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Visual Perception of Location and Distance

Jack M. Loomis, José A. Da Silva, John W. Philbeck, and Sergio S. Fukusima

Visual perception of three-dimensional space is one of the classic problems in philosophy and experimental psychology. It is important for two reasons. First, explaining the phenomenology of visual experience, of which space perception is central, is one of the major concerns of research on consciousness, mental events, and human cognition. Second, visual space perception plays an essential role in the control of much of human spatial behavior.

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WHAT NEEDS TO BE EXPLAINED?

Research on the topic has addressed two quite distinct empirical domains: the psychophysics of visual space and the visual control of action. Researchers concerned with the former have been interested in such issues as the mapping between physical and visual space; the intrinsic geometry of visual space; the stimulus cues and internal constraints that determine visual space; the interrelationship of perceived direction, distance, size, and motion; and the sensory mechanisms and neural computations involved in perceiving space.[1] Researchers concerned with the latter have focused largely on how visual information is used by the observer in the control of spatial behavior, such as reaching, ball catching, running, or driving.[2]

It is unfortunate that the programs of research on visual space and on the control of action have been conducted so independently of one another. The majority of visual perception researchers probably believe they are justified in investigating the psychophysics of visual space in isolation because the process of visual perception acts as a module functionally distinct from other modules involved in controlling action (e.g., the module that specifies the commands to the extraskeletal muscles). Furthermore, the output of the perception module—visual space—exists independently of any of the actions to be controlled. In this view, once the process of visual perception and the structure of visual space have been worked out, this knowledge can be readily applied to the problem of controlling action.

Taking issue with this view, however, are those researchers working on the control of action within the ecological framework. Their opposing view is that action

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is tightly coupled to visual stimulation. Very specific visual information, often some property of optical flow (the changing angular positions of environmental points), is used to control each spatial action (e.g., in driving, braking is controlled by the optical expansion of the forward field of view, and steering is controlled by the directional components of optical flow). Exponents of this view believe that adequate explanations of action are possible without postulating a role for the intervening concept of visual space.

Although we concur that the control of some behaviors can be explained adequately in terms of optical variables and the observer's sensitivity to these variables, we are even more convinced that many spatial behaviors require explanations posed in terms of visual space and other internal representations (e.g., those involved in planning). Accordingly, we side with the position that there are distinct modules of perception, cognition, and motor control and that scientists can indeed learn a great deal about these modules through programs of research directed to each. However, because understanding human action is surely one of the major goals of psychology, perceptual research that illuminates the problem of action is needed. Moreover, attempts to develop explanations of action in terms of sensory information, perception, cognition, and motor control are long overdue.

Our primary focus here is on properties of visual space. To begin, we must define two terms as they are commonly used in the literature. *Egocentric distance* is the distance between the observer and a point in space. *Exocentric distance* is the distance between two external points; the conventional meaning is that these two points lie along the same line of sight (defining a depth interval), but we assume no such restriction here. Other primitives we work with are *perceived direction* (from an observer to a point), *perceived egocentric distance, perceived location* (as specified by perceived direction and distance), and *perceived exocentric distance.*

PERCEPTION OF EGOCENTRIC DISTANCE AND LOCATION

Because perceived direction is generally believed to be veridical or nearly so, research in visual space perception has concentrated on the measurement of perceived distance. Although perceived egocentric distance is a self-evident property of visual space, knowing how to measure it has proven to be one of the major challenges in this research. Among the indicators used in measuring perceived distance are verbal reports, indirect estimates obtained from judgments of other perceptual variables, and estimates based on visually directed action. We and our colleagues have opted to use the latter indicator in our research. In tasks of visually directed action, the observer views a target within the immediate environment and then, with eyes closed, attempts to demonstrate knowledge of the object through some sort of action.

