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Internal and External Spatial Frameworks for Representing Described Scenes

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Four experiments explored readers' mental models of described scenes. Environments were described from one of two perspectives, an *internal* perspective of an observer within the scene, surrounded by objects, or an *external* perspective of an observer outside the scene, with objects in front. Subjects read narratives describing a scene and were probed for locations of objects. In the general case, reaction times to identify objects were fastest for the head/feet (above/below) axis, then the front/back (front/behind) axis, and then the left/right axis, conforming to the spatial framework analysis which reflects people's conceptions of space based on typical interactions in space. For the internal spatial framework, readers were faster to questions of front than back, reflecting the perceptual and biological asymmetries that favor an observer's front. For the external spatial framework, all objects were in front of the observer and readers were equally fast to questions of front and behind. The difference between internal and external spatial framework reflects the different perceptual experience of observers in the two perspectives. The two variants of the spatial framework allowed us to infer readers' spatial perspective for narratives with unspecified perspectives.

Suppose you are reading a story about Jim, who has become separated from his group in the jungles of Africa. "Seeing a snake, Jim quickly pulls himself onto a branch directly above the snake. Behind him, in a hole in the trunk, Jim notices a nest filled with buzzing insects. Above him, on another branch, a colorful bird is perched. . . ." Researchers investigating memory for discourse have proposed that, in order to comprehend such prose, readers construct mental or situation models embodying the spatial relations explicitly given in the text as well as those inferable from the text (e.g., Bransford, Barclay, & Franks, 1972; Johnson-Laird, 1983; van Dijk & Kintsch, 1983). Evidence for such mental models comes from several sources. Perrig and Kintsch (1985), for example, demonstrated that although subjects may be unable to recall the surface structure of a text, they perform quite well on a verification task of explicit and inferred spatial relations. Furthermore, people spontaneously make spatial inferences, and incorrectly recognize such inferences as having been presented in the text (Bransford et al., 1972). Other evidence suggests that spatial mental models derived from text are similar to those derived from direct experience. Mental models may include information about spatial properties such as relative po-

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sition (Mani & Johnson-Laird, 1982 Perrig & Kintsch, 1985; Taylor & Tversky, 1991), and relative distance (Franklin, 1991; Glenberg, Meyer, & Lindem, 1987; Morrow, Bower, & Greenspan, 1989; Morrow, Greenspan, & Bower, 1987; Wagener-Wender & Wender, 1990).

Recently, Franklin and Tversky (1990b) sought to characterize the spatial qualities of mental representations acquired from text describing a particular common spatial situation. Their subjects read narratives written in the second person describing a simple environment around themselves, locating objects beyond their head, feet, front, back, left, or right. For example, subjects read a story that described them standing on a ladder in the center of a barn with a saddle hanging on the wall directly in front of them, a lantern hanging directly above their head, and so on. After describing the locations of objects around the second-person observer (the reader), the narrative oriented him or her to face a particular object. The reader was then probed by egocentric direction names (head, feet, front, back, left, right) for the objects in those positions, then reoriented toward another object, probed by direction names, and so on. Response times varied systematically with the direction of the object from the observer and the posture of the observer, upright or reclining, revealing that subjects' spatial mental models were organized in terms of their three orthogonal body axes, and their position in space.

Spatial frameworks. A number of theorists have suggested that spatial language reflects the way we typically perceive and interact with the world (e.g., Clark, 1973; Fillmore, 1982; Levelt, 1984; Miller & Johnson-Laird, 1976; Shepard & Hurwitz, 1984). Although these writers were primarily concerned with the way people use and comprehend spatial terms, many of their arguments are derived from the way people conceive of space. Influenced by these analyses, Franklin and Tversky (1990b) hypothesized that readers of their narratives would construct a three-dimensional *spatial framework,* a mental model, or knowledge structure used to store, retrieve, and verify locations of objects relative to their own bodies. A spatial framework reflects the way people normally conceive of their perceptual world, based on their interactions with it.

