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Aging and the visual perception of exocentric distance

J. Farley Norman *, Olivia C. Adkins, Hideko F. Norman, Andrea G. Cox, Connor E. Rogers

Department of Psychological Sciences, Ogden College of Science and Engineering, Western Kentucky University, Bowling Green, KY 42101-2030, United States

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ABSTRACT

The ability of 18 younger and older adults to visually perceive exocentric distances was evaluated. The observers judged the extent of fronto-parallel and in-depth spatial intervals at a variety of viewing distances from 50 cm to 164.3 cm. Most of the observers perceived in-depth intervals to be significantly smaller than fronto-parallel intervals, a finding that is consistent with previous studies. While none of the individual observers' judgments of exocentric distance were accurate, the judgments of the older observers were significantly more accurate than those of the younger observers. The precision of the observers' judgments across repeated trials, however, was not affected by age. The results demonstrate that increases in age can produce significant improvements in the visual ability to perceive the magnitude of exocentric distances.

1. Introduction

Decades of research have conclusively demonstrated that human observers' perceptions of distance and spatial relationships are inaccurate. One frequent finding is that distances in depth (i.e., along an observer's line of sight) are compressed and appear smaller than equivalent fronto-parallel distances (Baird & Biersdorf, 1967; Gilinsky, 1951; He et al., 2004; Heine, 1900; Loomis et al., 1992; Loomis & Philbeck, 1999; Norman et al., 2005, 1996; Thouless, 1931; Wagner, 1985). Other research has frequently found that visual space is curved (e.g., Blank, 1961; Higashiyama, 1981). Over small areas, perceived distances and angles typically indicate that visual space is positively curved[1] (*elliptic*), while over larger areas, visual space is negatively curved (*hyperbolic*) (Battro, Netto, & Rozestraten, 1976; Koenderink, van Doorn, & Lappin, 2000; Norman et al., 2005). In contrast, Foley, Ribeiro-Filho, and Da Silva (2004) found that their observers' judgments of distance could not be explained by any metric geometry (i.e., neither Euclidean, affine, elliptic, nor hyperbolic). Finally, human observers' judgments of distance are task-dependent. In the study by Norman et al. (2005), for example, three observers' binocular judgments were consistent with Euclidean geometry when they adjusted three points in space (outdoors, in a grassy field) to form a perceived equilateral triangle. Those same observers' perceptions of distances became affinely compressed in depth when the task was changed to match in-depth and fronto-parallel intervals. This indicates that there is no single relationship between physical space and perceived space, even for single individuals (cf, Koenderink, 2001).

In 2013, Bian and Andersen reported a surprising finding. In their experiments, older and younger adults judged large egocentric distances in depth (4–12 m) outdoors. The younger observers (average age was 22.8 years) underestimated the egocentric depth intervals, consistent with much of the literature (e.g., Gilinsky, 1951; Loomis & Philbeck, 1999; Loomis et al., 1992; Norman et al., 2005; Wagner, 1985). The older observers (average age was 70.2 years), however, were consistently accurate in their egocentric depth judgments. Increases in age apparently produce improvements in egocentric distance perception (e.g., see Bian & Andersen's Figs. 2, 4, 6 and 8). This is a striking and unanticipated result. It is certainly not clear at present whether this age-associated improvement in distance perception is a general phenomenon or whether this improvement is limited to particular situations. The purpose of the current study was to further investigate distance perception in older and younger adults – do older adults, for example, accurately perceive *exocentric* distances in depth (as opposed to the egocentric distances examined by Bian & Andersen)? In addition, does the accurate performance of older adults generalize to the perception of smaller depth intervals that are prevalent in near to medium visual space? The purpose of the current experiment was to answer such questions.

2. Method

2.1. Apparatus and Stimulus displays

The endpoints of the spatial intervals to be judged on any given trial were marked by green light-emitting diodes (LED's). The

* Corresponding author.
E-mail address: Farley.Norman@wku.edu (J.F. Norman).

[1] For an enjoyable discussion of curved (Non-Euclidean) spaces, see Rucker (1977).

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spatial configuration of the horizontal intervals (i.e., possessed fronto-parallel orientations) and in-depth intervals was exactly the same as that used in Experiment 4 of Norman et al. (1996). The LED's were embedded in a surface made from a patterned sheet. Normal indoor levels of illumination were provided by flourescent light fixtures on the laboratory ceiling. The observers binocularly viewed the spatial configuration (their eye height was 15 cm above the plane of the LED's; the same eye height was used by Norman et al., 1996). In addition, the observers were allowed to make ordinary head movements, thus generating retinal motion parallax. Given ample overhead lighting (generating patterns of shading on the surface within which the LED's were mounted), the textured pattern of the viewed surface (generating binocular disparities and texture gradients), and the availability of motion parallax, the viewing conditions were full-cue. Many simultaneous optical sources of information were present to define the 3-dimensional (3-D) structure of the viewed scene and depicted spatial intervals. A photograph of the stimulus scene from the observers' approximate point of view is presented in Fig. 1 (the position of the camera used to create Fig. 1 is higher than the eye height actually used in the experiment so that readers can better see the spatial arrangement of the LED's on the supporting surface). Fig. 2 presents an overhead view of the horizontal and in-depth intervals that were judged by the observers. The nearest horizontal and in-depth intervals were located at a 50 cm viewing distance from the observers, while the farthest intervals were located at a viewing distance of 164.3 cm.