Figure 1 shows three of the visually directed actions we have used. In visually directed walking, the observer views a target and then, with eyes closed, attempts to walk to its location (the target is removed in the meantime). The walked distance is used as an indicator of the initially perceived target distance. In triangulation by pointing, the observer views the target and then attempts to point continuously in the direction of the target while walking past it without vision. The terminal

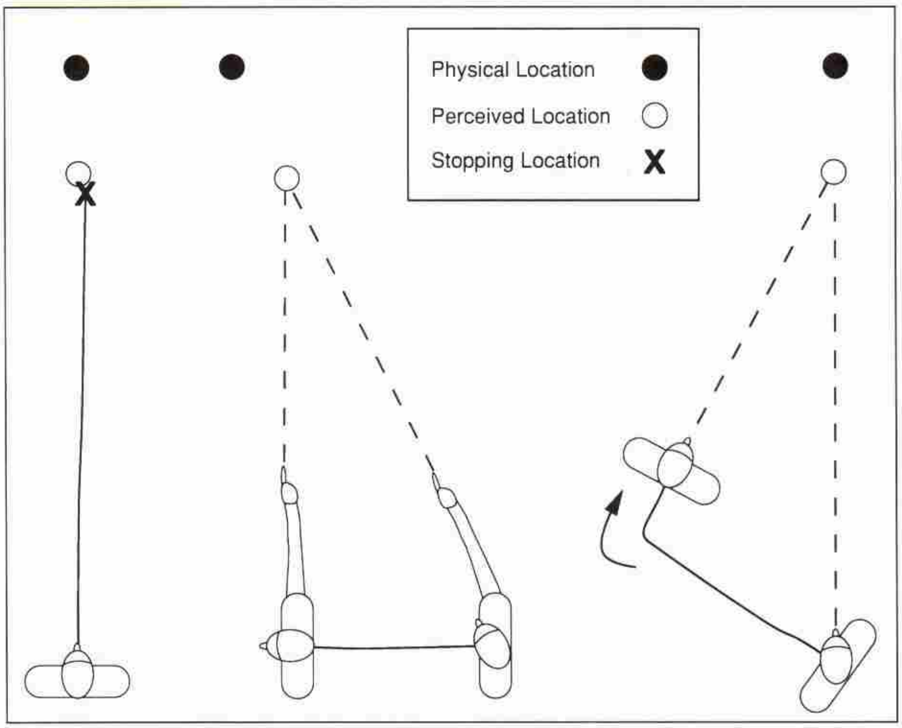

Fig. 1. Three tasks of visually directed action: visually directed walking, triangulation by pointing, and triangulation by walking (from left to right). Solid lines represent distances traversed while walking. Dashed lines represent pointing or facing directions to the perceived target.

pointing direction, in conjunction with the initial target direction, is used to specify the initially perceived target location and, thence, its perceived distance from the origin. In triangulation by walking, the observer views the target and then, with eyes closed, walks along an oblique path; on command, the observer turns toward the target and walks a short distance to allow measurement of the travel direction. This direction and that of the target from the origin are used to compute the initially perceived target location and, thence, its perceived distance from the origin.

Our research using these visually directed tasks has shown that, on average, observers are quite accurate in indicating the location of targets on the ground under full-cue viewing conditions; over a number of experiments, the mean error was less than 30 cm for target distances ranging from 4 m to 15 m.[3] When correct performance occurs, it is interpreted as indicating that the observer (a) correctly perceives the target location from the viewing location, (b) correctly perceives his or her own self-motion while walking, (c) correctly updates the internal representation of the target location on the basis of this perceived self-motion, and (d) correctly executes a motor response (e.g., pointing) that is directed to the updated target location.