The perceptual world of a human observer can be described in terms of three orthogonal body axes, one vertical and two horizontal. For the canonically oriented upright observer, the head/feet axis corresponds to the vertical, and the front/back and left/right axes are horizontal. According to the spatial framework analysis, objects located on the vertical head/feet axis should be more accessible to upright observers because of both properties of the world and properties of the body. The head/feet axis is physically asymmetric and normally correlated with the vertical gravitational axis of the world. As observers navigate the world, vertical spatial relations among objects remain largely constant with respect to the observer whereas spatial relations in the horizontal plane change. Both the biological asymmetry and the correlation with gravity impart a special status to the head/feet axis leading to easy and rapid access from memory of objects beyond the head and feet. The front/back axis is physically asymmetric, and the observer is perceptually and behaviorally oriented frontwards. However, the front/back axis is not correlated with an environmentally defined axis. What objects are located along this axis depend on the direction currently faced by the observer. Finally, the left/right axis is derived from the front/back axis of the observer and lacks both asymmetry and correlation with an environmental axis, making it the least salient spatial organizer. Thus, for the upright observer, the spatial framework analysis predicts that subjects' responses should be fastest to objects at the head or feet, followed by those to the front or back, followed by those to the left or right. This prediction was confirmed in four experiments by Franklin and Tversky (1990b). Subjects were also faster to respond to front than back, reflecting the perceptual and biological asymmetries that favor front over back.

For a reclining observer, the situation changes; the head/feet axis is no longer correlated with gravity and loses its predominance. In this case, the spatial framework analysis predicts that subjects should be fastest to respond to questions of front/back because of its perceptual, biological, and behavioral asymmetries. Head/feet should still be faster than left/right because of its biological asymmetry. In addition, subjects should be slower overall for a reclining than upright observer because people do not typically interact with the world in a reclining posture. This pattern of response times was observed by Franklin and Tversky (1990b) in two experiments.

Internal spatial viewpoint. Thus far, the spatial framework analysis has been developed and tested with a single narrative perspective. All of Franklin and Tversky's (1990b) narratives were written in the second person and described an array of five objects surrounding "you" the reader, locating objects with respect to "your" various body sides. The direction questions used to probe subjects, too, referred to objects located at specific directions from "your" body. This use of deictic terminology (e.g., Fillmore, 1975; Levelt, 1984; Miller & Johnson-Laird, 1976) in the narrative perspective specified what we will call an *internal* perspective for the reader, the point of view of an observer at the center of an array of objects. Although that situation may be prototypical of spatial cognition, other narrative perspectives, spatial viewpoints, and spatial arrays are possible.

External spatial viewpoint. It is possible to specify other spatial points of view, notably, one where the observer is looking toward an array of objects all located in front of the observer. We call this point of view an *external* perspective. In Experiment 1, subjects read narratives describing an array of objects external to an observer. The external viewpoint was specified by using deictic spatial terminology, just as the internal viewpoint was specified by deictic terminology by Franklin and Tversky (1990b). In the external case, for example, when the "mask" was described as being *behind* the "camera," and the "pumpkin" as being to the *right* of the "bowl," the terms *behind* and *right* were with respect to the external observer, and not with respect to the intrinsic sides of the camera or pumpkin. The direction questions probing for subjects' knowledge of the described scenes were also presented from the point of view of an external observer. A new variation of the spatial framework needs to be developed to account for keeping track of objects in an external array. In the external case, all of the array was in the observer's field of view, unlike the internal case where the objects surrounded the observer, and most were not in the observer's field of view. Because the array does not surround the observer, considerations of body symmetry are no longer relevant for predicting response times to access locations of objects in a scene. Rather, asymmetries in the typical visual field of the observer determine the relative accessibility of the three dimensions.

