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Searching Imagined Environments

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Subjects read narratives describing directions of objects around a standing or reclining observer, who was periodically reoriented. RTs were measured to identify which object was currently located beyond the observer's head, feet, front, back, right, and left. When the observer was standing, head/feet RTs were fastest, followed by front/back and then right/left. For the reclining observer, front/back RTs were fastest, followed by head/feet and then right/left. The data support the *spatial framework* model, according to which space is conceptualized in terms of three axes whose accessibility depends on body asymmetries and the relation of the body to the world. The data allow rejection of the *equiavailability* model, according to which RTs to all directions are equal, and the *mental transformation* model, according to which RTs increase with angular disparity from front.

Consider the following passage ("The Gambler, the Nun, and the Radio," Hemingway, 1927, p. 41):

> Out of the window of the hospital you could see a field with tumbleweed coming out of the snow, and a bare clay butte .... From the other window, if the bed was turned, you could see the town, with a little smoke above it, and the Dawson mountains looking like real mountains with the winter snow on them.

Narratives such as this one seem to induce mental pictures in the minds of their readers. Bransford, Barclay, and Franks (1972), Garnham (1981), Johnson-Laird (1983), and van Dijk and Kintsch (1983), among others, proposed that in comprehending such narratives, people retain more than a surface trace or a precise propositional record of the text; people also construct and make use of a mental model of the situation described by the text. Although different authors have proposed different ideas about what these "mental models" or "situation models" consist of, all agree that they represent spatial relations among objects and protagonists and that they, like representations of real-world events, can be updated as those relations change. In support of the proposal that mental models derived from text are similar to representations of real-world experience, several studies have demonstrated that models constructed from descriptions can include information about physical properties, such as the relative positions of objects (Mani & Johnson-Laird, 1982; Perrig & Kintsch, 1985) and the distances between them (Glenberg, Meyer, & Lindem, 1987; Morrow, Greenspan, & Bower, 1987). However, most researchers who have used descriptions for inducing mental models have done so for two-dimensional, rather than three-dimensional, configurations. In general, distance effects identified through response time measures for such studies have been weak and could be accounted for largely by recency of focus of attention. The evidence to date that mental models built entirely from description represent complex, three-dimensional spatial relations is scarce.

Theories of imagery are similarly based on the assumption that spatial information is preserved in mental representations, and a rich body of evidence has demonstrated that mental images can contain complex pictorial information. Visual properties, such as size (Kosslyn, 1976), shape (Shepard & Chipman, 1970), distance (Kosslyn, 1973), and color (Finke & Schmidt, 1977), have all been found to be represented in visual images. Although in some of these demonstrations the researchers have relied on descriptions (e.g., Kosslyn, 1976; Tversky, 1975), in most they have relied on memory for spatial configurations actually viewed. In studies based on memory for spatial configurations, researchers have also identified perceptionlike processes performed on mental images, such as mental scanning (e.g., Kosslyn, Ball, & Reiser, 1978) and mental rotation (e.g., Shepard & Metzler, 1971).

On the one hand, research in discourse processing has produced only limited evidence for spatial properties in mental models and for perceptionlike operations on them. On the other hand, research in the imagery literature has consisted mainly of investigating representations of static configurations that have been viewed, rather than of dynamic scenes that have been described. Our research is an attempt to further characterize some of the pictorial features and perceptionlike operations that may be associated with mental models derived from text. In the task developed here, subjects read narratives describing themselves in realistic three-dimensional environments in which they were periodically reoriented, and their response times for accessing information about objects in various directions with respect to themselves were measured.

This task was designed to capitalize on people's lifelong experience of encountering objects while navigating in complex environments. Three-dimensional rather than two-dimensional environments were chosen both to simulate that experience and to encourage subjects to use mental models instead of simple lists of objects. For complex described

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environments, it seems more difficult to recalculate direction–object paired associates when reorienting toward a new object; mental models seem to make recalculation of spatial relations less taxing. The narratives were written in the second person in order to encourage subjects to place themselves in the situations. Although the task was designed to induce imagery, subjects were not instructed to use it (except in Experiment 3). Three classes of models that might account for behavior in this and similar tasks will now be considered.

Three Classes of Models

Consider a simple environment in which you are standing and in which five objects are located in six positions around you in three-dimensional space. After you read a description of such an environment, the text reorients you to a new position and asks what is in front of you, at your back, above your head, below your feet, to your left, or to your right. The following models, successively imposing more constraints on the access of spatial information from memory, make different predictions about behavior in tasks such as this. According to the *equiavailability* model, access to information about each of the six positions is equally rapid, given that they are equidistant from you. In the other two models, access from the three dimensions is described as biased in some way, with certain directions more accessible than others. According to the *mental transformation* model, the object currently in front of you is most accessible, and the accessibility of the other objects decreases as a function of their angular disparity from the front. According to the *spatial framework* model, the accessibility of the objects depends on their direction along three differentially accessible axes defined with respect to your body.

Equiavailability

The first possibility is that you have unbiased access to locations in all directions and will be able to make decisions about each of the objects equally rapidly, given that the distance of each of the objects from you is the same. Evidence for access of this type was found by Levine, Jankovic, and Palij (1982) for simple cognitive maps. The result has been explained by proposals that the characteristics of cognitive maps are similar to those of viewed pictures and, as in viewed pictures, the different parts of a cognitive map are equally accessible. The map-scanning results of Kosslyn et al. (1978) are also consistent with this model, as only distance and not direction affected mental scanning times. Of course, one can also explain equiavailability without invoking imagery or other types of mental models. The information necessary to identify spatial relations could be stored simply as direction–object paired-associates with equal strengths of association. In either case, any model based on equiavailability would predict equal response times for all directions.

Mental Transformation

The situation that we are using, however, is not quite analogous to inspecting a picture because you are immersed in the imagined environment; that is, there are objects out of your view or nearly out of your view. If you are oriented in the imaginary world as instructed, you may have to mentally turn your body or your head in order to inspect the locations of those objects. The mental transformation model predicts that response times should vary monotonically with the amount of mental movement needed to inspect each location. In our situation, response times should be longest to inspect the location behind you; faster to inspect left, right, head, and feet locations; and fastest to inspect the front. Furthermore, you should be equally fast at identifying the objects in the directions of your right, left, head, and feet because they all are 90° away from the front.

There is indirect support for the mental transformation model from previous research. Shepard and his colleagues (Shepard & Cooper, 1982; Shepard & Metzler, 1971) have elegantly demonstrated that one can imagine objects rotating in order to verify their properties. In that research, only angular disparity, and not particular direction, affected rate of mental rotation. In other research, investigators have demonstrated that people can mentally perform smooth movements of their bodies or parts of their bodies in order to compare them with referent figures (Cooper & Shepard, 1975; Parsons, 1987a, 1987b; Sekiyama, 1982).

Spatial Framework

Our task, however, entails not just imagining locations in space and examining their contents but also comprehending the spatial language needed to construct the spatial mental model and to identify the probed directions. Several theorists have suggested that comprehension of spatial terms is biased in ways that depend on how people canonically perceive the world (e.g., Clark, 1973; Levelt, 1984; Shepard & Hurwitz, 1984; Talmy, 1983). What follows is an analysis of a spatial framework, which readers are hypothesized to construct in order to comprehend the descriptions and questions. The framework is based on the considerations raised by these theorists.