When the visual cues to egocentric distance are diminished, observers in these visually directed tasks respond quite differently. We[4] presented luminous rectangles subtending a fixed visual angle at eye level in an otherwise dark room. The targets ranged in distance from 0.8 m to 5 m and were viewed either monocularly (with one eye) or binocularly (with two eyes). Observers indicated perceived egocentric distance through visually directed walking and verbal report. For both measures, there was very little variation with target distance, signifying large systematic errors: Distances shorter than 2 m were overestimated, and distances larger than 3 m were underestimated. Because these results are consistent with others in experiments using a variety of distance indicators, they provide strong evidence that visually directed walking is indeed an indicator of perceived egocentric distance.

Even stronger evidence that visually directed action is responsive to perceived target location comes from a recent experiment[5] using a visually directed task that is a hybrid of visually directed walking and triangulation by walking. Observers were presented with single targets either under full-cue conditions (room lights on) or under re-

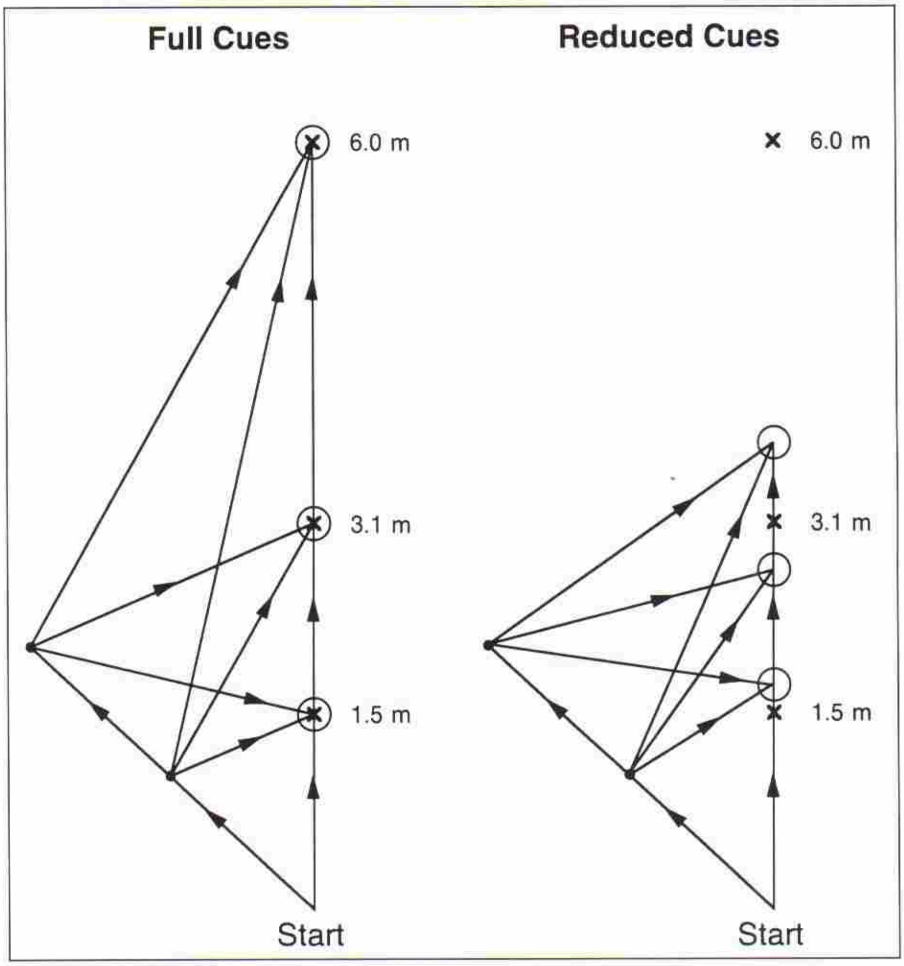

Fig. 2. Stimulus arrangement and predicted responses in an experiment by Philbeck, Loomis, and Beall.[5] The physical target locations are depicted by the *X*s and the preceived target locations by the open circles. On a given trial, the observer viewed a target and then attempted to walk to it with eyes closed along a direct path or along one of two indirect paths (as designated by the experimenter). The tactually sensed turn points for the indirect paths are depicted by the small solid circles. Under the assumption that observers direct their actions to the perceived target locations, it was predicted that in response to a given target, the observer would walk to the same location when traversing the direct and two indirect paths. Under full cues, it was predicted that the walking trajectories would converge on the physical target location for each of the three targets. Under reduced cues, it was predicted that the trajectories to the far target (6.0 m) would converge to a nearer location and that the trajectories to the near target (1.5 m) would converge to a more distant location.

