resulting in 48 actual maps, representing all of the possible arrangements of quadrants relative to the viewer. For half of these, the quadrants were aligned using the main axes of the space, relative to the viewer, while the other half were aligned relative to the oblique axes (Figure 4). These variations were used to offset any effects that might result from the layout of these quadrants.

On each map, the target could appear in any of the four quadrants. An object was randomly selected from each quadrant on each map to serve as the target. The other objects (if any) in the quadrant represent the local distractors in the analyses below. Therefore, in quadrants containing more than one object on a particular map, the same item served as the target across all trials in which that map was used and the target was in that quadrant. This was done to ensure that any effects involving the number of local distractors were not the result of differential low-level perceptual practice effects (e.g., Chua & Chun, 2003; Olson & Chun, 2002). Finally, four different viewer positions were tested in this experiment. The viewer was located at the bottom, right, left, or top of the map area. When the viewer was located at the bottom, the visual scene and the map were aligned. When the viewer was at the right or left side of the map, the views were misaligned by 90º. Finally, with the viewer at the top of the map, the two views were maximally misaligned, or misaligned by 180º. This design resulted in 768 possible trials. The quadrants were oriented according to either the main axes or the oblique axes, relative to the viewer. There were 6 unique maps presented in each of eight possible (45º) rotations (48 maps total), four possible targets on each map (among zero, one, two, or three local distractors), and four different misalignments.

The manipulations introduced in this experiment produced a large number of possible trials. To make the experiment manageable as a single-session study, the trials were divided in half, and different groups of participants completed the two different sets of trials. In particular, half of the participants completed trials in which the quadrants were defined by the main axes of the space relative to the viewer, and half completed trials in which the quadrants were defined by the oblique axes relative to the viewer. To compare performance across these two conditions, *metaparticipants* were created by using their scores on a version of the Vandenberg and Kuse (1978) Mental Rotation Test. This test provides a measure of spatial ability and involves comparing block figures (Shepard & Metzler, 1971). As was noted in the introduction, most researchers have pointed to mental imagery and rotation as an important aspect of performance on this kind of task (e.g., Hintzman et al., 1981; Presson, 1982; Shepard & Hurwitz, 1984; Wraga et al., 2000), suggesting that this measure should tap an important aspect of performance. This procedure produced a randomized block design, where the metaparticipants were the blocks.

After the participants had completed the experiment, they completed the mental rotation test. The participants in each condition were ranked on the basis of their scores, and the data from the corresponding participants in the two conditions were joined to produce the metaparticipants. For instance, the data from the participant with the highest score on the mental rotation test in one condition were combined with the data from the participant with the highest score in the other condition, creating a single metaparticipant. The correlation between the matched participants in terms of overall average RTs was .70, reinforcing the conclusion that the mental rotation test assessed an important aspect of performance in this task. The metaparticipants in this design allow for the more straightforward and thorough analysis of the impact of target location below. Importantly, however, the general conclusions do not change if the data are analyzed separately for the two groups of participants (see Gunzelmann, 2003).

Last, it should be noted that the quadrant structure used in this experiment resulted in spaces in which the organization of the objects was not obvious. When the design of the experiment was explained to the participants after they had finished, only 1 out of 20 indicated noticing this feature of the stimuli. The remaining participants reported not noticing any structure in the stimuli. This indicates that the participants were not explicitly picking up on the clusters that were used to organize the objects in the space. However, the design does allow for a test of whether or not the effects of target location found in Experiment 1 extend to situations in which the objects are not arranged so regularly in the space. If the central points from the quadrants are plotted on a map, they form a circle and line up with the object locations used in Experiment 1 (see Figure 4). This means

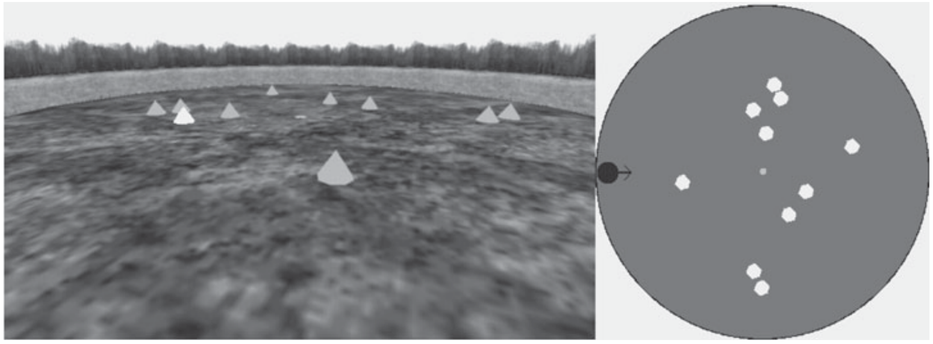

Figure 5. Sample trial for Experiment 2. There are a total of 10 objects in the visual scene, 1 of which is highlighted in red to identify it as the target. The map shows the space, including the location of the viewer.

that the performance of the metaparticipants in this experiment can be examined in a way similar to that for the data in Experiment 1, to see whether the same trends appear in the data.

Procedure. The participants were tested in a single session that lasted no more than 1.5 h. For each trial, a visual scene and a map were displayed, each showing the 10 objects in the space. The target was highlighted in red in the visual scene, and the viewer's location was indicated on the map. A sample trial is shown in Figure 5 (the target in the visual scene is white in this image). The participants were first introduced to the task and given a sample trial to solve. If they had any difficulty with the sample trial, the task was explained to them until they were able to complete it correctly. The participants made their responses by clicking on the object on the map that they believed corresponded to the target indicated in the visual scene.

In the experiment, each participant completed 384 trials, using the same dropout procedure as that in Experiment 1, which was described to them before they began. The experiment was broken up into blocks of 20 trials. Between each block, a message box appeared, telling the participants how many trials they had completed. The participants were told that if they needed a break, they could take one while this message was showing. Once they had finished the trials, participants were questioned briefly about how they had done the task. Then they completed the test of mental rotation ability described above. These data were used to create the metaparticipants in the manner described above. The analyses presented here are based on those 10 metaparticipants.

Results

RTs and accuracy were recorded for each trial in the experiment. Overall, accuracy was quite high (96%). The errors that the participants did make followed the predicted pattern. The participants made more errors as the misalignment between the two views increased and as the number of local distractors increased [$\chi^2(3) = 94.71, p < .001$, and $\chi^2(3) = 67.33, p < .001$, respectively]. These data are presented in Table 2. In addition, the participants' errors were more or less evenly distributed among the different target locations tested in this experiment (Table 3). This pattern of results is quite similar to that for the RT data, which are presented below ($r = .83$), suggesting that the results were not due to a speed–accuracy trade-off.