Narratives without a specified spatial viewpoint. Although some narratives specify a spatial viewpoint through the use deictic terminology, such as the internal viewpoint of Franklin and Tversky and external viewpoint of Experiment 1, other narratives do not specify a viewpoint. Going back to our description of Jim lost in the jungle, for example, readers could take an external point of view on the scene, "seeing" Jim in the tree with the snake below and the buzzing insects behind. Alternatively, readers could take the point of view of Jim, an internal perspective, and instead of "seeing" Jim, would "see" the snake below them and the insects behind. Such narratives, typical of fiction, describe spatial relations with respect to the intrinsic in a scene were randomly selected. Scenes and objects are listed in Table 1.

Narratives were given to subjects in two parts. The first, printed on a single sheet of paper, provided the name of the setting and a list of the eight objects in the scene. It then described the environment from the perspective of an implied observer outside the environment. The first part of *Halloween Party* narrative used in Experiment 1 follows as an example. Objects are italicized here, but were not in the version read by subjects.

The Joneses are having a Halloween party this evening in their backyard. The yard is fifteen feet on all sides and is covered by a large colorful tent which is supported by thick beams at all four corners. The Joneses have brought out all the things they will need for a successful party and have put them in the corners to keep the yard clear for dancing. In the lower left front corner of the yard, a plastic punch *bowl* has been placed on the ground. It is filled with a dark red punch for the party. To the right of the bowl, in the lower right front corner, a *pumpkin* is resting on the ground. It has yet to be carved, but a menacing jack-o-lantern face has been drawn on it with a black marker. Directly above the pumpkin, in the upper right front corner, a video *camera* has been fastened to the tent pole. The hosts think it will be fun to show a tape of the party at some future event. Directly behind the camera, in the upper right rear corner, a horrifying witch *mask* has been mounted on the tent pole. It has beady red eyes and leers evilly down on the yard. Below the mask, in the lower right rear corner, a *stereo* has been set up on the ground. The Joneses plan to have a lot of dancing at their party and want their guests to be able to select their favorite music. To the left of the stereo, in the lower left rear corner, there is a life size *coffin* resting on the ground. This is the most gruesome decoration at the party, as it was borrowed from a local funeral parlor. Above the coffin, in the upper left rear corner, a *ghost* doll has been hung from the rafters of the tent by a few thin wires. It is made mostly from a billowing white sheet with a round bulbous head. In front of the ghost, in the upper left front corner, a papiermache *skeleton* is also hanging from the rafters. It has a strange lipless grin on its face, giving it a disturbing and threatening air.

TABLE 1
SCENES AND OBJECTS OF EXPERIMENT 1

Scene	Objects
Halloween party	Bowl, camera, coffin, ghost, mask, pumpkin, skeleton, stereo
Hotel lobby	Banner, barbershop, desk, escalator, fountain, giftshop, pushcart, tavern
Construction site	Bucket, concrete, cord, jackhammer, ladder, lunchbox, shovel, wheelbarrow
Opera theatre	Bouquet, chair, sprinkler, lamp, loudspeaker, plaque, sculpture, table
Space exhibit	Computer, map, meteorite, moonrover, rocket, satellite, spacesuit, trashcan
Barn	Bag, barrel, footstool, lantern, pail, rake, saddle, shears
Work shed	Basket, bench, engine, fan, hammer, saw, tirepump, yardstick

The second part of each narrative was divided into eight blocks and presented sentence-by-sentence on an IBM-XT computer screen. A block consisted of, first, one orienting sentence, followed by two filler sentences, then three direction probe questions. The orienting sentence of each block named an object and gave some detail information about it. This object served as the referent object for the direction probes of that block. The next two sentences were fillers to focus attention on the object; they provided additional details about the object, such as its visual appearance, but did not mention it by name. The three probes in a block were separated by two such filler sentences each. An example of orienting and filler sentences from the Halloween narrative follow:

The Joneses have decided to use a plastic BOWL at the party for practical reasons.