duced-cue conditions (a single luminous target at eye level in an otherwise dark room; on a given trial, the egocentric distance of the target was 1.5, 3.1, or 6.0 m). The observer viewed the target for several seconds, after which vision was occluded. At this point, the observer was instructed to walk to the target along either a direct path or one of two indirect paths (Fig. 2). The initial segments of the indirect paths were parallel to a wall that the observer sensed with the hand; the near or far turn point (toward the target) could also be felt. After turning at the proper point, the observer walked in the direction of the imaginally updated target location. Figure 2 represents predicted performance if observers were indeed responding to perceived location. Under either full or reduced cues, the observers' direct and indirect walking trajectories were expected to converge on the same location for a given target (ostensibly, the perceived location). That this location was indeed the perceived location would be indicated if the point on which the trajectories converged varied systematically with cue availability. Under full-cue conditions, the convergence point was expected to coincide with the physical target location, but under reduced-cue conditions, the convergence point was expected to be short of the farthest target location and to be beyond the nearest target location. The results of the experiment were quite close to these predictions: On average, the direct and indirect trajectories converged on common points, and these points of convergence varied substantially with cue availability, with performance in the full-cue condition being considerably more accurate (although some systematic error remained).

These last results are strong evidence that perceived target location is a causal determinant of action. Whether the observer walked along the direct or indirect path, he or she tended to end up at the same location in space, and this location tended to differ from the physical target location when distance cues were diminished. Thus, the invariant that controls action in this task is not some aspect of the visual stimulus that is tightly coupled to the action, as ecological theorists would have it; rather, the invariant is something within visual space—namely, visually perceived location. If visually perceived location exists independently of any potential actions that it might control, the implication is that for a given degree of cue availability, the observer would respond to the same physical location regardless of the type of action involved, whether it be walking, running, sidestepping, or crawling on the knees.

DISSOCIATION OF PERCEIVED LOCATION AND PERCEIVED EXOCENTRIC DISTANCE

In physical space, exocentric distance is determined solely by the locations of the points defining the spatial interval. We have obtained evidence in our research that in visual space, perceived exocentric distance depends on more than the perceived locations of the points defining the interval.

In our research with visually directed walking under full-cue conditions, observers walked blindly with very little systematic error (either in direction or in distance) to targets ranging from 4 m to 12 m away. Yet under precisely the same viewing conditions, observers exhibited very substantial errors in the perception of exocentric distance.[6] In this task, observers were shown four targets on the ground. The distance from the targets to the observers ranged from 4 m to 12 m. As depicted in Figure 3, two of the targets defined a spatial interval lying in a frontoparallel plane (the plane perpendicular to the line of sight that passes through the center of the spatial interval). The other two targets defined a spatial interval in depth (sagittal plane). From the observers' vantage point, the targets de-

