REMEMBERING CHANGES IN DIRECTION

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ABSTRACT: Memory for turns of varying angularity encountered during pathway traversal was examined in a within-subjects design. Subjects walked eleven 8.3 m pathways, each containing one turn ranging in size from 15° to 165° from the direction of forward motion. After each pathway traversalubjects were required to estimate the angle traversed, point to the original direction of travel, and point to the start of the pathway. Results indicated that paths containing angles near 0°, 90°, and 180° from the direction of forward motion were the least disorienting and were most accurately remembered. Errors increased as angles diverged from these orthogonal coordinates. The data also revealed a pervasive tendency to estimate all angles as more like 90° than they actually were. Results were discussed in terms of hypothesized orthogonal reference axes that move through space with the observer.

The research reported below explores the ability of individuals to maintain a sense of orientation and direction after traversing pathways containing a single turn of varying angularity. It has been suggested (Anooshian and Siegel, 1985; Hart and Moore, 1973; Piaget and Inhelder, 1956) that spatial knowledge of a region involves at least two components: the directional relationship between places (landmarks or routes) and the distances between them. Although considerable empirical work has been directed at the ability to comprehend traversed distances (Allen, 1981; Sadalla et al., 1979; Sadalla and Magel, 1980; Sadalla and Staplin, 1980; Thorndyke, 1981), surprisingly little is known about subjects' ability to perceive and remember angular changes in the direction of travel. The present research was specifically designed to determine if consistent errors are associated with turns of different angular magnitudes.

The theoretical focus of the present research is on the nature and sensitivity of egocentric orientational systems. Egocentric orientation, which involves cues that depend upon the position of the observer (e.g., left-right, in front-behind), has been distinguished from allocentric orientation. In the latter, orientation is maintained through the use of either environmental features such as landmarks, or coordinate systems (e.g., north-south, east-west), which are independent of the position of the observer. In this study we employ a paradigm that evaluates how well individuals are able to update their knowledge of position and direction under conditions of impoverished environmental features. The relative absence of external cues maximizes the likelihood that subjects will rely on egocentric reference systems.

Underpinning this research is the assumption that subjects employ a pair of orthogonal reference axes when judging the magnitude of traversed angles. It is assumed that when moving through space subjects align one axis in the direction of travel. Turns that vary minimally from either the direction of travel or from an axis orthogonal to the direction of travel should be the most easily remembered and should be the least disorienting. Increasing error and disorientation should be associated with increasing angular deviation from either reference axis.

A number of reasons may be adduced to suggest that orthogonal reference axes constitute a fundamental component of egocentric orientation. The possible explanations

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include (a) the structure of the human body provides a number of ever present referents for orthogonality. For example, the arms when extended in the plane of the shoulders define turns at right angles to the direction of forward motion. Because of their physical structure, humans may comprehend right angle turns more easily than turns that have no obvious reference in relation to their body. (b) The earth's gravitational field defines a unique vertical dimension that is orthogonal to the generally flat horizontal dimension. As a result, the environment contains numerous examples of orthogonal relationships. As Shepard and Hurwitz (1984) have noted, the concept of vertical direction tends to be extended to represent horizontal directions that are straight ahead in the viewer's egocentric frame. The equation of vertical with the horizontal forward direction yields an egocentric "forward-up" reference axis that moves through space with the viewer. (c) Orthogonal changes in direction are easier to label verbally than are other directional changes and hence may be easier to remember. Terms such as *straight, right angle,* and *orthogonal* may be used to encode such directional changes. The labeling hypothesis, in addition, implies that *diagonal* (45°, 135°, 225°, and 315°) turns should also be relatively easy to cognize and remember. (d) The "carpentered world" hypothesis that emerged from cross-cultural studies of the trapezoidal window illusion suggests that subjects who reside in environments containing rectilinear architecture develop schemata for right angles (Allport and Pettigrew, 1957; Segall et al., 1966).