Plastic is difficult to break, but the container looks very much like a crystal one.

The rim, instead of being smooth, is serrated in order to give it a more stylish appearance.

Procedure

Subjects were given detailed instructions about the experimental procedure before beginning. They were instructed to read each narrative for understanding and told that they would be asked questions about the directions of objects with respect to each other. They were allowed to study the printed portion of the narrative for as long as they wished and then returned it to the experimenter. Subjects then proceeded to the second portion of the narrative which was presented on the computer. They read at their own pace, striking the space bar to advance to the next sentence. Subjects were not allowed to return to previous sentences.

Following the filler sentences, subjects were probed with a direction term for an object located in that direction from the current referent object. Each question had the following format. The name of the referent object appeared on the screen in capital letters. After striking the space bar, the subject was probed with one of six directions, indicated by a single word, "front," "behind," "above," "below," "left," or "right." Only three directions were occupied for any particular referent object (see Fig. 1), so only three directions were probed in any given block. Subjects were instructed at the beginning of the experiment that they were to interpret probes with respect to the referent object; e.g., "which object is in front of the referent object?" Subjects were told to press the space bar as soon as they were certain which object was located in that direction, without sacrificing accuracy. The time subjects took to do this was the critical response time, RT1. After subjects pressed the space bar, the names of six objects in the environment (excluding the referent object and the object located diagonally opposed to it in the cube) appeared on a line on the screen in random order, numbered 1 to 6. Subjects were told to press the number corresponding to the correct object as quickly as they could, without sacrificing accuracy. This was the second response time, RT2, which served as an accuracy check. Ideally, RT2 should only be affected by list position. The narrative continued with two more filler sentences pertaining to the referent object. Then the next question about the same referent object appeared, until all three occupied directions with respect to that referent object had been probed. Following this, a new block began and subjects answered questions about another referent object. The first narrative was for practice, during which subjects received feedback about their accuracy on questions. No feedback was given during experimental trials.

Design

The independent variable in this experiment was direction (front, behind, above, below, left, and right). The dependent variable was the time subjects took to decide which object in an environment was in a probed direction with respect to a specified referent object (RT1). Three subjects were assigned to four random orders of presentation of the narratives. Half the narratives located objects along the above/below, followed by left/right, then front/back axes (as in example above), and half along the front/back, then left/right, then above/below axes. These versions were alternated and half the subjects began with the first version and half with the second. There were three versions of the computer portion of each narrative, one for each possible order of direction probes within a block, and four subjects received each order of probes. The order of blocks was random.

Results

The second part of each question (RT2) was intended to serve as a check that subjects complied with the experimental instructions to decide which object was in the stipulated direction before asking for the alternatives. A repeated-measures analysis of variance on RT2 revealed a significant effect of direction, $F(5,55) = 32.20$, $p < .001$, indicating that subjects did not strictly follow instructions. The RT2 data, however, displayed the same pattern as the RT1 data alone. The RT2 data, where they deviated from equality, did so in the same direction as the RT1 data, but less reliably. Consequently, only RT1 data were used in subsequent analyses.

The RT1 data were adjusted according to the following criteria. Subjects made errors on 2.1% of the questions and these response times were discarded from analysis. Outliers, defined as response times more than two standard deviations greater than the subject's direction cell mean, accounted for 5.1% of the data and were also discarded from analysis. One subject failed to complete three stories in the allotted 2-h experimental session and this subject's means were based only on the narratives completed. Response times were collapsed across narratives within each subject to form mean response times for each direction. Mean response times to each direction are shown in Table 2. The subject means in this, and all subsequent experiments, were subjected to a log transformation because variability was positively correlated with mean response time. The natural log was taken for each subject mean and this served as the data point in the appropriate cell.