The canonical position of a person interacting with the environment is upright. The perceptual world of the canonical observer can be described by one vertical and two horizontal dimensions. The sole vertical dimension is, moreover, correlated with gravity, an important asymmetric factor in the world. Furthermore, for canonical movements, vertical spatial relations generally remain constant with respect to the observer, but horizontal spatial relations change frequently. Whereas the vertical dimension is defined by the environment (the ground and the sky, for example), the two horizontal dimensions depend on more arbitrary reference points, such as the prominent dimensions of the observer's own body. Two prominent anatomical axes, front/back and left/right, are natural reference axes for organizing horizontal space. The front/back dimension is asymmetric perceptually and functionally: The observer can more readily see, attend to, and move toward the front than toward the back. The left/right dimension is derived from the front/back dimension and has none of these asymmetries. The notorious confusion of "right" and "left" in language probably derives from this lack

of asymmetry. Thus for the upright observer, the predominant axis is the vertical, followed by front/back and then right/left. Partial support for this argument was provided by Hintzman, O'Dell, and Arndt (1981). Investigating access to real or imagined objects arranged only along the horizontal plane, they found that response times were fastest to the front, followed by back and then equally by left and right positions. Different considerations apply to the reclining case, which is described before Experiment 4.

The Present Experiments

We report fives studies. In the first, subjects read scenarios, written in the second person, describing five objects located above, below, ahead, behind, and either right or left of themselves. Periodically in the text, the second-person observers were reoriented to a new object on the horizontal plane; each time subjects were asked questions about the objects located in each direction. In the second experiment, all of the directions were egocentrically specified with respect to parts of the subject's body, so that "head," "feet," "front," and "back" replaced "above," "below," "ahead," and "behind." The results were not changed by this change in terminology. In the third experiment, subjects were instructed to imagine themselves turning in order to answer the questions. In the scenarios of the final two experiments, observers were described as reclining and turning around the head/feet axis.

General Method

Subjects

All subjects were tested individually, and none participated in more than one experiment. All were Stanford undergraduates partially fulfilling a course requirement and were native speakers of English.

Narratives

In all experiments we used 10 narratives, each involving a different environment in the second person. Each narrative was preceded by a list of the five objects in the scene (see Table 1). Each narrative was given to the subject in two parts. The first, printed on paper, described the environment from a fixed perspective, and the subject was given unlimited time to study it. The first part of the *opera* narrative used in the upright experiments follows as an example.

> You are hob-nobbing at the opera. You came tonight to meet and chat with interesting members of the upper class. At the moment, you are standing next to the railing of a wide, elegant balcony overlooking the first floor. Directly behind you, at your eye level, is an ornate lamp attached to the balcony wall. The base of the lamp, which is attached to the wall, is gilded in gold. Straight ahead of you, mounted on a nearby wall beyond the balcony, you see a large bronze plaque dedicated to the architect who designed the theatre. A simple likeness of the architect, as well as a few sentences about him, are raised slightly against the bronze background. Sitting on a shelf directly to your right is a beautiful bouquet of flowers. You see that the arrangement is largely composed of red roses and white carnations. Looking up, you see that a large loudspeaker is mounted to the theatre's ceiling about 20 feet directly above you. From its orientation, you suppose that it is a private speaker for the patrons who sit in this balcony. Leaning over the balcony's railing and looking down, you see that a marble sculpture stands on the first floor directly below you. As you peer down toward it, you see that it is a young man and wonder if it is a reproduction of Michelangelo's David.

The environments were chosen to be vivid and different. The objects for each setting were selected to be familiar and common, to be about the same size and distance from the observer, and to be plausibly located in any of five positions around the observer (beyond the observer's head, feet, front, back, and either left or right side). The objects in the horizontal plane were at eye level, and none of the objects was ever occluded by intervening surfaces.

Procedure

Subjects were told that they were to read the narratives for understanding and that they would be asked questions about the whereabouts of objects around themselves in the fictitious scenes. They were told that they could study the printed portion of the narratives for as long as they wished until they were sure of the positions of all the objects in the environment and that after they returned it to the experimenter, they would not be allowed to study it again. After returning the printed portion to the experimenter, subjects began the second portion of the narrative, presented on an IBM-XT computer. Subjects were told that they would read the story sentences on the computer at their own pace, without the opportunity to return to previous sentences, and that the story would be interrupted periodically with questions about the directions of the various objects in the scene. The first narrative was used as practice, and subjects were given feedback about the accuracy of their answers. During experimental trials, no feedback was given.

The computer presented one sentence at a time, and subjects advanced to the next sentence by pressing the space bar. In the portion of the narrative presented on the computer, the observer was described as facing one of three objects, and then a detail about that

Table 1
Objects Located Within the 10 Scenes for All Experiments

Scene	Objects
Opera theatre	Plaque, loudspeaker, sculpture, lamp, bouquet
Work shed	Yardstick, fan, saw, basket, hammer
Hotel lobby	Giftshop, banner, tavern, fountain, barbershop
Halloween party	Mask, skeleton, bowl, pumpkin, ghost
Barn	Saddle, rake, pail, lantern, shears
Lagoon	Towel, bottle, snorkel, frisbee, paddle
Escape-artist show	Camera, handcuffs, microphone, knife, blindfold
Construction site	Ladder, bucket, wheelbarrow, shovel, jackhammer
On a navy ship	Cannon, lifeboat, flag, antenna, anchor
Space museum	Spacesuit, meterorite, map, portrait, satellite

object was described. The next sentence did not refer explicitly to any of the five objects, in order to reduce any possible priming effects. The narrative for one of the opera reorientations follows as an example:

> As you remain where you are on the balcony, you turn your body 90 degrees to your right, and you now face the lamp.
> You look again at the short, rigid pole by which it is fixed to the wall.
> Perhaps this is a precautionary feature in case of earthquake.

After the filler sentence, subjects were asked about one of the five directions, which was denoted by a single word ("front," "back," "left," "right," "above," or "below"). Subjects were instructed to press the space bar as soon as they were sure of the object located in that position, without sacrificing accuracy. This was the first response time, or RT1. After subjects pressed the space bar, the names of all five objects appeared on the screen in random order with the numbers 1–5 beneath them. Subjects pressed the number corresponding to the correct object as quickly as possible without sacrificing accuracy. This was the second response time, RT2. The narrative continued, with questions interspersed to probe the other four directions. After this, computer narrative reoriented the observer to a different object and probed the five positions until the observer reoriented to three objects in the environment (the three objects not beyond the observer's head or feet). Subjects were unaware that response times were being recorded.

After completing each narrative, subjects were asked to describe the locations of the objects in the environment, and their descriptions were checked for accuracy. After the entire experiment, subjects completed a questionnaire containing detailed questions about how they thought they performed the task. Subjects were asked whether they found themselves forming mental pictures of their environment and, if so, what perspective they took on the scenes and whether they consulted their mental pictures to answer the probe questions. They were also asked whether they had used any other strategies for learning the scenes and answering questions, such as memorizing lists of sentences or direction–object pairs.

Design

Approximately equal numbers of subjects were assigned randomly to five orders in which the 10 narratives were presented. The first object faced during the second portion of any narrative was independent of the object faced during the printed portion so that the first set of questions usually did not involve the perspective in which the scene was originally learned. The order in which observers turned through various angles in order to reorient to new objects was counterbalanced across stories, and the order of the five questions for each orientation was counterbalanced.

Experiment 1: Upright

Method

Subjects. Fourteen men and 7 women completed this study. An additional subject failed to follow instructions and was dropped from the experiment.