DISTORTIONS IN COGNITIVE MAPS

The hypothesis that changes in the direction of travel are cognized in relation to orthogonal reference axes is consonant with cognitive mapping studies of urban spatial structure. Lynch (1960) asked residents of Boston, Jersey City, and Los Angeles to draw maps of their respective cities from memory. He reported "unaligned paths" as a common source of confusion and error in the map drawing task. Respondents were able to reproduce the grid system of downtown Los Angeles with acceptable accuracy, but had difficulty with the more irregular route system found in Boston. Bostonians misrepresented one major avenue containing a curve as straight and mistakenly assumed that all streets intersecting that avenue at right angles were parallel. Saarinen (1964) reported a similar map drawing study of the Chicago Loop area in which respondents based their maps on the predominant grid system in the area, and straightened out any variations from it.

The straightening of curves and the representation of a wide variety of angles as right angle intersections is a common result in such map drawing studies. Milgram (1976) analyzed hand-drawn maps of Paris by 218 Parisians. Over 90% of their subjects underestimated the curvature of the Seine River, which in turn distorted a significant portion of their urban maps. Chase and Chi (1981), Byrne (1979), and Tversky (1981) have reported map drawing data in which streets intersecting a major thoroughfare at oblique angles were mistakenly drawn at 90°.

The results of map drawing tasks inform us about the way in which subjects remember information about the spatial structure of routes and landmarks. As Tversky (1981) has demonstrated, such memories typically involve systematic distortions that may be accounted for in terms of general principles of perception. Such principles as *common fate, rotation,* and *alignment* constrain the manner in which subjects draw maps. Whether these same principles also produce disorientation during actual navigation remains an open empirical question. It seems possible, for example, that remembering a curved path as straight could produce minimal difficulties in navigation toward a landmark, but could produce considerable difficulties when drawing the shape of a route or when drawing the relative positions of landmarks.

EXPERIMENTAL STUDIES OF REFERENCE AXES

Rosch (1975) has explored the hypothesis that the lines defined by a pair of orthogonal axes and its diagonals would be used as references for judgment of the angular orientation of other lines. She conducted two experiments. The first employed a linguistic hedge task; the second involved a judgment task in which subjects estimated the distance between lines at varying orientations. Data from the linguistic task supported the hypothesis that both orthogonal coordinates and their diagonals constitute reference axes; data from the judgment task suggested that the orthogonal axes, but not their diagonals, are used to estimate the orientation of other lines.

Loftus (1978) conducted a study that is relevant both to questions concerning the primacy of orthogonal axes and to questions concerning the cognition of diagonals. In this experimental study subjects were presented with a number designating a compass direction between 0° and 350°. The subject's task was to indicate a comprehension of the direction by drawing a representation of it and then pressing a key. Reaction time data, which were used as an index of the time to comprehend the direction, were nonmonotonically related to position within a quadrant; RT rose to a peak at 40°-50° and then fell. Loftus's pattern of results suggests that the cardinal directions on a compass are psychologically primary and that other directions are computed by "computing the nearest cardinal direction and second, rotation from the cardinal to the desired direction" (Loftus, 1978: 420). In this study, diagonal directions appeared to require the most computation.

SPATIAL PROBLEM SOLVING: DETOURS, SHORTCUTS, AND EQUIAVAILABILITY

There are a number of ways to evaluate a traveler's ability to cognize changes in the direction of travel. In the study

described below we employ three: (1) the ability to estimate the angle of the turn, (2) the ability to estimate the original direction of travel (before turning), and (3) the ability to estimate the direction to the starting point of the journey. The ability to remember the original direction of travel is involved in detour problems. Such problems occur when a traveler sets out in a particular direction, but encounters an obstacle that impedes progress in that direction. Can the traveler coordinate the direction of the detour with the original course direction? Does the ability to estimate the original direction depend upon the angular course of the detour?

Shortcut problems are among the most ancient of spatial problems that confront humans. Imagine a hunter leaving a home base, tracking an animal for a period of time, and then wishing to return home. The hunter might either retrace the route that led away from home, or might attempt a shortcut based upon an estimation of the direction of home from the hunter's current position. The shortcut problem is related to the principle of equiavailability articulated by Levine et al. (1981). These authors suggest that "after experiencing a sequence of connected points, the human behaves as though the information has been placed into a simultaneous system." Equiavailability implies that "the subject can take new paths" and that "old and new path segments are equally available." Levine et al. present data that support their contention that subjects are capable of shortcuts even after traversing routes that contain multiple turns. In the research that follows, we explored the ability to construct shortcuts as a function of the magnitude of the angle encountered during route traversal.

