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The processing of linear perspective and binocular information for action and perception ☆

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Abstract

To investigate the processing of linear perspective and binocular information for action and for the perceptual judgment of depth, we presented viewers with an actual Ames trapezoidal window. The display, when presented perpendicular to the line of sight, provided perspective information for a rectangular window slanted in depth, while binocular information specified a planar surface in the fronto-parallel plane. We compared pointing towards the display-edges with perceptual judgment of their positions in depth as the display orientation was varied under monocular and binocular view. On monocular trials, pointing and depth judgment were based on the perspective information and failed to respond accurately to changes in display orientation because pictorial information did not vary sufficiently to specify the small differences in orientation. For binocular trials, pointing was based on binocular information and precisely matched the changes in display orientation whereas depth judgment was short of such adjustment and based upon both binocular and perspective-specified slant information. The finding, that on binocular trials pointing was considerably less responsive to the illusion than perceptual judgment, supports an account of two separate processing streams in the human visual system, a ventral pathway involved in object recognition and a dorsal pathway that produces visual information for the control of actions. Previously, similar differences between perception and action were explained by an alternate explanation, that is, viewers selectively attend to different parts of a display in the two tasks. The finding that under monocular view participants responded to perspective information in both the action and the perception task rules out the attention-based argument.
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1. Introduction

Findings from macaque neurophysiology and human neuropsychology have long argued for the existence of two separate pathways in the visual system, a dorsal pathway for encoding spatial location and a ventral pathway involved in object recognition (Ungerleider & Mishkin, 1982). Goodale and Milner (1992) suggested that the dorsal visual stream processes information for rapid and accurate action in space while the ventral stream generates visual representations and serves slower cognitive functions which require recognition. In the past decade, Goodale and his colleagues demonstrated that tasks requiring rapid actions produce smaller effects of visual illusions dependent on relational information than do perceptual tasks which ask participants to report their experience.

In a much cited study Aglioti, DeSouza, & Goodale (1995) employed the Ebbinghaus or Titchener illusion, a size-contrast illusion which includes two circles of equal size surrounded by a circular array of smaller or larger circles. Those researchers compared the opening between the fingers of a grasping hand toward the target disc with judgment of its size relative to a comparison disc. Grasping aperture was little affected by the surrounding circles, but size perception was strongly affected, consistent with the two-visual-pathways account. Others have found similar results using variations on this task (for a review see Carey, 2001).

☆ Study was carried out at the Institute of Child Development and the School of Kinesiology at the University of Minnesota.

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The two-visual-pathways explanation for the Aglioti et al. findings has been challenged by several groups of researchers who have suggested an alternate explanation. In the present paper we address the argument that the tasks are confounded with respect to the different attentional demands of the perception and action tasks (Bruno, 2001; Franz, Gegenfurtner, Bülthoff, & Fahle, 2000; Vishton, Rea, Cutting, & Nunez, 1999). We refer to this as the *attentional explanation*.

Franz et al. (2000) reasoned that participants who are asked to adjust the size of the target disc in the Ebbinghaus display attend to the smaller circles surrounding it, as well as to the larger circles surrounding the comparison disc. In contrast, when asked to grasp the target disc, they attend only to that disc and neglect the comparison disc and the circles surrounding it. They demonstrated that the dissociation between tasks ceased to exist when they removed display elements to which participants did not attend in the action task. Conversely, Vishton et al. (1999) demonstrated that, for the horizontal–vertical illusion, a similar dissociation ceased to exist when the action task was altered so attention to all display elements was required.

Bruno (2001) has argued that the tasks in the study by Aglioti et al. are confounded with respect to the frame of reference in which the tasks are performed. Action requires an egocentric frame of reference because the aperture of a grasp is programmed with reference to object properties such as its size relative to the body. In contrast, the perception task demanding size judgment relative to its surroundings is performed in an allocentric frame of reference. Bruno's analysis suggested that perception-based responses might be less affected by illusions when task requirements emphasize an egocentric frame of reference.