Effect of direction. Direction had a significant effect on subjects' response times, $F(5,55) = 15.67$, $p < .001$, and the pattern of results conformed to the predictions of the spatial framework. Subjects responded faster to questions of above/below than front/behind, $t(11) = 5.89$, $p < .001$, and faster to front/behind than left/right, $t(11) = 2.48$, $p < .05$.

Ordering of directions. The ordering of individual directions was below < above < front = behind = left = right, where "<" indicates a significant difference at or beyond the .05 level and "=" indicates no significant difference. (For below vs. above, $t(11) = 2.36$, $p < .05$; for above vs. left, $t(11) = 4.16$, $p < .01$; for front vs. behind, $t(11) = 0.02$, n.s.; for behind vs. left, $t(11) = 0.70$, n.s.; for left vs. right, $t(11) = 0.50$, n.s.) This pattern is predicted by the external spatial framework, except that response times to left were unexpectedly fast.

Explicitly vs. implicitly defined relations. Some of the spatial relations between objects in the cubic array were explicitly stated in the narrative, whereas others had to be inferred by the subject. One claim about mental models that distinguishes them from text representations is that explicit and implicit relations are equally accessible (Byrne & Johnson-Laird, 1989; Johnson-Laird, 1983). Subjects were not significantly faster when probed for explicit relations (2.33 s) than implicit relations (2.49 s), $F(1,11) = 2.83$, n.s., and this factor did not interact with direction, $F(5,55) = 1.17$, n.s. This result offers further evidence that subjects employed mental models to represent the described scenes.

Individual patterns and item effects. In order to assess whether individual subjects tended to display the pattern of response times predicted by the spatial framework, we treated subjects' response times as the product of a random binomial process. There were six possible orders of response times to the three dimensions, so that the spatial framework pattern (above/below < front/behind < left/right) had a ⅙ probability of occurring by chance. Nine of the 12

TABLE 2
MEAN RESPONSE TIMES (IN SECONDS) FOR EXTERNAL PERSPECTIVE NARRATIVES (EXPERIMENT 1)

Direction					
Above	Below	Front	Behind	Left	Right
2.05	1.75	2.57	2.57	2.57	2.89
1.90		2.57		2.73	

subjects exhibited the spatial framework pattern (binomial probability < .0001). Six of the 12 subjects responded faster to front than behind, and the remaining six responded faster to behind than front (binomial probability >.05). Thus, there was no difference between front and behind on the level of individual subjects. Females, in general, responded more quickly than males, $F(1,10) = 12.83, p < .01$, but subject gender did not interact with direction, $F(5,50) = 2.15$, n.s., and males and females exhibited the same pattern of response times.

In order to test for item effects, mean response times were calculated for each narrative by collapsing across subjects. The overall spatial framework pattern was evident in all six narratives (binomial probability <.00001), and response times were faster to front than behind in only two narratives (binomial probability >.05). Thus, the overall results of this experiment do not depend on any particular subset of items.

Discussion

In this experiment, subjects read narratives with a specified external perspective that described an array of objects arranged at the corners of an imaginary cube. Subjects responded as fast to inferred spatial relations as to spatial relations explicitly stated in the narrative, indicating the use of mental models. The external spatial framework analysis, based on the perceptual world of the observer, predicts that the vertical axis will dominate due to the asymmetric effects of gravity on the perceptual world and to the preservation of vertical spatial relations under typical horizontal navigation. Of the two horizontal dimensions, front/back should dominate left/right because it is the axis the observer is primarily oriented along and is perceptually asymmetric, with objects toward the front of the viewer being relatively larger, closer, and perhaps occluding more distant objects. These predictions were confirmed by the data. The results, however, contrast with those of Franklin and Tversky (1991b). Whereas response times for front were faster than times for back in Franklin and Tversky's experiments, with the observer internal to the array, response times to front and behind did not differ in the current experiment. This is consistent with predictions of the external spatial framework. Given an external viewpoint, properties of the observer's front/back body axis are not relevant to judgments of front and behind, and objects are equally accessible at either pole.