The RTs (once again, those for correct responses only) provide evidence about what aspects of the task impacted difficulty. To closely examine the different factors, statistics will be reported over both participants (F_p statistics) and maps (F_m statistics) in the results that follow. If an effect is significant over participants but not over maps, it suggests that the effect may be due to some feature of a subset of the maps. First, a four-way, repeated measures ANOVA (target side, target distance, number of nearby distractors, and misalignment direction) was conducted to determine whether the left–right axis influenced the results. Once again, the evidence suggested that overall performance did not differ as a function of which side of the space the target was on [$F_p(1,9) = 0.37$, $MS_e = 1.09$ sec^2, $p > .5$, and $F_m(1,5) = 0.26$, $MS_e = 0.94$ sec^2, $p > .60$] or in terms of the direction of the misalignment [$F_p(1,9) = 3.57$, $MS_e = 0.89$ sec^2, $p > .09$, and $F_m(1,5) = 2.47$, $MS_e = 0.77$ sec^2, $p > .15$]. Consequently, the data are averaged over left and right for the trend analyses presented below for this experiment. To examine the effects of the different factors, the data were analyzed using a three-way repeated measures ANOVA (target location [8], misalign-

Table 2
Proportion of Errors as a Function of Number of Nearby Distractors and Misalignment in Experiment 2

Viewer's Position (Misalignment)	Local Distractors			
	Zero	One	Two	Three
Bottom (0º)	.00	.02	.02	.00
Left (90º)	.01	.05	.07	.05
Top (180º)	.01	.09	.09	.10
Right (90º)	.02	.02	.05	.05

Table 3
Proportion of Errors as a Function of Target Location in Experiment 2

Target Location	Number of Errors
Bottom	.04
Near-left	.05
Mid-left	.04
Far-left	.03
Top	.03
Far-right	.05
Mid-right	.05
Near-right	.04

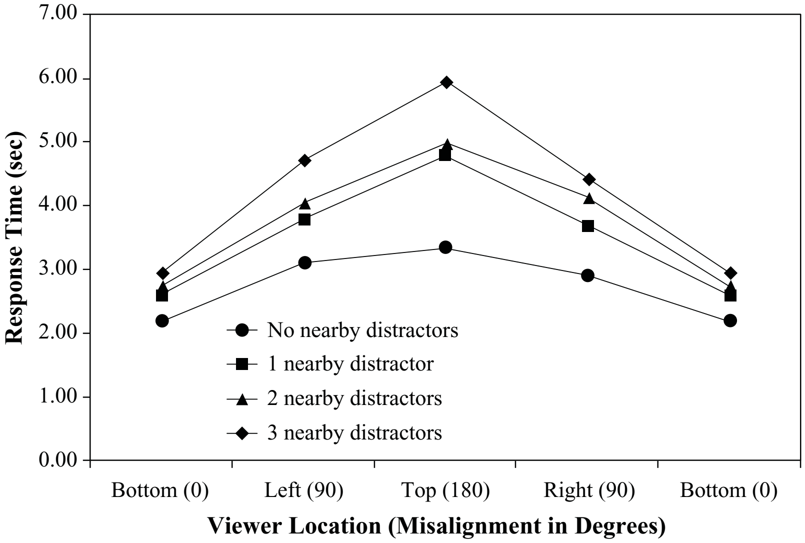

Figure 6. Response times in Experiment 2 as a function of misalignment and the number of distractors located near the target.

ment [4], and number of nearby distractors [4] were the factors). In terms of misalignment, the data correspond well with the results from Experiment 1 (Figure 6). As the misalignment between the two views increased, RTs increased as well [$F_p(3,27) = 38.62$, $MS_e = 6.47$ sec^2, $p < .001$, and $F_m(3,15) = 109.87$, $MS_e = 1.36$ sec^2, $p < .001$]. This effect mirrors the results found in Experiment 1, with evidence for a significant linear trend [$F_p(1,18) = 113.21$, $MS_e = 3.47$ sec^2, $p < .001$, and $F_m(1,10) = 250.75$, $MS_e = 0.94$ sec^2, $p < .001$], in addition to the lack of a significant quadratic trend [$F_p(1,18) = 0.62$, $MS_e = 3.47$ sec^2, $p > .40$, and $F_m(1,10) = 1.38$, $MS_e = 0.94$ sec^2, $p > .20$].

This experiment introduced a manipulation of how many distractors were located near the target. The number of nearby distractors did have an impact on performance, which is shown in Figure 6 as well. These data show that as more local distractors were present, the participants took longer to identify the correct object on the map. This effect was significant [$F_p(3,27) = 60.67$, $MS_e = 2.41$ sec^2, $p < .001$, and $F_m(3,15) = 24.16$, $MS_e = 3.64$ sec^2, $p < .001$]. The magnitude of this effect, however, depended on the degree of misalignment between the two views (Figure 6). Specifically, the impact of the number of local distractors increased as misalignment between the two views increased. This interaction was significant as well [$F_p(9,81) = 8.79$, $MS_e = 0.94$ sec^2, $p < .001$, and $F_m(9,45) = 8.32$, $MS_e = 0.60$ sec^2, $p < .01$]. Importantly, this effect did not depend on the small impact of the number of distractors when the two views were aligned. When those data were ignored, the interaction was still significant [$F_p(6,54) = 5.70$, $MS_e = 0.98$ sec^2, $p < .01$, and $F_m(6,30) = 4.62$, $MS_e = 0.73$ sec^2, $p < .03$].

The main goal of this experiment was to investigate the impact on performance of the target's location in space when the objects were organized more irregularly than in much previous research. In this experiment, the arrangement of objects in the space did not lend itself to the use of strategies that had been described previously in task situations like the one used in Experiment 1 (e.g., Gunzelmann & Anderson, 2002; Gunzelmann et al., 2004). Despite this, the location of the target in this experiment did have an impact on performance. As was indicated above, the central points used to place objects into quadrants in this experiment fell on a circle, corresponding to the arrangement of objects in Experiment 1. As a result, Figure 7 shows the data from this experiment, with the data from Experiment 1 superimposed. What is most interesting about these data is the similarity of the patterns in the two experiments. Even though the objects in the space in this experiment were organized in a very different way, the impact of the target's location replicated the M-shaped profile. Of course, it is difficult to base any strong conclusions on the data shown in Figure 7, since different participants contributed to different data points in this experiment. Also, it is possible that the participants in the two groups were able to take advantage of the alignment of the quadrants, since this limited the potential target locations. However, the overall similarity of the data to those in Experiment 1 is compelling ($r = .93$). In fact, in terms of the impact of target location, there was no interaction between the two experiments [$F(7,147) = 1.99$, $MS_e = 0.39$ sec^2, $p > .10$]. And this lack of a significant interaction exists in the context of a highly significant effect of target location on RTs in this experiment [$F_p(7,63) = 11.39$, $MS_e = 4.45$ sec^2, $p < .002$, and $F_m(7,35) = 37.82$, $MS_e = 0.80$ sec^2, $p < .001$].