We employed a procedure in which subjects walk a short distance on a path, make a single change in direction, and then proceed for another short distance. A variety of angular changes in direction were explored in a within-subjects design. Our hypotheses follow from the assumption that turns are cognized in relation to a pair of orthogonal axes, one of which is aligned in the direction of forward travel. Specifically, we hypothesize that both errors in estimation and spatial disorientation will increase as a function of the angle's distance from reference axes (diagonal turns will show the greatest error). Second, it is expected that all angle estimates will be distorted in the direction of the nearest orthogonal axis.

METHOD

Subjects. In total, 46 students, 25 females and 21 males, participated in order to receive extra credit in an upper-division psychology class.

Materials. The experiment took place in a large (10.7 × 11.7 m), empty room in the psychology building. The untextured floor provided no linear cues to the subject.

Every subject traversed 11 pathways, each containing an angular turn ranging in size from 15° to 165°, in 15° increments (see Figure 1). Half of the subjects walked paths veering off to the right, while the other half walked on paths that veered to the left. The paths consisted of a common initial segment made of tape, 4.17 m long, the beginning of which was marked with the word "start." A length of rope was attached to a pivot point 0.5 m from the end of the tape, and could quickly be moved to form the angular path required for that trial. The total length of the initial leg of each path was 4.6 m. The 0.5 meter empty segment between the end of the tape and the beginning of the rope segment was included to avoid giving subjects a concrete perceptible angle at the vertex, a simulation designed to mimic actual environmental pathways more closely. The second segment of the path was 3.66 m. A circular measuring device mounted on a stand 0.66 m high was placed at the end of the pathway, and was used to collect the estimates described below.

Subjects wore a specially designed headpiece made of dark, opaque cloth that prevented peripheral vision and restricted forward vision to 0.5 meters.