Procedure. The procedure followed the general method just outlined but differed from the other studies in the following ways. Probe questions were presented in whole sentences of the form "Which object is ——— you now?" The blank was filled with one of the expressions "above," "below," "right of," "left of," "ahead of," or "behind," as appropriate.

Results

RT2 data were subjected to a repeated-measures analysis of variance (ANOVA) in which we used the three angular categories 0°, 90°, and 180°. This is the simplest comparison for which each of the three models under consideration would predict a significant result, if any differences were to be found in RT2. There were no differences, $F(2, 40) = 1.47$, $p > .05$, which indicates that subjects were able to follow instructions by deciding which object was located in the probed direction during RT1. The analyses to be reported, then, are on RT1.

Several criteria were used to discard data. Errors constituted 0.4% of the data and were eliminated. Very long response times, defined as greater than twice the Mean Story × Question response time computed across all subjects, constituted 1.4% of the data and were discarded. One subject described one environment incorrectly during the interview, and all response times for that story were disqualified. One story for each of 2 subjects was lost because of experimenter error, and time constraints prevented 1 subject from finishing one story and 2 subjects from finishing two. The patterns of response times for the various questions were very similar across stories, and so the data were collapsed across stories. Missing data were replaced with the Story × Question cell mean computed across subjects. These means are presented in Table 2, which further specifies the mean RTs when objects occupied only the observer's right side, only the left side, or both sides.

There was a large effect due to question, $F(5, 100) = 62.61$, $p < .00001$, which allowed rejection of the equiavailability hypothesis. The mental transformation (in this case, mental turning) hypothesis was tested in two phases. A gross analysis of angular discrepancy, 0° (ahead) versus 90° (right, left, above, or below) versus 180° (behind), yielded a significant overall effect favoring the mental transformation hypothesis, $F(2, 40) = 15.46$, $p < .0001$, as well as significant differences between categories, $t(20) = 2.07$, $p = .05$ (0° vs. 90°), and $t(20) = 4.17$, $p < .001$ (90° vs. 180°). However, a closer analysis of the 90° categories allowed rejection of the mental transformation hypothesis. In particular, the 90° RTs for above and below questions turned out to be faster than the 0° RTs for ahead, $t(20) = 6.37$, $p < .00001$, and the 90° RTs for right and left turned out to be slower than the 180° RT for behind, $t(20) = 5.80$, $p < .00001$.

Table 2
Mean Response Times (in s) for Experiment 1 (Upright)

Sides occupied	Question word						
	Above	Below	Ahead	Behind	Right	Left	*M*
Right	1.54	1.49	1.70	2.05	2.12	—	1.78
Both	1.66	1.55	1.86	—	2.27	2.29	1.93
Left	1.56	1.61	1.70	1.91	—	2.14	1.78
M	1.59	1.55	1.75	1.98	2.20	2.22	1.83

The spatial framework model fared better in accounting for the pattern of data. The overall ordering for the six directions was above RTs (1.59 s) = below RTs (1.55 s) < ahead RTs (1.75 s) < behind RTs (1.98 s) < left RTs (2.20 s) = right RTs (2.22 s), where "<" indicates a significant difference at or beyond the .05 level. For above versus below, $t(20) = 0.60$, $p > .05$; for below versus ahead, $t(20) = 5.76$, $p < .0001$; for ahead versus behind, $t(20) = 4.29$, $p < .0005$; for behind versus left, $t(20) = 4.34$, $p < .0005$; and for left versus right, $t(20) = 0.26$, $p > .05$. Times for the vertical dimension, then, were faster than times for the front/back horizontal dimension, which in turn were faster than the time for the right/left horizontal dimension. Ahead RTs were faster than behind RTs but no asymmetry appeared within the above/below or right/left dimensions.

Moreover, individual subjects' patterns highly conformed to the group pattern. There were 24 possible orderings of the four significantly different question categories (above/below, ahead, behind, and right/left). Of 21 subjects, 11 exhibited the group pattern (binomial test, $p < .00001$), and the remaining subjects did not consistently follow any of the other possible patterns.

Perspective. Evidence from Black, Turner, and Bower's (1979) study suggests that the mental models developed by readers incorporate information about perspective and that readers prefer a consistent point of view when following narratives. Did the original perspective presented in our narratives have such a privileged status? An ANOVA with repeated measures suggested that it did; RTs were lower when observers assumed the perspective from which the scene was originally described (1.75 s) than when they assumed either of the two other orientations (.188 s), $F(1, 20) = 41.42$, $p < .00001$. Perspective and probed dimension (head/feet, front/back, and left/right) did not interact, $F(92, 246) = 1.95$, $p > .05$, which suggests that the response time patterns for the original and new perspectives did not differ.

Questionnaires. All subjects reported that they experienced imagery while reading the descriptions, and all but 2 reported that they consistently took the observer's perspective on the environment. Most volunteered that they used their images in order to answer the questions, and several reported that they experienced mentally "turning" and "looking" in the specified direction.

Discussion

In searching imagined scenes, subjects were fastest to locate objects above or below the observer, slower to locate objects in front of the observer and then behind, and slowest to locate objects to the left or right. The fact that there were clear differences between RTs to questions strongly contradicts the equiavailability explanation, and the finding that some 90° question RTs were faster than the 0° question RTs and that others were slower than the 180° question RTs refutes the mental transformation hypothesis. In addition, simple text effects such as recency and frequency of mention cannot account for the results because the forward object was always the last mentioned before each probe and because the observers never faced the objects above or below them. Instead, response times were ordered in conformity with the differential accessibility of three dimensions predicted by the spatial framework, and each direction was adjacent in the ordering to the polar opposite with which it is hypothesized to be conceptually paired. As for secondary comparisons within dimensions, front RTs were faster than back RTs and right and left RTs and above and below RTs did not differ from each other.

Beyond the global differences between the various directions, there appears to be a residual effect associated with perspective. Associations between objects and directions were more accessible for the original perspective. This may be due to the fact that subjects had more experience imagining the scene from the original perspective than from other perspectives.

Experiment 2: Upright With Egocentric Questions

Some of the questions in Experiment 1 were defined with respect to the observer (left, right, ahead, behind), and some were defined with respect to the world (above and below). In Experiment 2, all the questions were egocentric, or defined with respect to the observer, which allowed us to examine effects of the questions per se. In addition, egocentric questions were necessary for Experiments 4 and 5, in which the observers' reclining posture would make the terms "above" and "below" ambiguous (Clark, 1973; Levelt, 1984), and so using egocentric questions allowed for comparison across studies. Because subjects in a pilot study who were asked to give egocentric descriptions of spatial relations in three-dimensional scenes most commonly used the terms, "front," "back," "left," "right," "head," and "feet," we used these terms for this experiment and explained what we meant by them.

Method

Subjects. Ten men and 4 women participated in this study.

Procedure. Questions for the remainder of the experiments consisted of one-word egocentrically defined direction labels. Thus the set of questions asked in Experiments 2–5 was "Front?," "Back?," "Head?," "Feet?," "Right?," and "Left?"

Results

A repeated-measures ANOVA in which we used the three rotation categories 0°, 90°, and 180° showed no differences for RT2 data, $F(2, 26) = 2.96$, $p > .05$, which indicates that subjects followed instructions not to press the space bar until they knew the correct answer. We thus used only RT1 data in all analyses.