Finally, the data from this experiment show the relationship of target location to other factors in the task. The M-shaped pattern was produced regardless of the number

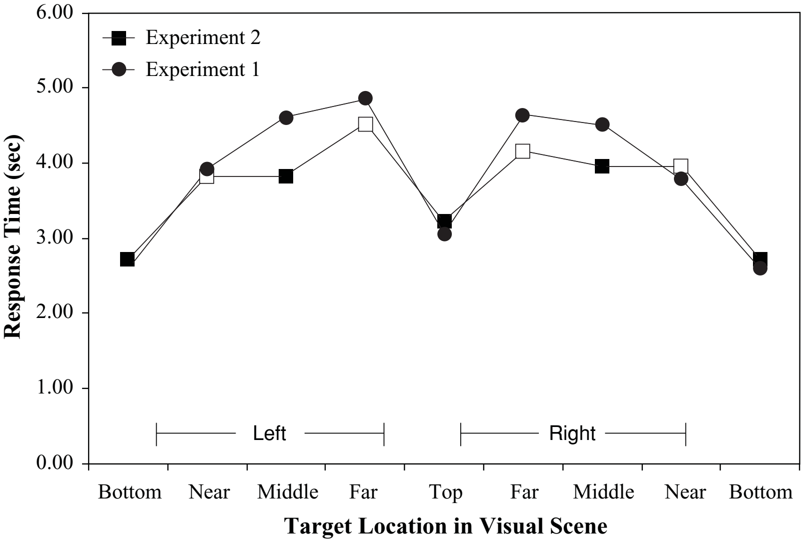

Figure 7. Effect of the target's location in the visual scene on response times in Experiment 2. Hollow points are from the condition in which the quadrants were oriented obliquely, and solid points are from the condition in which the quadrants were oriented according to the major axes.

of distractors that were located near the target (Figure 8). There was not a significant interaction between the location of the target and the number of nearby distractors [$F_p(21,189) = 1.79$, $MS_e = 0.90$ sec^2, $p > .15$, and $F_m(21,105) = 0.84$, $MS_e = 1.16$ sec^2, $p > .50$]. In contrast, the target's location did have an influence on the impact of misalignment (Figure 9). This effect mirrors the finding from the last experiment, showing that the impact of misalignment is diminished when the target is in line with the viewpoint. The interaction is significant in these data [$F_p(21,189) = 3.78$, $MS_e = 1.45$ sec^2, $p < .02$, and $F_m(21,105) = 6.87$, $MS_e = 0.48$ sec^2, $p < .01$]. A comparison of the slopes of the misalignment effect for these cases, similar to the one performed in Experiment 1, further supports this conclusion. Overall, the slope of the misalignment effect was larger when the target was lo-

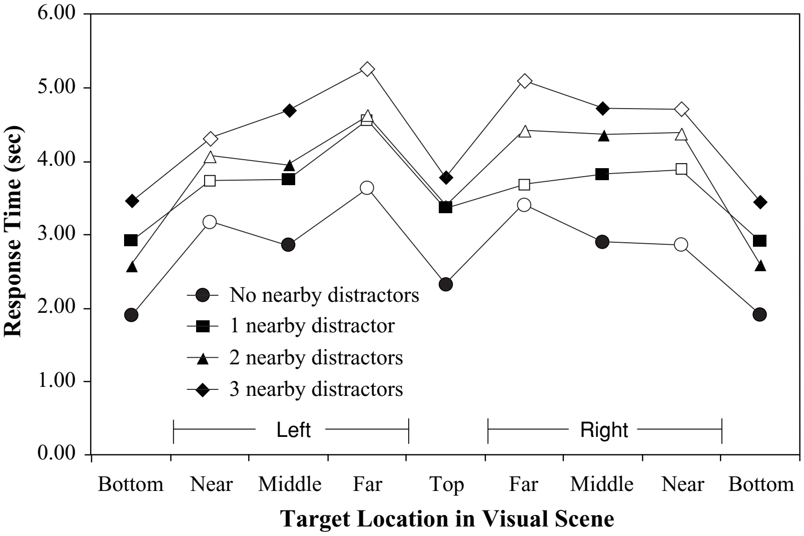

Figure 8. Response times in Experiment 2 as a function of target's location relative to the viewer and the number of distractors located near the target. Hollow points are from the condition in which the quadrants were oriented obliquely, and solid points are from the condition in which the quadrants were oriented according to the major axes.

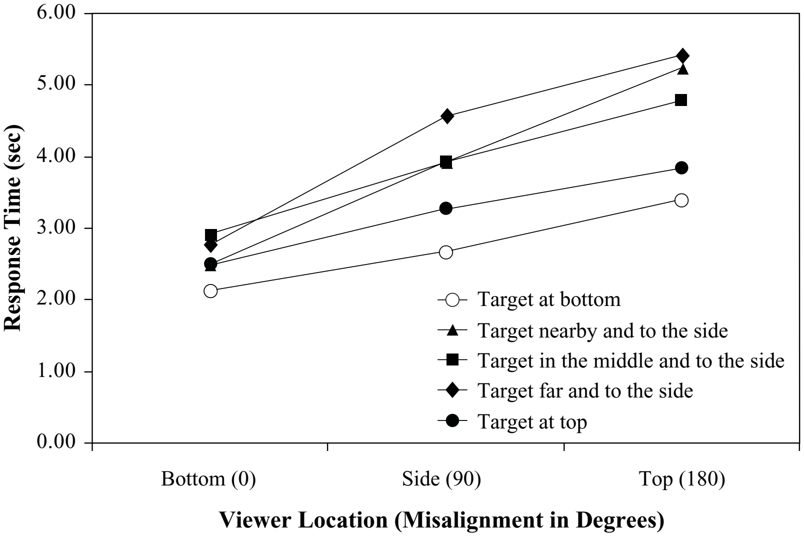

Figure 9. Response times in Experiment 2 as a function of the target's location relative to the viewer and the degree of misalignment between the two views. Hollow points are from the condition in which the quadrants were oriented obliquely, and solid points are from the condition in which the quadrants were oriented according to the major axes.

cated on one side or the other of the visual scene than when it was in line with the viewer [1,214 vs. 655 msec/90º; $F(1,9) = 9.50$, $MS_e = 0.16$ sec^2, $p < .02$].