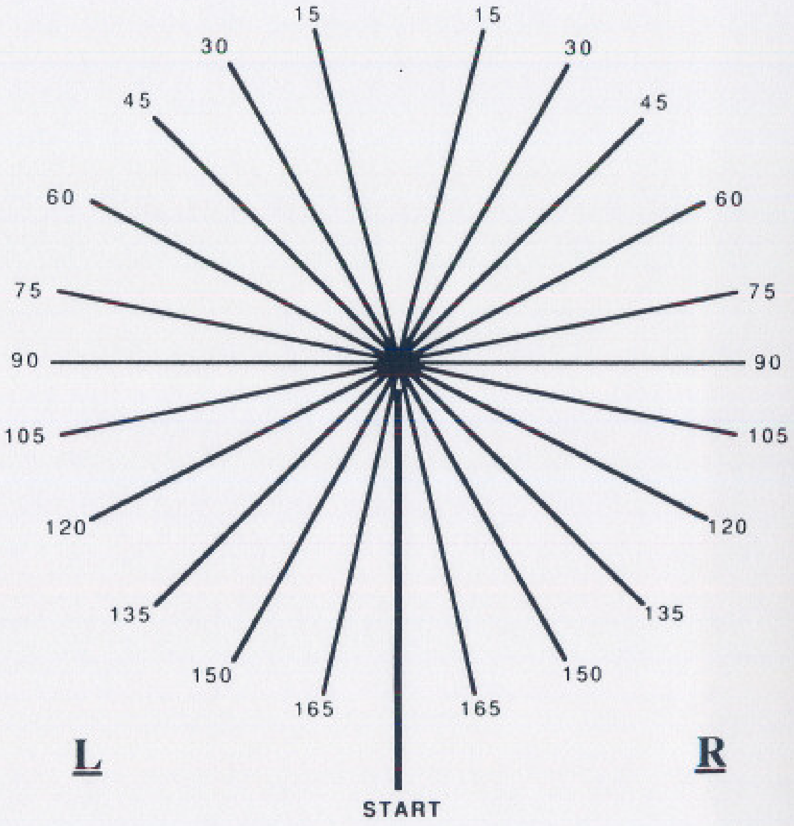

Figure 1: Angular Pathways Used in the Experiment

Procedure. Subjects were run individually. After being fitted with the headpiece outside the experimental room, they were led into the room and over to the starting position at one end of the tape segment. After receiving brief instructions concerning the tasks to be performed, subjects proceeded to walk along the path. Upon arriving at the end of the pathway, subjects encountered the circular measuring device. The pointer was aligned with the radius drawn on the device, and both radius and pointer were aligned with the final segment of the pathway. This position corresponded to 180° on the device. At this time, the subject made three estimates in an order that was counterbalanced across subjects.

Measure 1 required subjects to form an angle with the pointer and radius that represented the angle that they had previously traversed on the pathway. Measure 2 required them to move the pointer until it pointed in their original direction of travel, the direction they would then be facing if they had not made a turn on the path. The third measure required subjects to move the pointer so it pointed directly toward the position marked "start" at the beginning of the tape segment.

After completing the three estimates, subjects walked back along the pathway to the starting position. The procedure was repeated until each subject had made the three estimates for all 11 pathways. The order of the angular turns was fully randomized for each subject.

RESULTS

The error scores from each of the three measures employed in this study were examined both as over- or underestimates with respect to the correct estimate, and as absolute deviations from the correct estimate for that angle. Directional errors indicate the extent of a positive or negative bias; absolute errors reflect the average inaccuracy per subject regardless of direction. Initial ANOVAs revealed that angles involving right turns were estimated no differently than were angles involving left turns on any of the three dependent variables. Angular turns to the right and to the left are therefore collapsed in the following analyses.

ERRORS IN ANGLE ESTIMATION

Of primary interest in the present investigation was whether or not the pattern of errors for Measure 1 (angle

estimation) would follow our hypothesis that accuracy would be greatest for turns nearest the orthogonal coordinates (0°, 90°, and 180°) and would get progressively worse as turns neared a perfect diagonal (45° and 135°). The absolute errors in angle estimates are plotted in Figure 2.

A multivariate approach to repeated measures was used to analyze both directional and absolute errors to investigate the premise that recall accuracy and consistency would be different for turns of different sizes. The size of the angle served as a within-subjects factor; gender served as a between-subjects factor. A main effect for angle size was found for both directional errors, $F(10, 35) = 6.44$, $p < .0001$, and absolute errors, $F(10, 35) = 5.71$, $p < .0001$, indicating that accuracy was different for angular turns of different sizes. Neither of the MANOVAs revealed a gender main effect nor gender by angle interaction.

Inspection of Figure 2 reveals the predicted quartic trend that reflects highly accurate estimates on angles near orthogonal coordinates and decreasing accuracy on angles near the diagonals. The presence of this trend was confirmed by repeated measures trend analyses, $F(1, 45) = 4.79$, $p < .05$.

The hypothesis that angle estimates would be distorted in the direction of the nearest orthogonal axis was not supported by the data. The data indicate that turns between 0° and 90° were all overestimated, while turns between 90° and 180° were all underestimated. A repeated measures trend analysis performed on directional errors revealed a significant cubic trend, $F(1, 45) = 5.87$, $p < .05$. All turns were thus distorted in the direction of 90°. Turns between 0° and 90° will be referred to as being in quadrant 1; turns between 90° and 180° will be referred to as being in quadrant 2. The observation that the direction of error was different in the two quadrants was tested by calculating t-scores for the directional errors averaged over all angles in a quadrant. These were then tested for their difference from 0. These