The criteria for eliminating data and the methods for replacing response times were the same as for Experiment 1. Four subjects each described one scene incorrectly. Of the remaining data, 1.0% were errors and 4.5% were very long. Because the patterns of response times for the various questions were very similar across stories, the data were collapsed across narratives (see Table 3).

A comparison among the six question labels showed a large effect, $F(5, 65) = 34.95$, $p < .00001$, which demonstrated that RTs to these questions were not equal. In addition, a repeated-measures ANOVA in which we compared the three categories

Table 3
Mean Response Times (in s) for Experiment 2 (Upright, With Egocentric Label)

Sides occupied	Question word						
	Head	Feet	Front	Back	Right	Left	*M*
Right	1.41	1.32	1.42	1.80	2.13	—	1.62
Both	1.45	1.32	1.64	—	2.00	2.16	1.71
Left	1.31	1.31	1.45	1.61	—	1.76	1.49
M	1.39	1.32	1.50	1.71	2.07	1.96	1.61

of angular discrepancy showed an overall effect, $F(2, 26) = 9.36, p < .01$. The difference between the 0° and 90° RTs was significant, $t(13) = 2.83, p < .05$, and the difference between the 90° and 180° categories was not, $t(13) = 1.76, p > .05$. Segregating the 90° data into horizontal and vertical categories in a repeated-measures ANOVA yielded a highly significant main effect favoring the vertical, $F(3, 39) = 35.37, p < .00001$. Thus the data again refuted the equiavailability and mental transformation models. The ordering among the four question categories was the same as was found in Experiment 1: head/feet RTs < front RTs < back RTs < left/right RTs. The ordering of RTs for the six questions was also similar to that found in Experiment 1: feet (1.32 s) < head (1.39 s) < front (1.50 s) < back (1.71 s) < left (1.96 s) = right (2.07 s). For head versus feet, $t(13) = 3.14, p < .01$; for feet versus front, $t(13) = 6.68, p < .00001$; for front versus back, $t(13) = 4.12, p < .005$; for back versus left, $t(13) = 2.61, p < .05$; for left versus right, $t(13) = 1.66, p > .05$. Although the two poles of the left/right dimension did not differ significantly, feet RTs were slightly but significantly faster than head RTs.

The data of individual subjects were again highly consistent with the group data. Of the 14 subjects, 8 displayed the trend above/below RTs < front RTs < behind RTs < right/left RTs (binomial test, $p < .00001$), and the remaining subjects did not consistently follow any of the other 23 possible patterns for the four categories.

Perspective. The mean RT when observers assumed the original perspective (1.51 s) was significantly faster than the mean RT for new perspectives (1.65 s), $t(13) = 3.68, p < .005$, which replicates the difference found in Experiment 1. Perspective did not interact with probed dimension, $F(2, 162) = 1.60, p > .05$.

Questionnaires. All subjects reported that while reading the descriptions, they experienced imagery as though from the observer's perspective. Most subjects asserted that they made use of their images to answer the questions, particularly by mentally turning to "look" in the probed direction.

Discussion

In Experiment 2 we replicated the results of Experiment 1 despite the change of questions; this indicated that differential accessibility depended on the directions themselves and not the particular words used to denote them. Again, the results gave strong support to the spatial framework and contradicted the equiavailability, mental transformation, and simple text explanations. As predicted by the spatial framework hypothesis, objects beyond the observer's head and feet were most accessible, followed by objects along the front/back axis, followed by objects to the left and right. Secondary comparisons showed faster response times for front than for back and for feet than for head and no difference between right and left. As in Experiment 1, the original perspective was faster than the subsequent perspectives.

Experiment 3: Upright With Instructions to Mentally Inspect

Although the results so far support the spatial framework model over the mental transformation model, many subjects reported that they imagined themselves mentally turning while performing the task. Moreover, experiments by Parsons (1987a, 1987b) and Cooper and Shepard (1975) suggested that people mentally relocate themselves or parts of themselves in similar tasks. Even though subjects in Experiments 1 and 2 had reported experiencing imagery, it was unclear how, or whether, they made use of their images to answer the questions. In Experiment 3, subjects were instructed to image the described environments around themselves and to answer only after they mentally turned and could imagine seeing the target object. This allowed us to examine whether explicit adoption of such a search strategy would affect the pattern of response times.

Method

Subjects. Five women and 3 men completed the study. An additional subject was dropped from the experiment for not following instructions.

Procedure. Subjects were told to image the environments around them. The procedure was otherwise identical to that of Experiment 2, except for the addition of the following instructions for answering questions:

> When you read a question, you should first figure out the answer. *Always* do this by consulting your image, even if you can figure out the answer without mentally "looking" at the objects we ask you about. Imagine yourself rotating to look in the questioned direction in order to "see" which object is there. Only *after* you have "rotated" to "look" in the questioned direction and have determined which object is there, press the space bar in order to see a set of five possible answers for you to choose from. After you answer the question, you should mentally return to the position you were facing just before you received the question.
> If you are asked about what is at your head or your feet, do what you might naturally do in the real world: mentally stretch your neck upward or downward to "look" in that direction, then once you've answered the question, return your "gaze" to the object at your front. So, when asked what is at your head and feet, you should NOT mentally rotate your entire body to face the specified direction.

Results

A repeated-measures ANOVA on RT2 data in which we used the categories 0°, 90°, and 180° showed no significant differences, $F(2, 14) = 0.15$, $p > .05$, which indicates that search did not continue after the period measured by RT1. All analyses, then, were on RT1.

The criteria for eliminating data and the methods for replacing response times were the same as for previous experiments. Errors constituted 1.0%, and very long response times constituted 4.0% of the data. Across stories, the pattern of response times for the various questions was similar, and so data were collapsed across stories (see Table 4).

A large effect due to question, $F(5, 35) = 28.83$, $p < .00001$, disconfirmed the equiavailability hypothesis. In the first analysis of angular distances, head and feet questions were included in the 90° category, even though the strict rotation instructions did not apply to them. A repeated-measures ANOVA produced the trend found in the first two experiments, $F(2, 14) = 62.24$, $p < .00001$; both pairwise differences were significant, $t(7) = 4.96$, $p < .005$ (0° vs. 90°), and $t(7) = 6.49$, $p < .005$ (90° vs. 180°). A repeated-measures ANOVA after we segregated the 90° data into head/feet and left/right categories was highly significant, $F(3, 21) = 38.58$, $p < .00001$. The ordering among the four categories was similar to those of Experiments 1 and 2. The head/feet category was not answered significantly faster than the front question, but those two RTs were faster than back RTs—for front RTs, $t(7) = 11.47$, $p < .00001$—and *back* RTs were faster than *right/left* RTs, $t(7) = 2.41$, $p < .05$. Feet and head RTs did not differ significantly, $t(7) = 0.51$, $p > .05$, nor did left and right RTs, $t(7) = 1.19$, $p > .05$. The overall ordering of the six questions was head RTs (1.59 s) = feet RTs (1.59 s) = front RTs (1.63 s) < back RTs (2.08 s) < right RTs (2.31 s) = left RTs (2.20 s). For head versus feet RTs, $t(7) = 0.51$, $p > .05$; for feet versus front RTs, $t(7) = 1.04$, $p > .05$; for front versus back RTs, $t(7) = 11.47$, $p < .00001$; for back versus right RTs, $t(7) = 3.36$, $p < .05$; and for right versus left RTs, $t(7) = 1.19$, $p > .05$. Response times for the vertical directions were not different from those for the front, but when attention was restricted to only the directions to which the strict rotation instructions applied, response times followed the patterns of the earlier experiments.