Discussion

This experiment represented an initial attempt to examine orientation tasks in which the objects in the space were not arranged in a regular manner. The results highlight several factors that contribute to difficulty in such tasks. First, misalignment between the two views of the space impacted difficulty in much the same way as that shown in a variety of previous studies (e.g., Gunzelmann & Anderson, 2002; Gunzelmann et al., 2004; Hintzman et al., 1981; Rieser, 1989; Shelton & McNamara, 2001; Shepard & Hurwitz, 1984). This reinforces the idea that resolving the conflict between the two frames of reference is a major source of difficulty in this kind of task.

Beyond misalignment, this experiment illustrates how the locations of the objects in the space (including the target) impact the difficulty of the task. The influence of the target's location replicates the M-shaped profile found in Experiment 1, using a more naturalistic arrangement of objects. These findings show that the location of the target relative to the viewer within a space is an important factor in determining how difficult it will be to locate it on a map of the space. In addition, the outcome suggests that the participants used the viewer's location in the space as a key reference feature to help them determine the location of the target, because RTs were shorter when the target was located where it could be encoded more easily with respect to the viewer's position in the space. This matches the predictions of theories that emphasize the importance of the axes of the body for encoding spatial location (Easton & Sholl, 1995; Franklin & Tversky, 1990; Sholl & Nolin, 1997; Tversky, 2003). Further evidence related to this claim will be presented in the next experiment.

The findings also show that as more objects were located in the vicinity of the target, difficulty increased. This result illustrates that the position of the target relative to the viewer is not the only influence on the difficulty of this task. Rather, the context surrounding the target also influences difficulty. In addition, it appears that the participants were not considering the locations of all of the objects in the space to do the task, since the total number of objects was held constant across all trials. Last, this effect did not depend on the particular location of the target. This outcome shows that nearby distractors influence how hard it is to uniquely identify a target's location, a factor that needs greater consideration in theories of spatial coding.

On the basis of the results, one can view the process of solving these tasks as developing a description of the target's location, which then has to be transformed to apply to the map. This description can be verbal or can involve the creation of a mental image. In either case, given the paucity of salient features in the space, it would make sense for participants to use the viewer's position to help them encode some information about the location of the target in the space. That information should become more difficult to extract as the target is located farther from the viewer or farther off to one side or the other. Also, the description of the target's location that is generated, be it verbal or imaginal, should become more complex as more distractors are placed near the target, since more information must be included in the description to uniquely identify the target. Finally, as the complexity of that description increases, it will become more difficult to transform it to resolve any misalignment between the views (e.g., Bethell-Fox & Shepard, 1988).

This general conceptualization of human performance is supported by retrospective verbal reports, which were collected from the participants when they completed the experiment. In general, the participants indicated that they engaged in a two-step process to find the answer. First, they identified a *cluster* of objects that contained the target and attempted to locate that cluster on the map. Once the cluster had been identified, the participants determined which of the objects in the cluster was the correct response. This hierarchical solution process illustrates how the participants were able to limit their search to a portion of the space and supports the explanation above. First, locating the correct cluster essentially involves finding the right area of the map to search in to find the target. It seems that this step can be accomplished by identifying the target's general location relative to the viewer. The difficulty of this step, as a function of the location of the target relative to the viewer, is reflected in the main effect of target location in the data. The interaction of the location of the target with misalignment suggests that the description of this general location, or the transformations that are needed, is more complex when the target is located off to one side or the other in the visual scene.

It is in the second step that the target's location is identified uniquely. Since more distractors are placed near the target, a more complex description is needed to disambiguate the target from the other objects in the vicinity. The main effect of the number of nearby distractors provides evidence for this. Then, when the two views are misaligned, that description will need to be updated to apply to the map. This process may involve mental rotation or updates to a verbal description, but in both cases those updates would take longer when the description was more complex (Bethell-Fox & Shepard, 1988). The need for updates is illustrated in the main effect of misalignment, whereas the interaction between the effects of misalignment and the number of nearby distractors illustrates the impact of complexity on the updating process. Finally, the verbal reports suggested that the two steps were independent, which was supported by the finding that there was no interaction between target location and the number of nearby distractors. That is, the process of identifying the target's location within the cluster appears not to depend on where the cluster is in the space.

Although this solution process serves to explain many aspects of our data, it still leaves something of a mystery as to exactly why there is an effect of target location. This experiment indicates that it is not simply an artifact of having the target and distractors neatly arrayed around a circle. Somehow, the location of the target in space must influence the complexity required to uniquely describe the target's position. The explanation just provided suggests that the general location of the target influences the difficulty of identifying the cluster. Before speculating further on this relationship, we will describe our third experiment, which was designed to more thoroughly examine the effect of target location.

EXPERIMENT 3

The results from Experiment 2 mirrored the findings from Experiment 1, indicating that the target's location relative to the viewer influences difficulty and that this effect does not depend on the arrangement of objects within the space. This final experiment provided an important extension of those results by testing a more comprehensive set of target locations. The target locations in Experiments 1 and 2 were based on past research, which generally has placed objects in a circle to carefully control the stimulus environment. In addition, in many previous studies, researchers have looked at situations in which the participant was positioned in the center of the stimulus space (e.g., Franklin & Tversky, 1990; Hintzman et al., 1981; Rieser, 1989). Thus, the arrangement of objects in a circle within the space corresponded to important egocentric reference directions, such as *ahead*, *behind*, or *to the side*. However, defining target locations by using such general descriptions obscures some of the details about the target's position within the space.

Recall from the introduction that information about the spatial location of an object in a visual scene is available in terms of the object's egocentric distance and bearing. Since those factors were not manipulated orthogonally in the previous experiments, their separate effects cannot be teased apart. In this experiment, the set of target locations was defined by manipulating egocentric distance and egocentric bearing independently, to closely examine the impact of these two factors on the difficulty of this task. Existing theories seem to imply that increasing egocentric bearing, as well as increasing distance, will result in longer RTs. This experiment explicitly tested those predictions. In addition, because some of the target locations overlapped with those used in Experiment 2, the present experiment provided an important within-subjects replication of some of the findings in that experiment, which were based on metaparticipants.

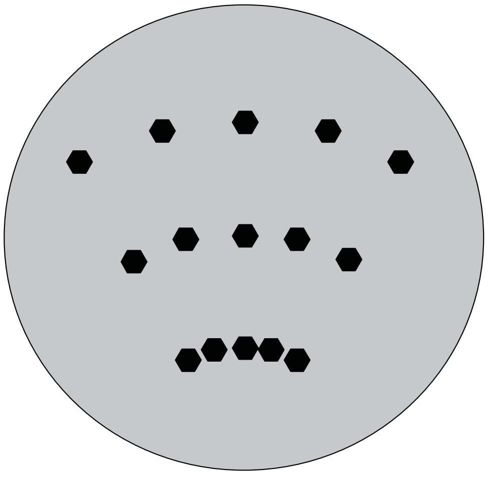

Figure 10. Possible target locations used in Experiment 3.