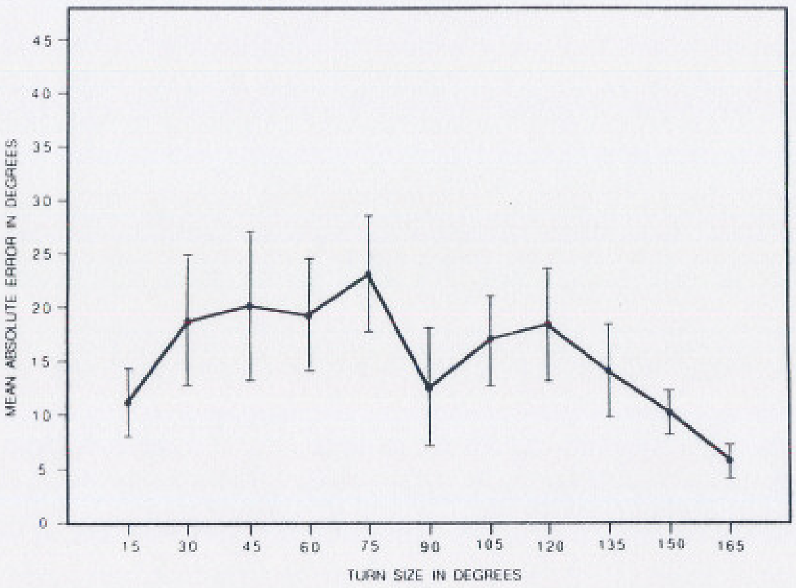

Figure 2: **Mean Absolute Errors and 95% Confidence Intervals for *Angle Magnitude* Estimates**

analyses indicated that errors in quadrant 1 were significantly greater than 0, $t(45) = 3.56$, $p < .001$; errors in quadrant 2 were significantly less than 0, $t(45) = -2.01$, $p < .05$. Both of these biases indicated distortion toward a right angle.

ORIGINAL DIRECTION OF TRAVEL

Figure 3 presents the mean absolute errors for each angle on measure 2, judging the original direction of travel. The multivariate approach to repeated measures was again used with both directional and absolute errors to investigate the hypothesis that recall would be differentially accurate for turns of different sizes. The main effects of angle were significant for both directional errors, $F(10, 35) = 6.80$, $p < .0001$, and absolute errors, $F(10, 35) = 5.68$, $p < .0001$. There were neither main effects nor gender by angle interactions.

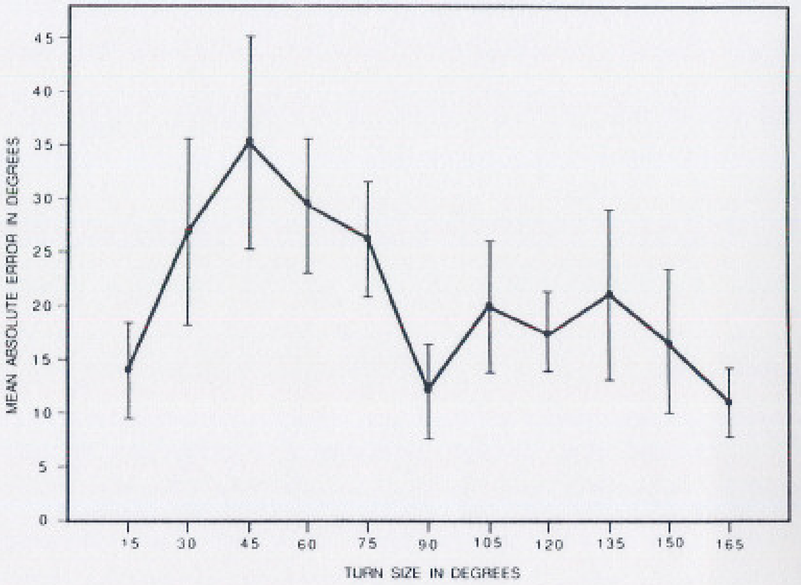

Figure 3: **Mean Absolute Errors and 95% Confidence Intervals for *Original Direction of Travel* Estimates**

The next analysis tested the hypothesis that accuracy in judging the original direction of travel would be superior on pathways with turns nearest the orthogonal coordinates, and would get progressively worse as turns neared a perfect diagonal. Just as for measure 1, a predicted quartic trend was indicated by the graph in Figure 3, and was confirmed by repeated-measures trend analysis, $F(1, 45) = 20.64$, $p < .0001$.