Of the 8 subjects, 4 exhibited the group trend head/feet RTs = front RTs < back RTs < left/right RTs (binomial test, $p < .0005$), and the ordering for 3 of the remaining subjects conformed to the group pattern for three of the four question categories. The group data thus seemed to reasonably reflect individual subjects.

Perspective. A repeated-measures ANOVA in which we compared the original perspective (1.85 s) against the new perspectives (1.84 s) showed no significant difference between the two mean RTs, $F(1, 7) = 0.02$, $p > .05$. Under the modified task requirements, there was no evidence for any advantaged status of the original perspective. The interaction between perspective and probed dimension was also nonsignificant, $F(2, 90) = 0.42$, $p > .05$.

Questionnaires. All subjects reported that they constructed vivid images of the environments and that they followed the imagery and rotation instructions at least 80% of the time. In addition, subjects were asked to guess the purpose of the experiment. Guesses varied over a wide range of possibilities, and, surprisingly, none approached the true purpose of the study.

Discussion

In Experiment 3, subjects were instructed to imagine themselves in the place of the observer in the environments and to imagine themselves inspecting each location for its object, mentally turning when appropriate. Despite explicit instructions encouraging smooth mental transformation, the pattern of data again conformed most closely to the spatial framework hypothesis: Vertical direction RTs were faster than the front/back horizontal direction RTs, which were faster than the left/right horizontal direction RTs. A secondary finding was that front RTs were faster than back RTs, and neither front and back RTs nor left and right RTs were significantly different from each other. The pattern of data for Experiment 3 differed in one way from the patterns of the previous two experiments: Response times for front questions were as fast as response times for head and feet questions, instead of slower. Nevertheless, this departure does not constitute evidence for the mental transformation model, which predicts that response times for front questions should be faster than those for head and feet questions (and those for left and right questions should be faster than those for back questions).

Despite the fact that all subjects reported having followed instructions to mentally turn themselves to perform the task, their data were very similar to those of Experiments 1 and 2 and did not conform to the mental transformation model. It is possible that subjects in these first three studies were indeed mentally turning to search the imagined scene but that this contribution to response time was overwhelmed by other factors that depend on the spatial framework. On the other hand, it is also possible that subjects' intuitions about the cognitive processes underlying search were inaccurate (e.g.,

Table 4
Mean Response Times (in s) for Experiment 3 (Upright With Instructions to Image)

Sites occupied	Question word						
	Head	Feet	Front	Back	Right	Left	*M*
Right	1.54	1.64	1.64	2.27	2.34	—	1.89
Both	1.66	1.60	1.68	—	2.27	2.13	1.87
Left	1.58	1.54	1.58	1.88	—	2.27	1.77
M	1.59	1.59	1.63	2.08	2.31	2.20	1.84

Nisbett & Wilson, 1977) or that they could not gain control over those processes to comply with instructions. In any case, the factors underlying the response time patterns observed in these experiments are apparently robust enough to maintain those patterns in the face of competing instructions.

Experiment 4: Reclining

In three experiments, subjects identified objects located imaginally on the vertical axis faster than objects located on either of the horizontal axes. The explanation usually given for the predominance of the vertical axis is that it canonically coincides with gravity, which induces significant asymmetries in people's perceptual and motor world. However, there is another possible explanation for the rapid access of vertical objects in the first three experiments. The objects beyond head and feet or above and below were the only ones that did not change with changes in the position of the observer. In the next two experiments, we had observers recline and reorient by rolling onto their front, back, right, and left sides. Again, the objects located beyond the head and feet were constant, but the head and feet now coincided with a horizontal axis rather than the vertical axis. Thus none of the axes of the body corresponded to the environmental vertical.

This manipulation, of having the observer lie down, unconfounds the orientation of the body with the vertical axis of the world, but it may also introduce interference. Although the questions in this study are egocentrically specified, head and feet are canonically aligned with the vertical, and so dissociating them from the vertical may create conflict and, consequently, longer response times. Even more important, because of the dissociation between the orientation of the body and the dominant axis of the perceptual world, the head/feet axis loses much of the reason for its special status when the observer reclines. Although the up/down axis determined by gravity is still highly salient in the perceptual world, it no longer correlates with any of the three natural axes of the body when observers recline. Thus although the equiavailability and mental transformation models made the same predictions for the reclining case as for the upright position, the spatial framework made new predictions.

For the reclining position, the spatial framework depends on the natural egocentric axes of the body rather than those of the perceptual world combined with those of the body. Given that the observer is in a noncanonical orientation with respect to the perceptual world, the dominant axis of the body is the front/back axis. This axis separates the world that can be seen or easily manipulated from the world that cannot be seen or easily manipulated without movement. For the reclining observer, neither the head/feet axis nor the left/right axis coincides with significant asymmetries in the perceptual or functional world. The body, however, is itself asymmetric with respect to the head/feet axis but not with respect to the left/right axis. Moreover, the left/right axis is a derivative one; left and right are determined by their relation to the front. Thus the spatial framework suggests that for the reclining observer, the front/back axis will predominate and be followed by the head/feet axis and then the right/left axis.

In both Experiments 4 and 5, subjects read scenarios similar to those in the previous experiments. In Experiment 4, observers always reclined, and in Experiment 5, observers were both upright and reclining. The constancy explanation for the predominance of the head/feet axis in the first three experiments would be supported if the head/feet axis RTs emerged as fastest when observers reclined. The dominance of the vertical would be supported if response times for objects above and below the observer turned out to be fastest, regardless of the labels used to refer to them. The spatial framework would be supported if the front/back axis RTs emerged as fastest and were followed by the head/feet and then the left/right RTs. Of course, there were many other possible patterns of data that would support none of these hypotheses.

Method

Subjects. Eleven men and 5 women participated in this study.

Procedure. Except for the fact that scenarios described reclining observers, all other procedural details were identical to those of Experiment 2. The questions consisted of single-word egocentric labels whose interpretations, because they were independent of the subject's position within the environment, were the same as they had been in Experiments 2 and 3. Observers still always reoriented around the head/feet axis, now lying on their fronts, backs, and whichever side, right or left, that allowed them to face an object.

Results

A repeated-measures ANOVA on RT2 in which we used the categories 0°, 90°, and 180° showed no significant differences among them, $F(2, 30) = 1.38$, $p > .05$; thus all analyses to be reported were on RT1.

Unacceptable data were eliminated and missing data were replaced in the same manner as described earlier. Because of time constraints, 7 subjects were not able to complete a total of 19 stories. In addition, 4 subjects described a total of four scenes incorrectly. Of the remaining data, 1.6% consisted of errors and 5.1% consisted of very long RTs. The pattern of response times for the various questions was similar for all stories, and so data were collapsed across narratives. In Table 5 we present the mean response times for the various questions and further specify the means according to the body surface on which observers reclined.