Method

Participants. The participants in this experiment were 15 individuals recruited from an e-mail b-board at Carnegie Mellon University. Their mean age was 20.8 years. There were 9 females and 6 males. They were paid $15 for their participation in the experiment, which lasted no more than 2 h.

Materials. The spaces used in this study were constructed in the Unreal Tournament (2001) game engine, and the space was the same size as the one used in the previous experiments. This experiment tested 15 different target locations. There were three target distances, at a quarter, half, and three quarters of the diameter of the space. This factor was crossed with five egocentric bearings, at 0º, 14º to the left or right, and 28º to the left or right.[1] Figure 10 shows the resulting target locations plotted on a map. In addition, the target was located among one or three local distractors. These distractors were positioned randomly within a circular region around the target, according to a uniform distribution. Additional objects were placed randomly within the rest of the space, so that there was a total of 10 objects in the space for each trial, as in Experiment 2. The same four viewer positions (misalignments) were tested in this experiment as in Experiment 2. Finally, the participants completed four different instances for each of the possible combinations of the factors. As a result, the participants completed 480 trials (3 distances, × 5 bearings, × 2 distractor levels × 4 misalignments × 4 instances), which involved 120 distinct spaces. Each space represented an instance of distance, bearing, and distractor level. A visual scene was obtained from each of these spaces. Then, by rotating the map image in 90º increments, four different levels of misalignment were created.

Procedure. The procedure in this experiment was identical to the one used in Experiment 2, with the exception that there were 480 trials in the experiment (there were 384 trials in the last experiment).

Results

As in the previous experiments, accuracy was quite high, with the participants responding correctly to 96% of the trials, on average. The data on errors are presented in Tables 4 and 5. In terms of target location, the participants tended to make more errors when the target was located farther from the viewer, and errors were more or less evenly divided among the different bearings that were tested in the experiment [$\chi^2(2) = 23.00$, $p < .01$, and $\chi^2(4) = 11.08$, $p < .03$, respectively; see Table 4]. These data do not line up perfectly with the RT data ($r = .31$), but they still seem to support the conclusion that speed–accuracy trade-offs were not responsible for the trends that were observed in the RTs. As in Experiment 2, the errors in this experiment were more frequent when misalignment between the two views was greater [$\chi^2(3) = 80.06$, $p < .001$], which further supports this claim (Table 5). Finally, of the errors that were made by the participants, the overwhelming majority (79%) involved clicking on one of the nearby distractors. This result suggests that most of the errors that the participants made arose during the second step of the two-step solution process described previously. That is, it seems that most of the errors made by the participants came in trying to identify the correct object within the appropriate cluster.

Table 4
Proportion of Errors as a Function of Target Location in Experiment 3

	Egocentric Bearing of Target				
Target Distance	28º Left	14º Left	Center	14º Right	28º Right
Far	.06	.04	.03	.07	.06
Intermediate	.06	.03	.08	.03	.04
Near	.02	.01	.05	.03	.02

Table 5
Proportion of Errors as a Function of Misalignment in Experiment 3

Viewer Location (Misalignment)	Errors
Bottom (0º)	.01
Left (90º)	.04
Top (180º)	.07
Right (90º)	.04

Once again, the data on RTs exclude error trials. A five-way ANOVA (target distance, target side, target bearing [14º or 28º], misalignment direction, and number of nearby distractors) indicated that there was no significant difference in overall performance as a function of which side the target was located on [$F_p(1,14) = 0.27$, $MS_e = 1.10$ sec^2, $p > .60$, and $F_m(1,96) = 0.11$, $MS_e = 0.73$ sec^2 $p > .70$] or as a function of the direction of misalignment [$F_p(1,14) = 0.11$, $MS_e = 1.79$ sec^2, $p > .70$ and $F_m(1,96) = 0.07$, $MS_e = 0.73$ sec^2, $p > .70$]. Consequently, to increase power and simplify the data presentation, all of the analyses in this section were conducted by averaging over left and right (for bearing and misalignment). Statistics are presented over both participants (F_p statistics) and maps (F_m statistics) again, to verify that the differences were not due to features of a subset of those maps. Note that, because different maps were used in this case to manipulate the target location, target distance and target bearing are repeated measures factors in the analyses over participants and independent measures factors when the data are analyzed over maps. Also, in the data from this experiment, there was no difference in performance as a function of the number of local distractors [$F_p(1,14) = 0.28$, $MS_e = 2.85$ sec^2, $p > .60$, and $F_m(1,54) = 0.42$, $MS_e = 0.50$ sec^2, $p > .50$]. This seems to be the result of how the stimuli were designed for this experiment versus Experiment 2. This will be discussed further after the results have been presented. However, as a consequence, the data presented below are averaged over this factor as well. The resulting analysis was a three-way ANOVA (using distance of the target [3], bearing of the target [3], and degree of misalignment [3] as the factors).

The data representing the impact of the target's location are presented in Figure 11. These data illustrate the impact of both the target's distance from the viewer and its bearing relative to the viewer on performance. First, the data show that targets located near the viewer were identified most quickly. Although RTs increased as egocentric bearing increased for the nearby target locations, responses to targets in all of the near locations were faster than those to any of the other locations tested in the experiment by at least 300 msec. After the near target locations, targets that were farther away and in line with the viewpoint (egocentric bearing of 0º) were identified most quickly. Interestingly, after these, the target position at the

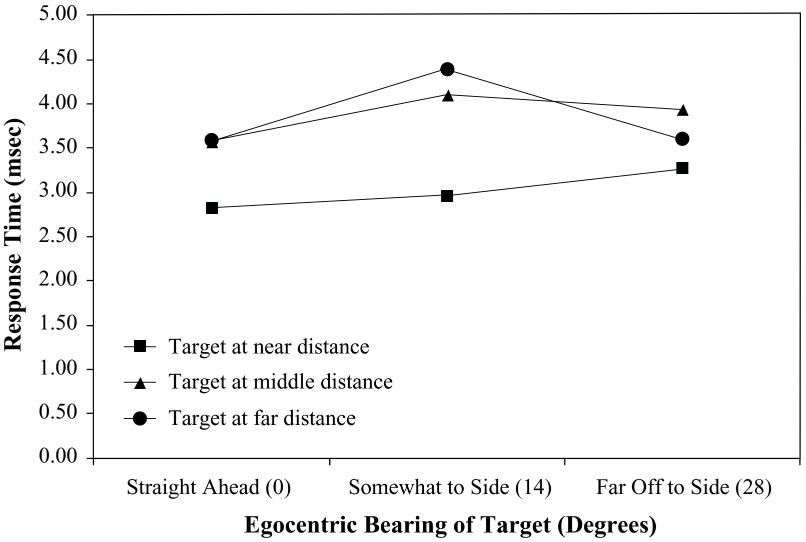

Figure 11. Effect of the target's location in the visual scene on response times in Experiment 3. The data are averaged over left and right bearings.

most extreme combination of distance and bearing (a far target at 28º) was the easiest for the participants to locate. The average RTs when the target was in this position was significantly shorter than the average RTs when the target was located in other positions that were neither nearby nor had an egocentric bearing of 0º [3.60 vs. 4.15 sec, on average; $F(1,14) = 26.95$, $MS_e = 0.08$ sec^2, $p < .001$]. This is a key result in this experiment. A simple model that relates difficulty to the distance and bearing of the target relative to the viewer cannot account for this finding. The implications of this will be discussed in detail in the General Discussion section.