Experiment 2: Unspecified Perspective: Central Person

The narratives of the first experiment and of Franklin and Tversky (1990b) specified the point of view of the reader by describing the spatial arrays, and probing locations of objects deictically with respect to the reader. Another way to describe a spatial array is with reference to the intrinsic sides of an object or a third-person observer in the scene. In the next two experiments, narratives describe spatial situations quite similar to those of Franklin and Tversky (1990b) except that they locate objects with respect to a central person (Experiment 2) or a central inanimate object (Experiment 3). Narratives written in this way afford the reader more than one point of view on the scene. The reader can either adopt an external perspective, "looking" at the character surrounded by objects, or an internal perspective, that of the central character or object. These two viewpoints correspond to the internal viewpoint specified by the narratives of Franklin and Tversky and the external viewpoint specified in Experiment 1, respectively.

A priori, it seems reasonable to expect that a narrative describing a character in the third person would evoke an external perspective, much like a play or movie, or, for that matter, life, where we frequently find ourselves in the position of an external observer looking at others and their surroundings. On the other hand, if readers adopt external viewpoints on such scenes, they would have to keep in mind two viewpoints in order to respond to direction probes, their external point of view and the point of view of the central person/object, because the probes refer to the intrinsic sides of the central figure. Adopting the viewpoint of the central figure would simplify the readers' mental world by allowing them to keep in mind only one point of view. Whether readers adopt an internal or an external viewpoint can be determined by their response times to "front" and "back" questions. Specifically, if response times to front are faster than those to back, an internal viewpoint is indicated; if not, an external viewpoint is indicated.

Method

Subjects

Subjects were nine male and eight female Stanford undergraduates who participated for credit in an introductory psychology class, or for pay.

Narratives

Nine narratives (one of which was a practice story) were adapted from Franklin and Tversky (1990b). Each narrative described, in the third person, a different setting containing a character surrounded by five objects. Each narrative had two versions, one with a male character and the other with a female character. The settings and the objects were selected to be familiar and common (see Table 3), and the sizes of objects and the distances between them were all roughly equal within a narrative. The locations of objects were selected randomly. An example of a scene used in this experiment is depicted in Fig. 2, but subjects never saw this or any other diagram.

Narratives were presented to subjects in two parts. The first, printed on paper, provided the name of the setting and a list of the five objects, in the scene, then described the environment with respect to the character of the narrative. The first part of the *Space Museum* narrative used in Experiment 2 follows as an example. The key objects are italicized here, but were not in the narratives subjects read.

TABLE 3
SCENES AND OBJECTS OF EXPERIMENT 2

Scene	Objects
Navy ship	Anchor, antenna, cannon, flag, lifeboat
Halloween party	Bowl, ghost, mask, pumpkin, skeleton
Hotel lobby	Banner, barbershop, fountain, giftshop, tavern
Construction site	Bucket, jackhammer, ladder, shovel, wheelbarrow
Opera theatre	Bouquet, lamp, loudspeaker, plaque, sculpture
Space exhibit	Map, meteorite, portrait, satellite, spacesuit
Barn	Lantern, pail, rake, saddle, shears
At the lagoon	Bottle, frisbee, paddle, snorkel, towel
Work shed	Basket, fan, hammer, saw, yardstick

Sue is at the local Museum of Natural History, visiting the Space Exhibit, which occupies two stories of the building. Except for a narrow circular walkway, the second-story floor is missing so that large objects can be displayed in an open area spanning the two floors. Sue is currently standing on this walkway, looking around at the many fascinating displays. As she stands at the edge, Sue looks directly in front of her and sees a *map* of the solar system, including the orbit paths of all the planets. The map covers many square feet of wall space and is large enough for Sue to easily read from where she stands. Directly to her right, a full-sized *spacesuit* hangs by a thin wire from the ceiling. It is shiny and white, and it looks like it was never used. Next, Sue twists her neck to look directly behind her at a life-sized *portrait* of John Glenn. The portrait is a bright watercolor painting that makes the famous astronaut look very dashing. Peering downward toward the first floor, Sue sees a large rocky *meteorite* resting on a pedestal on the floor of the museum. The meteorite is about the size of a small boulder, but it looks to Sue to be dense enough to weigh a ton. Stretching her neck to look directly above her head, she sees a communications *satellite* suspended from the ceiling. It consists of a metal ball, about 2 feet in diameter, with a metal dish attached to it.