There was a large effect due to question, $F(5, 75) = 37.44$, $p < .00001$, which allowed rejection of the equiavailability hypothesis. A repeated-measures ANOVA to compare the three rotation categories revealed a significant overall effect, $F(2, 30) = 33.62$, $p < .00001$. Under our manipulation, however, there was a shift in the categories' ordering. The 0° category was not answered significantly faster than the 180° category, but both were answered faster than the 90° category; for example, for back questions, $t(15) = 7.27$, $p < .00001$. A comparison among the four categories of response times allowed us to examine the question of constancy posed in the introduction to this study. Very fast head/feet response times would indicate that constancy strongly facilitates access. Although a repeated-measures ANOVA was significant, $F(3, 45) = 46.32$, $p < .00001$, the ordering did not favor the

Table 5
Mean Response Times (in s) for Experiment 4 (Reclining)

	Question word						
Lying on	Head	Feet	Front	Back	Right	Left	*M*
Front	2.65	2.23	2.27	2.31	3.20	2.93	2.51
Right	3.09	2.06	2.53	—	3.79	3.70	3.03
Left	2.80	2.22	2.04	—	2.96	3.78	2.76
Back	2.42	2.13	2.20	2.27	3.26	2.60	2.38
M	2.66	2.17	2.24	2.29	3.26	3.24	2.59

constancy hypothesis. Front and back RTs were fastest and not significantly different from one another, $t(15) = 0.93$, $p > .05$, and were followed by the head/feet category RTs—for example, for back RTs, $t(15) = 2.77$, $p < .05$—and then by the right/left category RTs, $t(15) = 7.15$, $p < .00001$. Although overall RTs for head and feet questions were faster than RTs for right and left questions, they were slower on the whole than RTs for front and back questions.

All question labels except for *head* and *feet* referred sometimes to the gravitational up and down, depending on which part of the body subjects were imagining themselves to be lying on at the time. To test for effects of the vertical, the data were recategorized according to question-by-position conjunctions. The mean vertical response time (2.68 s) was slower, not faster, than the mean time for both front/back (2.26 s) and head/feet (2.42 s) questions.

The ordering of the six questions was as follows: feet RTs (2.17 s) = front RTs (2.24 s) = back RTs (2.29 s) < head RTs (2.66 s) < right RTs (3.26 s) = left RTs (3.24). For feet versus front RTs, $t(15) = 1.18$, $p > .05$; for front versus back RTs, $t(15) = 0.93$, $p > .05$; for back versus head RTs, $t(15) = 5.05$, $p < .0001$; for head versus left RTs, $t(15) = 4.05$, $p < .001$; and for left versus right RTs, $t(15) = 0.17$, $p > .05$. Thus, on the whole, front/back RTs were fastest, followed by head/feet RTs and then by left/right RTs. Within dimensions, as noted, front and back RTs did not differ. Right and left RTs were once again not different from each other, but subjects were faster to respond to feet than to head questions, $F(1, 15) = 40.84$, $p < .00001$.

The patterns of RTs in individual data once again conformed highly to the group pattern. The individual data for 11 of the 16 subjects followed the trend *front = back < head/feet < right/left* (binomial test, $p < .00001$). The remaining 5 subjects did not consistently follow any of the other possible patterns.

Perspective. A repeated-measures ANOVA showed that RTs were faster for the original perspective (2.42 s) than for the other perspectives (2.67 s), $F(1, 15) = 16.91$, $p < .001$. Furthermore, perspective interacted significantly with probed dimension, $F(2, 186) = 11.17$, $p < .00001$. For new perspectives, the front/back dimension RTs (2.15 s) were faster than the head/feet dimension RTs (2.48 s), $t(31) = 4.77$, $p < .00001$, and head/feet RTs were faster than left/right RTs (3.44 s), $t(31) = 8.71$, $p < .00001$. For the original perspective, head/feet RTs (2.31 s) and front/back RTs (2.41 s) did not differ, $t(31) = 1.65$, $p > .05$, but both were faster than right/left RTs (2.67); for front/back RTs, $t(31) = 2.74$, $p < .01$.

Questionnaires. All subjects reported that they used imagery to accomplish the task, and all but 1 subject reported "seeing" the environment from the point of view of the reclining observer. Most reported having used their images to answer the questions.

Discussion

Narratives in this experiment described observers as reclining and reorienting by rolling around the head/feet axis. The objects located beyond the head and feet were constant, but constancy did not confer fast access to these directions; thus constancy was disconfirmed as an account of fast access to the head/feet axis in the upright experiments. Nor were objects located on the vertical axis faster than were other objects; thus verticality was refuted as an explanation for the upright results. According to the spatial framework hypothesis, when observers recline, no natural axis of the body coincides consistently with the salient axis of the world. Thus the mental spatial framework established to comprehend the description and questions can depend only on the characteristics of axes of the body. These axes seem to have a subjective order of salience: first, front/back because of its body asymmetry and asymmetries in seeing and manipulating the world, then head/feet because of its body asymmetry, and, last, left/right, which has neither physical nor functional asymmetry. The present pattern of data conformed best, though not perfectly, to the spatial framework hypothesis. On the whole, front/back RTs were faster than head/feet RTs, which were faster than left/right RTs; however, front RTs were no faster than head and feet RTs. As for secondary effects within dimensions, left and right RTs did not differ, nor did front and back RTs, and feet RTs were faster than head RTs. Interestingly, response times for the reclining study were considerably longer (500–700 ms) than response times in the upright study. Apparently, adopting a reclining perspective and accessing spatial information from it is more difficult than adopting the upright perspective.

Experiment 5: Upright and Reclining

In the previous experiments, the axes of the spatial framework were ordered differently, depending on whether the observer was upright or reclining. Would these separate patterns remain when observers were upright and reclining within the same scenarios, or would the patterns interact with the order in which observers stood and reclined? Specifically,

would anticipation of a second posture affect the search strategy used for the first, and would the use of a search strategy for the first posture bias the selection of a search strategy for the second? In Experiment 5, observers adopted an upright posture and a reclining posture within each narrative. To the extent that the within-group patterns of data corresponded to the previous between-group patterns, this experiment would be a replication of the previous ones.

Method

Subjects. Ten men and 8 women served as subjects.

Procedure. For half of the stories, in the printed portion by which subjects learned the environment, observers were standing upright. In the other half, subjects initially learned the environment from the point of view of reclining observers. Then, when subjects turned to the computer, they were told for half of each type of story that the protagonist immediately changed posture. Posture was blocked within each narrative; once observers stood or reclined in the computer-presented segment of the narrative, they stayed in that posture, making all appropriate reorientations, before assuming the other posture.

Results

The criteria for eliminating data were the same as for previous experiments, and missing data were replaced with the Posture × Story × Question cell mean computed across subjects. Ten subjects described a total of twelve scenes inaccurately. Of the remaining data, 1.6% were errors and 4.8% were very long response times.

RT2 data were divided into six categories according to two levels of posture and three levels of rotation. A repeated-measures ANOVA yielded a significant overall effect, $F(5, 85) = 2.46$, $p < .05$, although the pattern of RT2 neither matches that of RT1 nor describes sensible orderings. Thus in subsequent analyses we used only RT1 data.

Within each of the two postures, the pattern of response times was similar across stories, and so data were collapsed across stories for all analyses. In addition, a repeated-measures ANOVA indicated that there was no significant effect of the initial posture of observers, upright or reclining, in the narratives, $F(1, 68) = 0.89$, $p > .05$, and so data were collapsed across this factor for subsequent analyses as well (see Table 6).