Overall, both the distance of the target from the viewer and the egocentric bearing of the target had significant impacts on performance [$F_p(2,28) = 23.29$, $MS_e = 1.39$ sec^2, $p < .001$, and $F_m(2,54) = 34.30$, $MS_e = 0.50$ sec^2, $p < .001$ for the effect of distance, and $F_p(2,28) = 10.91$, $MS_e = 0.79$ sec^2, $p < .001$, and $F_m(2,54) = 9.19$, $MS_e = 0.50$ sec^2, $p < .001$ for the effect of bearing]. In the case of distance, near targets were identified most quickly, but there was little difference overall for targets located at an intermediate or far distance. For the bearing effect, targets located at an intermediate bearing (14º) were most difficult for the participants to identify overall, and targets positioned at an egocentric bearing of 0º were easiest. In addition to the main effects for distance and bearing in this experiment, there was also a significant interaction between the two factors [$F_p(4,56) = 6.99$, $MS_e = 0.46$ sec^2, $p < .01$, and $F_m(4,63) = 2.97$, $MS_e = 0.58$ sec^2, $p < .03$]. For targets located at intermediate and far distances, intermediate bearings were most difficult. For targets at a far distance, the difference in RTs for intermediate (14º) versus large (28º) bearings was over 750 msec. However, when the target was located nearest the viewer, the relationship was reversed. In these cases, targets at the most extreme bearing (28º) took over 300 msec longer for the participants to identify than those located at an intermediate (14º) bearing. These results provide further evidence that how far off to the side an object is does not necessarily determine how difficult it is to locate, as some previous accounts might predict.

Last, this experiment provides one more demonstration of the impact that misalignment has on performance (Figure 12). There was a significant effect of the viewer's position on the map [$F_p(2,28) = 41.90$, $MS_e = 2.65$ sec^2, $p < .001$, and $F_m(2,126) = 337.94$, $MS_e = 0.18$ sec^2, $p < .001$]. RTs increased linearly as the degree of misalignment between the two views increased [$F_p(1,28) = 83.80$, $MS_e = 2.65$ sec^2, $p < .001$, and $F_m(1,108) = 758.65$, $MS_e = 0.18$ sec^2, $p < .001$ for the linear trend, and $F_p(1,28) < .01$, $MS_e = 2.65$ sec^2, $p > .95$, and $F_m(1,108) < .01$, $MS_e = 0.18$ sec^2, $p > .95$ for the quadratic trend]. Once again, this effect was diminished for targets with an egocentric bearing of 0º (Figure 12A). In addition, the impact of misalignment was reduced when the target was located near to the viewer (Figure 12B). Both of these interactions were significant [$F_p(4,56) = 5.83$, $MS_e = 0.22$ sec^2, $p < .01$, and $F_m(4,126) = 3.90$, $MS_e = 0.18$ sec^2, $p < .02$ for the interaction of misalignment with bearing, and $F_p(4,56) = 3.02$, $MS_e = 0.44$ sec^2, $p < .06$, and $F_m(4,126) = 4.05$, $MS_e = 0.18$ sec^2, $p < .02$, for the interaction of misalignment with distance].

It is again possible to compare the slopes of the misalignment effect to evaluate the differences that were found, this time using a two-way ANOVA with target distance and target bearing as the factors. When the target was near the viewer, the slope of this effect was 741 msec/90º. In contrast, when the target was at an intermediate or far distance, the slope of this effect was 1,085 msec/90º and 897 msec/90º, respectively. The difference between these was significant [$F(2,28) = 4.04$, $MS_e = 0.33$ sec^2, $p < .04$]. In terms of bearing, the slope of the misalignment

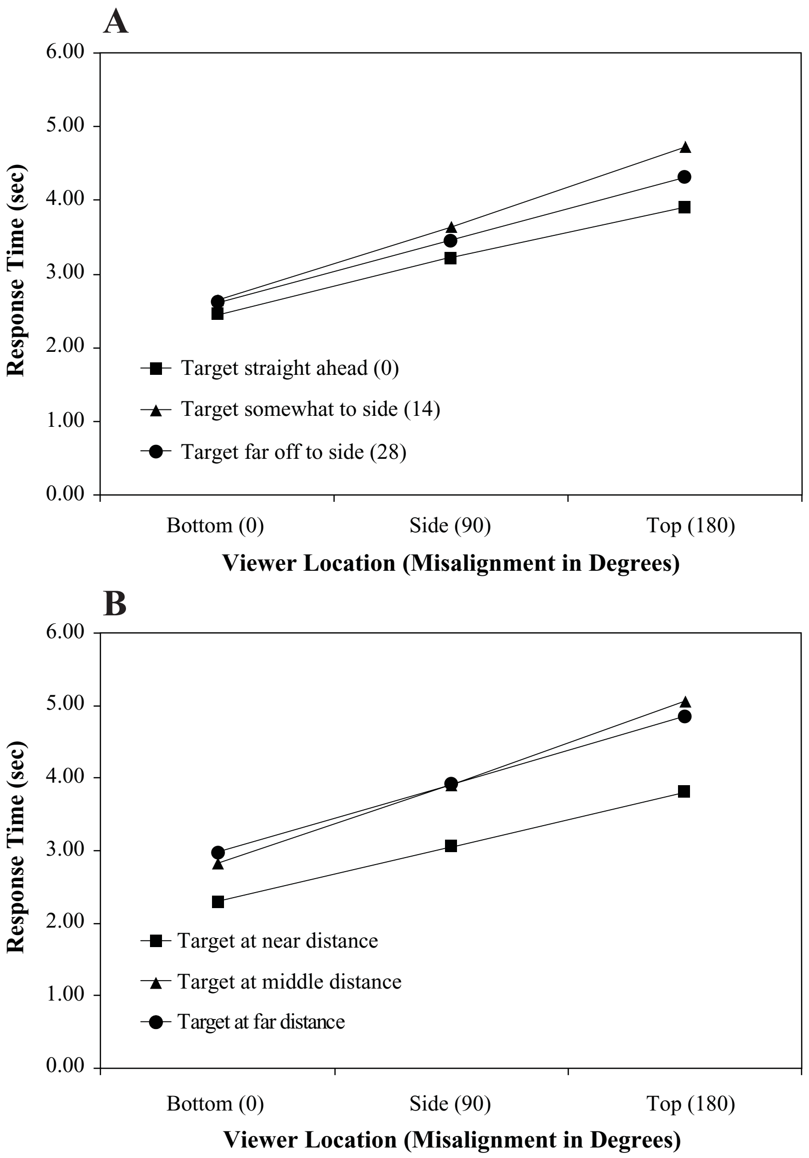

Figure 12. Response times in Experiment 3 as a function of misalignment and (A) the bearing of the target and (B) the distance of the target.