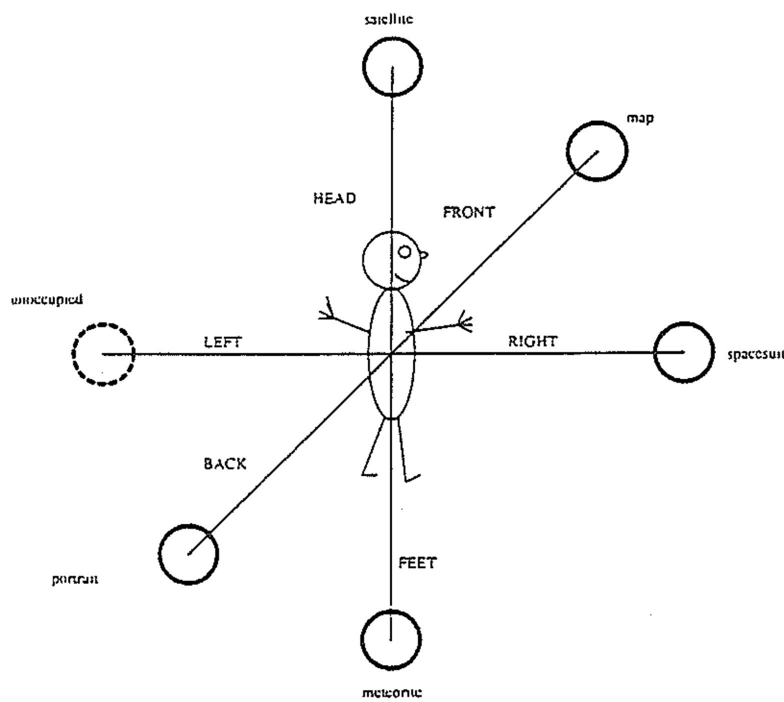

FIG. 2. A depiction of the *Space Museum* person-centered array (Experiment 2). Objects were located with respect to the intrinsic sides of the character shown at the center of the array.

The second part of each narrative was divided into six blocks and presented sentence-by-sentence by computer. Each block began with two sentences orienting the character toward one of the five objects in the environment while either standing upright or reclining. This was followed by two filler sentences that described the object currently to the character's front, without mentioning it by name. The dual purposes of the filler sentences were to focus attention on the object and to prevent priming of the object's name when subjects responded to direction probes. A description of one of the orientations along with the associated detail and filler sentences of the *Space Museum* narrative follows as an example:

After a while, Sue becomes bored and decides to study a different exhibit.

So she turns to her right and faces the spacesuit.

By looking carefully, she can read the insignia on one arm.

The patches identify the astronaut, his rank, and the mission on which he served.

Following the filler sentences, subjects were given direction terms and probed for the objects lying in those directions, and then reoriented toward another object. Direction probes were separated by three filler sentences each. After three reorientations, the character changed posture from upright to reclining, or vice versa, and had two subsequent reorientations in that posture. When reclining, characters lay on their back, front, or sides, and turned along their head/feet axis.

Procedure

The procedure was similar to that of Experiment 1. Subjects read an initial portion of narratives for understanding, then proceeded sentence by sentence through the second portion. Following the filler sentences, subjects were probed with one of six directions, indicated by a single word, "front," "back," "head," "feet," "left,"