Effect of posture and question label. A repeated-measures ANOVA in which we compared response times for the six direction labels was highly significant, $F(5, 85) = 61.21$, $p < .00001$, which disconfirmed the equiavailability hypothesis. A two-factor ANOVA with repeated measures on posture and question category (head/feet vs. front vs. back vs. left/right) showed both main effects to be significant, $F(1, 136) = 24.14$, $p < .00001$, for posture; $F(3, 136) = 17.38$, $p < .00001$, for rotation category. Their interaction was also highly significant, $F(3, 136) = 5.96$, $p < .001$; the pattern of response times within each posture mirrored those found in the previous experiments. For upright observers, head/feet RTs (1.50 s) were faster than front RTs (1.62 s), $t(17) = 4.07$, $p < .001$, which were faster than back RTs (1.88 s), $t(17) = 4.28$, $p < .001$, which were faster than left/right RTs (2.06 s), $t(17) = 3.37$, $p < .005$. For reclining observers, back RTs (1.82 s) and front RTs (1.82 s) were not significantly different, $t(17) = 0.09$, $p > .05$, but both were faster than head/feet RTs (2.13 s)—for example, for front versus head/feet RTs, $t(17) = 5.92$, $p < .00001$—and head/feet RTs were faster than left/right RTs (2.59 s), $t(17) = 5.92$, $p < .00001$. Subjects were faster on the whole at answering questions when observers were upright than when they reclined.

The ordering of the individual directions within each posture was consistent with the previous findings. When observers were upright, feet RTs (1.47 s) < head RTs (1.53 s) < front RTs (1.62 s) < back RTs (1.88 s) < right RTs (2.03 s) = left RTs (2.11 s). For head versus feet RTs, $t(17) = 2.81$, $p < .05$; for head versus front RTs, $t(17) = 2.94$, $p < .01$; for front versus back RTs, $t(17) = 4.28$, $p < .0005$; for back versus right RTs, $t(17) = 2.00$, $p < .05$; and for right versus left RTs, $t(17) = 1.11$, $p > .05$. When observers reclined, front RTs (1.82 s) = back RTs (1.82 s) < feet RTs (2.07 s) < head RTs (2.20 s) < right RTs (2.53 s) = left RTs (2.65 s). For front versus back RTs, $t(17) = 0.09$, $p > .05$; for back versus feet RTs, $t(17) = 3.46$, $p < .003$; for feet versus head RTs, $t(17) = 3.24$, $p < .005$; for head versus right RTs, $t(17) = 4.93$, $p < .0001$; and for left versus right RTs, $t(17) = 1.75$, $p > .05$. Again, subjects were faster to respond to feet than to head questions.

Order of postures. In order to determine whether the order in which observers stood and reclined affected the pattern of response times for either posture, an ANOVA with repeated

Table 6
Mean Response Times (in s) for Experiment 5 (Upright and Reclining)

	Question word						
Condition	Head	Feet	Front	Back	Right	Left	*M*
Upright: Side occupied							
Right	1.56	1.44	1.58	1.87	1.98	—	1.69
Both	1.41	1.47	1.63	—	2.07	2.15	1.75
Left	1.63	1.49	1.66	1.89	—	2.06	1.75
M	1.53	1.47	1.62	1.88	2.03	2.11	
Reclining: Lying on							
Front	2.30	2.30	1.76	1.87	2.41	2.79	2.15
Right	2.05	1.99	1.58	—	2.27	2.23	2.02
Left	2.11	2.05	1.91	—	2.64	2.61	2.26
Back	2.20	1.87	1.88	1.75	2.80	2.82	2.10
M	2.20	2.07	1.82	1.81	2.53	2.65	

measures was performed with question category (head/feet, front, back, and right/left), posture (upright or reclining), and order of upright and reclining postures during the computer-presented segment of the stories as factors. A three-way interaction would suggest that experience with or anticipation of one posture had affected subjects' search patterns for the other posture. The analysis, however, showed no significant interaction, $F(3, 272) = 0.29, p > .05$.

Constancy and verticality. As in Experiment 4, the response times for the constant dimension (2.14 s) and for the vertical dimension (2.05 s) were slower, not faster, than the response times for front/back questions (1.82 s).

Individual differences. Individual subjects' patterns of response times within each posture for the head/feet, front, back, and right/left categories were once again consistent with the data collapsed over subjects. The data of 9 subjects were consistent with both the reclining pattern and the upright pattern for the group (binomial test, $p < .00001$), and 15 of the 18 subjects showed the appropriate trend for at least one of the two postures. The remaining subjects did not consistently follow any of the other possible patterns.

Gender differences were apparent in this experiment, although they had not been found previously. Men (1.82 s) on average responded faster than did women (2.05 s), $F(1, 28) = 11.61, p < .001$. Gender did not interact with either the factor of question category or posture, which indicates that although men responded faster than did women, their search strategies did not differ.

Perspective. Stories were grouped according to the posture in the printed segment of the story. Then RTs to original and new orientations within each posture were compared with a paired t test. RTs to original (1.66 s) and new orientations (1.66 s) did not differ for the upright posture, $t(17) = 1.32$, $p > .05$, but the original perspective RTs (2.06 s) were faster than the new (2.22 s) orientations' RTs for the reclining posture, $t(17) = 3.80, p = .001$. In a repeated-measures ANOVA, the Perspective (original vs. new) × Posture (upright vs. reclining) × Dimension (head/feet vs. front/back vs. left/right) interaction was nonsignificant, $F(2, 420) = 0.34$, $p > .05$.

Questionnaires. All subjects reported experiencing imagery while reading the descriptions and answering the questions, and all reported "seeing" the environments from the point of view of the observers.

Discussion

In this experiment, observers were both upright and reclining in each narrative. Subjects were able to achieve the major shift in perspective associated with changing posture but were slower on the whole to answer questions when observers reclined; this indicates that even egocentrically labeled directions are easier to comprehend and to search in a canonical position than in a noncanonical position. The increased response time due to assuming a noncanonical posture was greater for head/feet and left/right questions that for front/back questions.

Adopting both postures did not change the pattern of results for either. For the upright posture, as in the previous experiments, the head/feet axis RTs were fastest, followed by front/back and then by left/right RTs. Within dimensions, front RTs were faster than back RTs, feet RTs were slightly but significantly faster than head RTs, and right and left RTs did not differ. For the reclining posture, the front/back axis RTs were fastest and were followed by head/feet and then by right/left RTs. This replicates the pattern of results from Experiment 4, except for the unexpectedly fast times for feet questions found in Experiment 4. Within dimensions, feet RTs were again slightly faster than head RTs, but front and back RTs and left and right RTs did not differ.

As before, neither the equiavailability nor the mental transformation model was supported. The spatial framework model describes the findings for both upright and reclining orientations quite well, including the shift in the predominant axis with the shift in posture.

General Discussion

General Findings

In five experiments, subjects read narratives describing objects located around observers in naturalistic settings. The narratives were written in the second person in order to draw readers into them. The objects were described in relation to the observer as beyond the head, beyond the feet (or above vs. below in Experiment 1), in front, in back, to the left, or to the right. After reading the narratives describing the directions of the objects, subjects turned to a computer, which continued the narrative by orienting the observer toward one of the objects in the setting and then probing the objects located in all directions. Then the narrative described the observer as facing a different object and again probed the objects in each direction, and so on. Sometimes the observer was standing upright and turned to face left or right or back, and sometimes the observer reclined and rolled onto the left, right, front, or back. The data of interest were the response times to identify the objects in each direction (head, feet, front, back, left, and right) for each posture (upright or reclining). The mean for each dimension for each of the experiments is displayed in Table 7.