effect was 753 msec/90º when the target was directly in front of the viewer. When the bearing was ±14º, the slope was 1,084 msec/90º, and it was 885 msec/90º when the bearing to the target was ±28º. Once again, these values are significantly different [$F(2,28) = 7.93$, $MS_e = 0.16\ \text{sec}^2$, $p < .01$]. These results give additional support to the account of performance described in Experiment 2. That is, misalignment had less of an effect when the target was located where a less complex description of its position was possible.

Discussion

Unlike in Experiment 2, there was no impact of the number of nearby distractors in this experiment. As was mentioned above, this effect seems to have been a consequence of how the stimuli were designed for this experiment versus Experiment 2. In Experiment 2, the objects were randomly placed around a central point in the quadrant, and then one of the objects was randomly selected to be the target. This means that the object could appear in any position, relative to the other objects in the quadrant. In the third experiment, however, the target was placed at a particular location, and the local distractors were placed randomly around the target. Consequently, when there were three local distractors, the target nearly always ended up being in the center of the group, which seems to have made it relatively easy for the participants to encode its position within the cluster. Anecdotal support for this conclusion comes from the participants, several of whom reported noticing that the target usually appeared in the middle when it was part of a *larger cluster* of objects.

The data from this experiment replicate the finding that misalignment between the two views of a space impacts the difficulty of spatial orientation tasks. More importantly, the results provide further evidence that the location of the target in the space influences difficulty. This experiment provides a more thorough examination of this effect by systematically varying both the egocentric distance and the egocentric bearing of the target. The results show that both of these factors are important. However, they also indicate that the influences of these factors are not as straightforward as previous research may have suggested, as illustrated by the interactions in the data. Although the results show that the target's location relative to the viewer is an important factor in this task, the data do not support the conclusion that this is the only important factor related to the target's location. Before concluding, the data from this experiment will be compared briefly with the results of Experiments 1 and 2.

In Experiments 1 and 2, there were 8 central points or target locations, whereas there were 15 potential target locations in Experiment 3. If all of these locations are plotted on a map of the space, some of the points from the three experiments are very near to each other (Figure 13). To compare the results, it is possible to graph the data from these common points. This is done in Figure 14 for the data from Experiment 1 and from the one-local-distractor conditions in Experiments 2 and 3. It seems as though these were the most comparable situations among the experiments, on the basis of the stimuli and the anecdotal reports from the participants. The data in Figure 14 are graphed in the same way as the data from Experiments 1 and 2 in Figure 7. Not only does this figure show the similarity of the data among all three experiments, but it also illustrates that the data from the present experiment replicate the M-shaped profile as well. The average correlation between the data for the relevant target locations for the three experiments is $r = .94$, even though there is a significant interaction between the experiments on the effect of this factor [$F(10,175) = 2.75$, $MS_e = 0.38$ sec^2, $p < .02$]. This analysis includes only the target locations that were present across all three experiments, and Figure 14 shows that the participants responded more quickly to the middle and far targets in Experiments 2 and 3 than to targets in the same locations in Experiment 1. However, the overall pattern of data is still quite similar across all three experiments. This suggests that the *M*-shaped pattern typically found in studies of spatial orientation may actually be a reflection of a more complex pattern in the data. In the General Discussion section, we will offer our interpretation of that pattern.

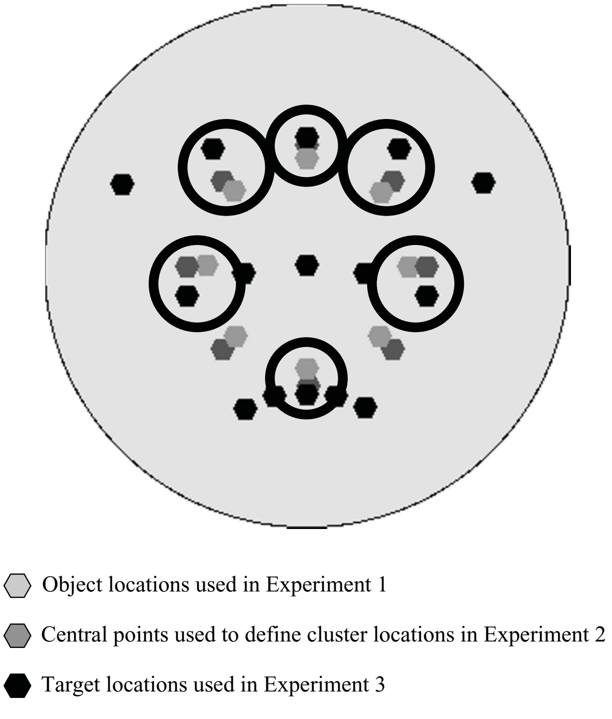

Figure 13. Location of targets in Experiment 3 shown along with the central points used in Experiments 1 and 2 to locate target objects, highlighting those points that are nearby.

GENERAL DISCUSSION

This research was conducted to develop a better understanding of how and why difficulty varies in orientation tasks as a function of the target's location in the visual scene. Recall from the introduction that establishing correspondence between two views of a space requires that two links be made between them. All of the experiments suggest that the target's location influences this process, but the cumulative results do not support the idea that the impact of this factor depends entirely on the target's location relative to the viewer. There are two results that lead to this conclusion. First, the number of nearby distractors impacted performance in Experiment 2. Even though this result was anticipated, it does show that the participants were not able to perform the task by simply encoding the target's location in terms of distance and bearing to make their response. Rather, the context surrounding the target influences performance. Second, in Experiment 3, the easiest targets to locate were those closest to the viewer and those with an egocentric bearing of 0º. However, the next easiest point was the target located at the most extreme combination of distance and bearing. If the location of the target relative to the viewer was the only influence on difficulty, this target location should have been most difficult for the participants to identify. We think that the relative ease of this point reflects the fact that it was near the edge of the space and, thus, was relatively easy to describe with respect to another referent (the edge) than with respect to the viewer. In general, we think that the data point to the conclusion that the effect of target location is largely a matter of how easy it is to describe that location