Differences in the direction and amount of error in quadrant 1 versus quadrant 2 were next examined for measure 2. T-scores for the directional errors averaged over all angles in a quadrant were computed, and tested for their difference from 0. The results again demonstrated that

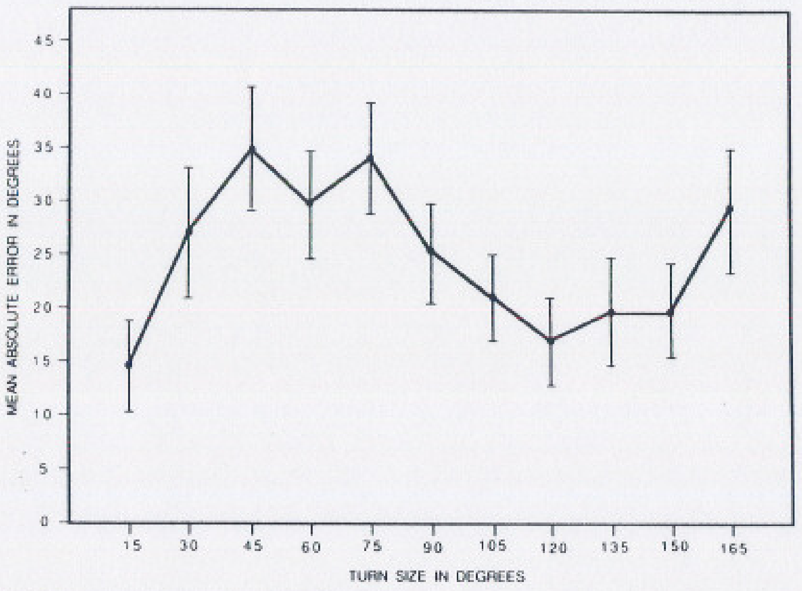

Figure 4: **Mean Absolute Errors and 95% Confidence Intervals for *Point to Start* Estimates**

errors in quadrant 1 were significantly greater than 0, $t(45) = 6.13, p < .0001$, while errors in quadrant 2 were significantly less than 0, $t(45) = -3.45, p < .001$. Analysis of directional errors on measure 2 indicated a significant cubic trend, $F(1, 45) = 19.75, p < .0001$. Just as for measure 1, these biases indicate distortion toward a right angle, but no bias in the direction of 0° and 180° coordinates.

POINTING TOWARD START

Absolute errors on measure 3, pointing to the start, are plotted in Figure 4. The initial repeated-measures MANOVA on these errors revealed a significant main effect for angle magnitude, $F(10, 35) = 7.06, p < .0001$. A similar result was found for directional errors; the main effect of angle magnitude was significant, $F(10, 35) = 23.44, p < .0001$. Neither an effect of gender nor a gender by angle effect was observed.

Because accuracy in measure 3 involved estimation of traversed distance as well as direction, it was unclear which angles would be estimated most accurately. Post-hoc trend analyses were performed on both directional and absolute errors. Results for the directional errors indicated a large quadratic component, $F(1, 45) = 155.44, p < .0001$. Errors in pointing to start were at a minimum at 15° and 120°, and at a maximum at 45° and 165°. The pattern of absolute errors in Figure 4 suggested the presence of a cubic trend. A repeated measures trend analysis confirmed that the cubic trend was highly significant, $F(1, 45) = 81.47, p < .0001$. Interestingly, the pattern of results suggests that when pointing to start, subjects formed an angle with the direction *they were then facing* that was closer to a right angle than the correct response. In the case of the two most obtuse turns, 150° and 165°, this resulted in a negative distortion; for the rest of the turns, this led to positive distortions (90° would have been the correct response had the subject made a turn of about 142°). Thus, as with measures 1 and 2, subjects tended to distort their estimates for measure 3 toward a right angle.

DISCUSSION

This study explored the assumption that angular changes in a pathway are cognized in relation to a pair of reference axes. The first axis was assumed to project directly forward in the viewers egocentric frame; the second was assumed to be orthogonal to the first, projecting laterally in both directions from the subject's body.

The pattern of data obtained in this study generally supports this model. Error scores, which reflect both angle estimation and estimates of the original direction of travel, increased in magnitude as traversed angles deviated from a straight line, reaching a maximum at approximately 45°, then decreased as angles approached 90°. Error scores in quadrant 2 showed the same pattern, increasing in magnitude as angles deviated from 90°, reaching a maximum at 135°, then decreasing as angles approached 180.