2.2. Procedure

The procedure was identical to that used by Norman et al. (1996) (also see Norman, Lappin, & Norman, 2000; Norman et al., 2004b). The LED's defining the spatial extents or distances to be judged were controlled by a Dell Dimension XPS T450 computer using a Data Translation DT-335 Digital Output Board. On every trial, the computer would highlight a pair of LED's and the observer would be asked to adjust the length of a line segment presented on a 22-inch Mitsubishi Diamond Plus 200 monitor (located at a distance of 185 cm) until its length matched the distance between the 2 highlighted LED's. The observers adjusted the length of the line segment displayed on the monitor by pressing the up and down arrow keys on the computer keyboard; the adjustable line segment displayed on the monitor always remained in the same oblique orientation no matter whether an observer was judging horizontal or in-depth spatial extents. There were a total of 11 horizontal (fronto-parallel) intervals and 11 in-depth intervals (as shown in Fig. 2). Each of the 11 horizontal intervals was approximately matched in terms of viewing distance with an in-depth interval (i.e., they were located at the same distance in depth from the observers; e.g., intervals 1 & 2, 9 & 10, 22 & 23, etc). Each observer judged all of the 22 stimulus lengths (presented in a random order) 5 times in a single experimental session. Because of these repeated judgments, we could measure our observers' precision as well as their accuracy; in the seminal study by Bian and Andersen (2013), they evaluated accuracy, but were unable to evaluate the precision of their observers' estimations of egocentric distance. The observers were given no feedback about performance during their experimental session.

2.3. Observers

There were a total of 18 observers. Nine of the observers were older adults (mean age was 74.9 years, sd = 3.5, range was 69–80 years), while the remaining nine were younger adults (mean age was 21.2 years, sd = 1.6, range was 19–24 years). All observers gave written consent prior to participation in the experiment. The experiment was approved by the Western Kentucky University Institutional Review Board. Our research was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). Two of the younger observers were student coauthors (OCA & AGC) who had never before participated in an experiment evaluating the perception of distances in depth.

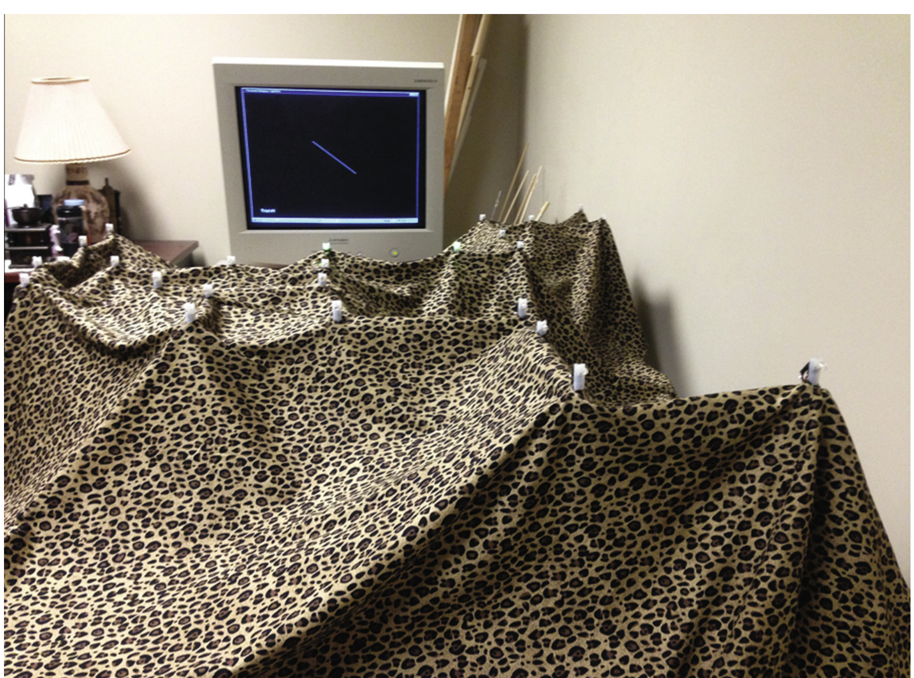

Fig. 1. A photograph of the horizontal and in-depth spatial intervals used as stimuli in the experiment. The endpoints of the spatial intervals that were judged are marked by light-emitting diodes (LED's), which were embedded within a textured surface. The adjustable line segment used in the matching task is visible on the computer monitor located behind the textured stimulus surface.