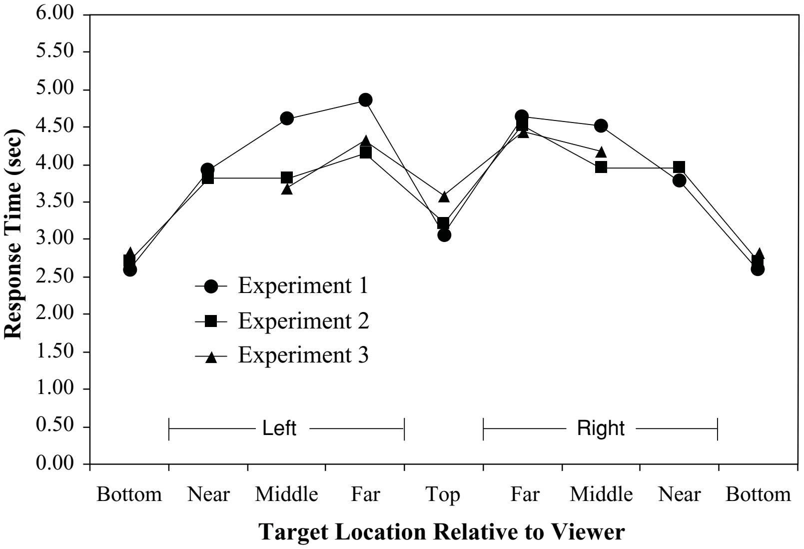

Figure 14. Performance across all three experiments for target locations that are comparable in those experiments.

relative to some referent in space. The self is always one referent, but many spaces offer other such referents.

Describing the target's basic location relative to a referent in the space corresponds to the first step in the solution strategy described by the participants. The difficulty of developing the description will depend on the relationship between the target and the referent. For instance, when the cluster is very close to the viewer or directly in front of the viewer, this step should be easier, since there is no need to consider left and right when developing a description of the cluster's location. In these cases, the description would not need to be updated, even if the two views were misaligned. This also means that when the target is located in a cluster that is nearby or straight in front of the viewer, the impact of misalignment should be diminished, just as was found in the data. In addition to the advantage of being aligned with the point of view, there is an effect of distance from referent, with the target being harder to describe the further it was from a reference point (in Experiment 3, either the self or the edge of space). This suggests that locating the appropriate area of the map begins by finding the referent with respect to which the target location was described. Assuming that this is the initial step in that process, areas near the referent should be identified more quickly.

The first step utilizes a general description of the target's location, which will not always be sufficient to uniquely identify the target. When it is not, a second step is necessary to differentiate among the various objects in the same vicinity and determine which is the target. The descriptions that are developed to encode this information may be verbal descriptions (e.g., "the second object from the left") or may take the form of mental images. In most cases, the description will become more complex as the number of objects nearby increases. This explains the main effect of nearby distractors on performance in Experiment 2. In addition, transformations of the descriptions are necessary to make them correspond to the map when the two views are misaligned. These descriptions will be more difficult to transform as they become more complex (Bethell-Fox & Shepard, 1988). In the data, this is reflected in the interaction between the number of nearby distractors and misalignment.

This interpretation suggests that the target's location impacts the complexity of the description in the first step and the number of nearby distractors impacts complexity in the second step, thereby affecting how long it takes to make the necessary transformations. The finding that there was no interaction between the target's location and the number of nearby distractors, although not conclusive, supports the position that these factors influence different aspects of the description. In general, this perspective supports a theory of human spatial reasoning that involves hierarchical encoding of spatial information. A number of researchers have proposed hierarchical theories of spatial representation in the literature (e.g., Hirtle & Jonides, 1985; McNamara, 1986; Stevens & Coupe, 1978). Here, the two-step process involves identifying an area of the map that contains the target, followed by a more detailed processing of that area to find the target itself.

Although the stimuli in Experiment 2 were created by using clusters, recall that only 1 out of 20 participants explicitly noticed this feature of the stimuli. Thus, it does not appear that the results stem from explicit strategy choices whose aim is to take advantage of the organization of the objects in the space. Still, it is possible that the design of the stimuli influenced the participants' performance. One direction for future research is to evaluate human performance on this kind of task when the objects in the space are positioned in a completely random fashion. If participants continue to report a strategy that is similar to the one described here, it would provide further support for the conclusion that they tend to take a hierarchical approach to encoding the necessary spatial information in this kind of task.

The results also suggest that individuals are flexible in their ability to use features of a space to locate targets. They indicate that the influence of the target's location on performance in orientation tasks depends less on the target's exact position in the space and more on how easily its position can be encoded with respect to other features of the space. That is, the more easily the target's location can be described relative to perceptually salient aspects of the space (i.e., reference features), the easier it should be for participants to identify. It just so happens that in these experiments (and others in the literature), there were few salient features in the space, which seems to have led the participants to use the viewer's location in most cases. However, when the target was located near the edge of the space, the data show that the participants were able to use that to help them encode the target's location, making it easier for them to locate the correct item on the map.

The results showing that the participants were able to use different reference features in the space to help them locate the target on the map relate to theories that emphasize the role of landmarks in cognitive representations of space and for navigation (e.g., Presson & Montello, 1988; Siegel & White, 1975). Research has shown that landmarks have a special status in spatial representations and that humans use such distinct features of the environment to help them encode spatial information (e.g., McNamara & Diwadkar, 1997; Pick, Montello, & Somerville, 1988; Sadalla, Burroughs, & Staplin, 1980). This research extends those findings, showing how reference features or landmarks can be used to facilitate the integration of two views of a space in orientation tasks.

In conclusion, a general theory of human performance in spatial orientation tasks has been generated from the results presented in this article. The results show that the M-shaped pattern of data described in much previous research does not depend on the orderly arrangement of objects in the space. Rather, it seems that the pattern of data arises due to how the targets are positioned relative to other features of the space and because of more general aspects of how participants solve the task. Specifically, we believe that participants encode the location of the target in the visual scene hierarchically, using reference features in the space to anchor the descriptions and interrelationships among nearby objects to further specify the target's location. The descriptions are then mentally transformed so as to apply to the map, a process that becomes more difficult as misalignment increases and as the description of the target's location becomes more complex. Participants seem to apply this strategy flexibly, making use of different reference features and stimulus regularities when they facilitate the solution process. This perspective provides a more robust account of the observed effects than do previous theories that rely solely on perceptual mechanisms or on strategies that require an orderly layout of objects in a space.

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NOTE

1. At the greatest distance from the viewer, 28º represents the largest bearing that does not restrict the placement of nearby distractors around the target. Thus, even at the most extreme combination of distance and bearing, there is an equal probability that a nearby distractor will be positioned on any side of the target.

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