The present study addresses these attention-based challenges by examining the processing of linear perspective and binocular information (binocular disparity and angle of convergence) in perception and action. We investigated whether the action of pointing to the edges of an object appearing to be slanted in depth is less influenced by a perspective depth illusion than is the perception of the position of the object's edges in depth. Although both tasks directed the participants' attention to the edges of the object, participants had more time to look at the perspective depth illusion parts of the object in the perception task than in the action task. To control for this confound, a monocular presentation condition was added to establish a baseline comparing task performance. If the action task allows for less time to look at the whole object and reduces responsiveness to the perspective depth illusion, this difference should also be present when the display is viewed with one eye.

Our display was an actual static Ames trapezoidal window and was not an image presented on a computer monitor (Fig. 1A). The pictorial information it generated, when presented in the fronto-parallel plane, specifies a rectangular window slanted in depth at about 45°. In contrast, motion parallax and binocular information specify a display at a 0° slant. In addition, in a region of a low slant, binocular information is sufficiently informative to allow viewers to detect small differences in orientation whereas pictorial information provides less specificity (Hillis, Watt, Landy, & Banks, 2004; Knill, 1998). The current experiment is designed to exploit this difference in information for orientation provided by binocular and pictorial input.

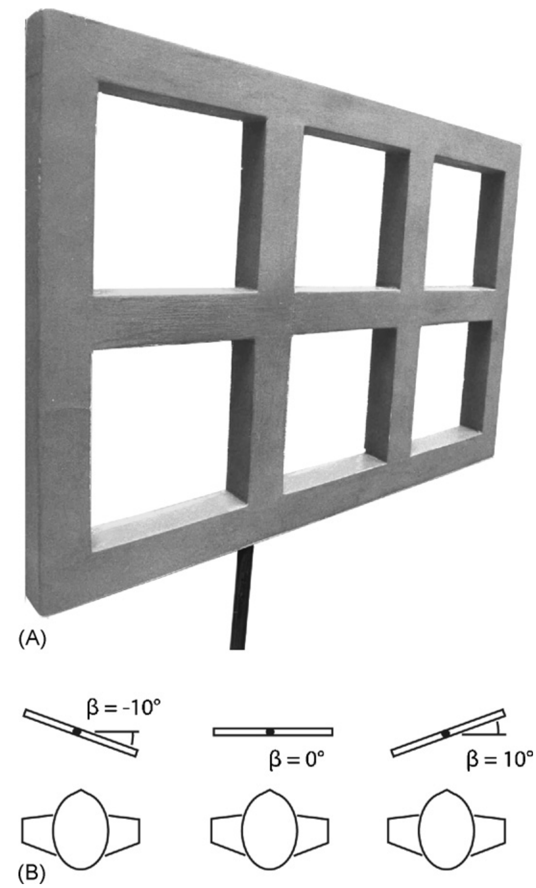

Fig. 1. (A) The static version of an Ames trapezoidal window as used for this experiment. (B) The three orientations of the display in relation to the observer. The angle β indicates physical slant of the display with respect to the viewer's fronto-parallel plane.

According to the two-visual-pathways account, spatial information for perception is primarily processed in the ventral pathway and is sensitive to perspective information, requiring the recognition of a visual pattern. In contrast, spatial information for the control of rapid action is processed in the dorsal pathway, which is especially sensitive to accurate binocular information for the egocentric distance to the right and left sides of a display. Thus, on action trials binocular information dominates and pointing should match the actual orientation of the display. In contrast, in the perceptual judgment trials, because pictorial information influences perception, the fronto-parallel trapezoidal window should be experienced as slanted in depth. In addition, when the orientation of the window is varied, depth judgment should be less responsive to the substantial changes in binocular information.

In summary, we predicted that when presented to only one eye, both action and perception tasks would show responsiveness to the linear perspective of the trapezoidal window. On the other hand, when the display is viewed with two eyes, compared to perception, action should be more sensitive to the actual slant of the display and less sensitive to linear perspective. Moreover, action should respond accurately to small changes in display