Three classes of models making different predictions about behavior in this task were considered.[1] According to the *equiavailability* model, all directions are equally accessible. One analog for this model is scanning a picture, in which, given that all locations are equidistant from the observer, no particular position is privileged. Another analog for this model is searching a list of direction–object pairs, either in parallel or in series, in which the list is randomly ordered or searched. The expectation from this model, whether instantiated as a picturelike image or as a list of direction–object pairs, is that response times to identify objects should be the same regardless of direction. The second class of model considered was a

[1] It is possible to construct versions of the models that are not incompatible (for instance, those in which mental transformations are performed on a spatial framework). Exact predictions are difficult to make in that case for our task.

Table 7
Mean Response Times (in s) for Each Dimension for All Experiments

Dimension	Experiment 1	2	3	4	5
Upright					
Head/feet	1.57	1.36	1.59	—	1.50
Front/back	1.84	1.58	1.81	—	1.72
Left/right	2.21	2.02	2.26	—	2.07
Reclining					
Head/feet	—	—	—	2.42	2.14
Front/back	—	—	—	2.26	1.82
Left/right	—	—	—	3.25	2.59

mental transformation model. If subjects imagined themselves in the place of the observer in the scenes, then they were mentally facing a particular location when they were probed. In order to identify objects in other directions, they may have imagined themselves looking at the named direction to inspect it for the correct object, mentally turning when necessary. If mental transformation occurred, response times should have been fastest for objects in front of the observer and slowest for objects behind the observer. Identification times for directions 90° from the observer (left, right, head, or feet) should have been intermediate.

According to the third class of models, in order to comprehend the narratives and questions, subjects constructed and used a *spatial framework*. That framework rendered certain directions more accessible than others, depending on the natural axes of the body and the position of the body with respect to the perceptual world. We first consider the perceptual world of the upright observer, which can be described by one vertical axis (head/feet) and two horizontal axes (front/back and left/right). The vertical axis has a special status for the upright observer for a number of reasons. It coincides with gravity, which exerts an asymmetric force on the perceptual world, rendering the upward parts of most objects and organisms quite different from their downward parts. In addition, because the observer canonically navigates on a horizontal plane, the vertical relations among objects generally remain constant under navigation, but the horizontal ones do not. Of the two egocentric horizontal axes, the front/back axis predominates over the left/right. The front/back axis separates the world that can be viewed and manipulated from the world that cannot be easily seen or manipulated. The left/right axis is particularly difficult and confusing because the body itself and many objects and organisms that people view are bilaterally symmetric. Thus for the upright observer, the head/feet axis should be most accessible and followed by the front/back axis and then the left/right axis.

The picture is quite different for the reclining observer. The head/feet axis of the body no longer coincides with the vertical axis, and so it loses its special status. Nor does any other axis of the body coincide with the vertical. The spatial framework thus depends on asymmetries in the natural axes of the body. Of those, the body is asymmetric around the front/back and head/feet axes but symmetric around the left/right axes. In addition, the front/back axis is distinguished perceptually and functionally; it separates the visible and manipulable world from the invisible and the hard-to-reach. The head/feet axis has no such distinction, although it does have asymmetry, which the left/right axis lacks. Thus for the reclining observer, the front/back axis should predominate and be followed by the head/feet and then the left/right axes.

These predictions of the spatial framework model fit the data collected in the five experiments quite well. That is, for the upright observer, identification times were fastest for the head/feet axis, slower for the front/back axis, and slowest for the left/right axis, and for the reclining observer, RTs were fastest for the front/back axis, slower for the head/feet axis, and slowest for the left/right axis. Each of the other models and explanations had serious inadequacies in accounting for the data. The equiavailability model was easily rejected in all experiments because response times consistently differed for the different directions. The data did not conform well to the mental transformation model, either. According to that model, response times to objects located to the left or right should have been faster than response times to objects located beyond the back because a larger mental movement was needed to inspect objects beyond the back. However, in all experiments, the response times for left and right questions were slower than the times for back questions. The observed patterns could not be due simply to the comprehension of labels for the probed directions, inasmuch as different orderings were found for the questions in the two postures. Furthermore, similar patterns of results (specifically, faster response times to 180° positions than to intermediate positions) have been found when subjects are oriented and probed by means of arrows, object names, and tactile stimulation (Hintzman et al., 1981).

Secondary Effects

According to the analyses underlying the spatial framework, times for right and left questions should not differ, and indeed they did not. The advantage of head/feet over right/left RTs, according to the spatial framework, depended in part on the asymmetry of this dimension of the body. Despite the asymmetry, however, neither head nor feet RTs had a theoretical advantage over the other. In Experiments 2, 4, and 5, feet RTs were faster than head RTs. We can only speculate about the reasons for the feet advantage. The feet are canonically located on the ground, whereas the head has a more variable location, so the feet may serve as a better anchor in the world

than the head. The analysis behind the spatial framework does suggest that responses to front questions should be faster than responses to back questions. The asymmetry on that dimension has perceptual and functional significance favoring the front; that is, most of the perceptual apparatus is oriented frontwards, as are the activities of the major limbs. When the observer in these studies was upright, front RTs were in fact considerably faster than back RTs (on the order of magnitude of the between-dimension differences), in correspondence with the analysis of the spatial framework. When the observer reclined, however, front and back RTs were equivalent. For the reclining observer, the perceptual advantage of the front remained, but the functional advantage of the front disappeared. Movement frontward is not possible when one reclines on one's back or front, and it is awkward when one reclines on one's side. It is possible that the response time difference between front and back questions diminished in the reclining case because when one reclines, the behavioral asymmetry of front and back also diminishes.

Extensions

The spatial framework analyzed and demonstrated in these experiments is a useful schema for organizing and keeping track of information about objects located in three canonical dimensions around an observer who can turn in place and change posture. The spatial framework, however, can be enriched and extended. In the experiments reported here, the use of animate central figure and the use of the second person encouraged subjects to take the perspective of the central figure. Without these conditions, it is not clear whether readers would take the perspective of the central figure or, instead, take the perspective of an observer looking in on the scene. Similarly, if there were two observers with different perspectives in the scene, it is uncertain whether readers would consistently take the point of view of only one of the observers or would switch from one to the other. In our experiments, observers were stationary; however, in life and in narrative, observers traverse and keep track of an ever-changing set of objects around them. Several objects may be located in a particular direction at different distances from an observer. Objects may be located at oblique angles in directions between the three canonical axes. These are but a few of the ways the spatial framework can be extended and enriched to incorporate more of the spatial world into the mental world.

Implications

Readers spontaneously construct spatial mental models from prose and use these models for verification and retrieval of information. Unlike subjects in much of the previous related research (e.g., Kosslyn, 1973; Kosslyn et al., 1978; Morrow et al., 1987; Pinker, 1980), subjects in our studies were neither shown a visual display nor (except in Experiment 3) instructed or trained to image. Rather, the natural processes entailed by comprehension of the narrative and questions induced the spatial mental model. The mental model constructed was spatial in the sense that it represented relative spatial directions. However, it did not appear to have the analog, continuous, perceptual qualities that were demonstrated in previous research on image inspection (e.g., Kosslyn et al., 1978) and image transformation (e.g., Shepard & Cooper, 1982) and that are often argued to be characteristic of imagery (e.g., Kosslyn, 1980; Shepard & Podgorny, 1978). The critical evidence is that different spatial locations are differentially accessible, a finding easier to account for in terms of the conception of space than in terms of the perception of space. Of course, the mental model of the subjects in these experiments was derived from a naturalistic description rather than direct perception, in contrast to previous studies of mental rotation and mental scanning. Thus to account for the complex mental models used in comprehension, simple perceptionlike analogs are not sufficient but must be supplemented with analyses of how space is conceived.

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