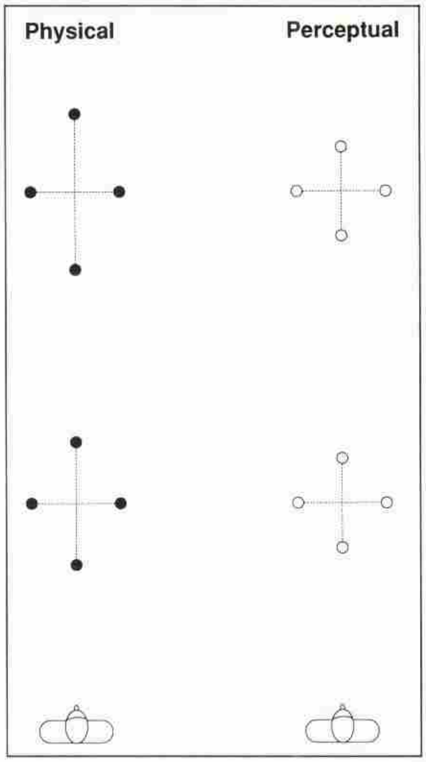

Fig. 3. Depiction of the results of a task in which the sagittal (depth) interval defined by two targets on the ground was adjusted so that it perceptually matched a frontoparallel interval defined by two other targets on the ground. The panel on the left represents two configurations of four such points, one configuration being closer to the observer than the other. The panel on the right represents the corresponding perceptual configurations. In order for the perceptual configurations to appear as squares (with the perceived sagittal intervals equal to the perceived frontoparallel intervals), the corresponding physical sagittal intervals (on the left) need to be made larger than the frontoparallel intervals. The degree of this perceptual distortion increases with distance of the configuration from the observer.

fined a quadrilateral. By means of instructions to the experimenter, each observer adjusted the exocentric distance between the two targets in the sagittal plane until the observer felt that this distance was objectively equal to the exocentric distance between the two targets in the frontoparallel plane (thus creating what the observer believed to be a square shape). Observers consistently made the sagittal interval 50% to 90% larger than the frontoparallel interval (see Fig. 3) in performing the match, implying that had the frontoparallel and sagittal intervals been physically equal, the frontoparallel interval would have appeared much larger. The degree of perceptual distortion increased with distance, and increasingly larger sagittal intervals were needed to create figures that were perceived as squares.

On the one hand, the triangulation and visually directed walking tasks strongly suggest that target location is perceived without systematic error under full-cue conditions. On the other hand, there is clear systematic error in the perception of exocentric distance under the same viewing conditions. The implication is that the perception of exocentric distance is to some extent dissociated from the perception of location.[7] Indeed, when asked to mark the endpoints of a spatial interval by blindly walking to one endpoint and then proceeding to the other, observers showed no tendency to mark off a shorter distance for the interval lying in the sagittal plane than for a physically equal interval lying in the frontoparallel plane.[6] We concluded then that observers directed their walking to locations in space without considering explicitly the intervals defined by these locations; that is, observers do not represent the task as one of walking to the location of the first target and then walking an additional distance specified by the perceived exocentric interval.

There is additional evidence for this putative dissociation between perceived location and perceived exocentric distance. Using visually directed walking to targets on the floor and visually directed pointing to targets on a tabletop, we[8] found that the perceived location of a single target viewed under normal room lighting was the same whether viewing was monocular or binocular. Yet when the observer's task was to match the sagittal interval defined by two such targets to that of the frontoparallel interval defined by two targets, binocular viewing led to substantially more veridical performance than did monocular viewing, indicating that the depth intervals were perceived differently under the two conditions. It appears that although introducing binocular disparity increases the veridicality of perceived exocentric distance, binocular disparity and convergence exert no discernible influence on the perceived locations of targets that are already well specified by monocular cues of egocentric distance.[9]

This dissociation between perceived location and perceived exocentric distance is of fundamental importance. For one thing, it makes intelligible the accuracy with which people can act despite systematic distortion of exocentric distances. The usual way of explaining the accuracy and precision of human action despite distortions in visual space is to argue that continuously available optical flow information allows for the accurate control of action without the explicit need for metric information about distance. Yet the accurate performance of visually directed action under full-cue conditions does not depend on optical flow information during the action, for the observer moves with eyes closed. Thus, accurate metric information about location must be available to the observer from the initial vantage point.