This statistically significant quartic trend in the magnitude of error scores was predicted from the premise that angles close to a reference axis would be more easily and more accurately estimated than would angles more distant from a reference axis. No support was found for the premise (Rosch, 1975) that diagonals could be used as references for judging angularity.

The direction of error scores observed in this study did not follow initial expectations. It was anticipated that angle estimates would be distorted in the direction of the nearest reference axis. Subjects in the present study instead tended to distort their estimates in the direction of 90°. Angles in quadrant 1 were overestimated, while angles in quadrant 2 were underestimated. In terms of dependent variables 1 and 2, all angles were estimated to be more like 90° than they actually were.

Data obtained in this study are consonant with the results of other studies of spatial orientation. Both Shepard and Hurwitz (1984) and Levine (1982) have shown that subjects cognize their immediate spatial environment in terms of an egocentric frame of reference that projects directly forward in the viewer's visual field. Points more distal are regarded as "up" relative to more proximal points on this reference axis. Our data provide further support for the premise that subjects use such a reference axis to maintain spatial orientation, and additionally suggest the presence of a second "lateral" axis oriented orthogonally to the "forward-up" axis.

Use of the lateral axis for orientation may be associated with a type of error that might be called mirror image reversals. In the present study, we observed a significant number of instances in which subjects correctly estimated the magnitude of turns, but erred in the left-right orientation of those turns. Shepard and Hurwitz (1984) noted that "unlike the front-back distinction there is also no salient perceptual difference between the two sides of those many significant objects, including our own bodies, that closely approximate bilateral symmetry." Memory for left versus right should thus be intrinsically more difficult than memory for forward versus backward.

Our data also supplied qualified support for the concept of equiavailability (Levine et al., 1981). Equiavailability implies that after walking two sides of the angle that composed our pathway, a subject should have a representation of the path back to the origin. In terms of the current operations, subjects should be able to point to start. We observed some ability to do so. Point-to-start responses were not as accurate as were our other measures of spatial orientation, but neither were they random. Subject errors varied with the magnitude of the angle traversed and appeared to be influenced by two biases: (1) the tendency to regard the turn as more like 90° than it was, and (2) the tendency to regard the direction toward the origin as closer to 90° (from the direction they were facing) than it was.

Loftus's data on the reaction time necessary to cognize a presented compass direction (e.g., 75°) indicate that subjects comprehend directions in terms of a pair of orthogonal axes that correspond to the four cardinal directions. This environmental frame should be distinguished from the egocentric frame that subjects were constrained to employ in the present study. Although the theoretical literature in spatial cognition suggests a developmental progression from egocentric to nonegocentric frames of reference (Hart and Moore, 1973; Anooshian and Siegel, 1985), the extent to which each of these frames is actually used to maintain spatial orientation remains an open empirical question.

Results of the present study indicate that traversed angles that are close to 0°, 90°, and 180° from the direction of forward motion are the least disorienting and are the most accurately remembered. The data also indicate a pervasive tendency for all angles to be remembered as more like 90° than they actually were. The methodology employed in this research was not designed to uncover the cognitive processes that lead to the pattern of errors observed. It is possible that the present results stem from a tendency to encode angles in relation to orthogonal axes. Alternatively, they may result from organizational processes (e.g., orthogonal schema) that govern storage, or from processes (e.g., response biases) that operate on output.

To what extent are the results of the present research generalizable to nonlaboratory environments? Although the study took place within the confines of a room and involved short paths, the procedures used were designed to mimic information-processing problems that are encountered during the traversal of large-scale routes. Subjects wore a hood that prevented a view of the entire pathway and ensured the sequential processing of information that characterizes large-scale spatial cognition. Subjects were required to integrate a series of perceptual events that were sequentially experienced into representations of distance and direction. The restriction of visual experience may, however, have forced subjects to rely on the egocentric reference frames that were the focus of our investigation. The extent to which such frames are employed in large-scale settings with differentiated environmental features remains an open empirical question.

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