Another implication of this dissociation is that one must be cautious in using judgments of perceived exocentric distance to draw conclusions about perceived egocentric distance, and vice versa. Gilinsky[10] attempted to do just that with her method of "equal appearing intervals." The observer's task was to set a succession of physical depth intervals on the horizontal ground surface using interval matching; as egocentric distance increased, each successive interval had to be made physically larger than the preceding one in order to appear perceptually equal. Gilinsky then constructed a scale of perceived egocentric distance by associating with each successive number of equal-appearing intervals the summed distance of the corresponding physical intervals; Gilinsky interpreted the resulting hyperbolic function to mean that perceived distance is a nonlinear function of physical distance. If perceived exocentric distance is not fully constrained by the perceived locations of the interval endpoints, this method of scale construction is thrown into question. Indeed, our results indicate that perceived egocentric distance is much more nearly linear over distances ranging from 0 m to 20 m than Gilinsky's hyperbolic function suggests.

SUMMARY

Research with visually directed action under both full-cue and reduced-cue viewing conditions strongly suggests that observers respond to the initially perceived target location. When there is an abundance of visual distance cues, observers respond on average to a location that is quite close to that of the physical target location, implying that the mean perceived target location is nearly coincident with the target. This finding means that perceived egocentric distance is quite accurate under full cues for the range of distances studied. When visual cues to distance are diminished, observers make systematic errors in their visually directed responding. When the target is closer than 2 m, they tend to respond to a more distant location, indicating that the perceived location is more distant; when the target is farther than 3 m, they tend to respond to a nearer location, indicating that the perceived location is closer.

Under the same viewing conditions that lead to accurate visually directed action, observers exhibit systematic errors in perceiving exocentric distances. We conclude that perceiving two locations without systematic error does not imply that the exocentric distance between them is perceived without systematic error. Further evidence of a dissociation between perceived location and perceived exocentric distance is provided by comparing monocular and binocular viewing. Whereas perceived location does not vary with the introduction of binocular cues (when monocular cues are sufficient for localization), perceived exocentric distance improves with the addition of binocular disparity.

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6. Loomis, Da Silva, Fujita, and Fukusima, note 3.

7. Loomis, Da Silva, Fujita, and Fukusima, note 3. For other results supporting a dissociation between perceived location and perceived exocentric distance, see R.A. Abrams and J.Z. Landgraf, Differential use of distance and location information for spatial localization, *Perception & Psychophysics, 47*, 349–359 (1990). Other researchers have found evidence of a different type of dissociation, namely, one between conscious perception and action. See B. Bridgeman, M. Kirch, and A. Sperling, Segregation of cognitive and motor aspects of visual function using induced motion, *Perception & Psychophysics, 29*, 336–342 (1981); M.A. Goodale and A.D. Milner, Separate visual pathways for perception and action, *Trends in Neuroscience, 15*, 20–25 (1992).

8. J.M. Loomis and J.W. Philbeck, *Distortion of visual space under full cues is not scale invariant*, paper presented at the annual meeting of the Psychonomic Society, St. Louis, MO (November 1994).

9. Binocular convergence is an egocentric distance cue that derives from the relative pointing directions of the two eyes. Binocular disparity is an exocentric distance cue and refers to the difference in the angular sizes of the left- and right-eye retinal images, both of which correspond to a single interval in three-dimensional space.

10. Gilinsky, note 1.

Violence Against Stepchildren

Martin Daly and Margo I. Wilson

On February 20th, 1992, 2-year-old Scott M. died in a Montreal hospital of massive internal injuries caused by one or more abdominal blows. At the manslaughter trial of his mother's 24-year-old live-in boyfriend, doctors testified that Scott's body displayed "all the symptoms of a battered child," mainly because of "numerous bruises of varying ages." The accused, who portrayed himself as Scott's primary caretaker, admitted assaulting the mother and other adults, but "I don't hurt kids." According to an acquaintance, however, the accused had admitted striking the child with his elbow because Scott was "bothering him while he was trying to watch television." The trial outcome was conviction.[1]

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