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Aging and the visual perception of exocentric distance

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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

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[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.

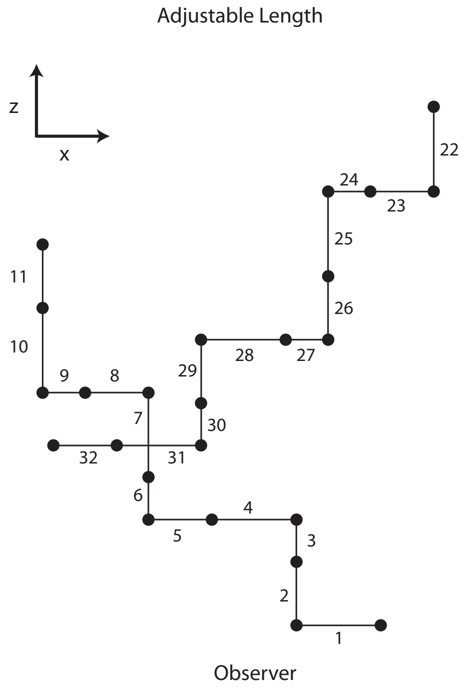

Fig. 2. A schematic illustration of a top view of the configuration of 24 LED's used to define the spatial intervals judged in the current experiment (the same spatial arrangement of LED's was used in a previous experiment by Norman et al., 1996). Each stimulus interval was identified by number (from 1–11 & 22–32; intervals 12–21 correspond to obliquely-oriented intervals used in the experiment of Norman et al. (1996), and were not investigated in the current study). The locations of the observers and the adjustable lengths used in the distance matching task are shown relative to the horizontal and in-depth spatial intervals.

All other observers were naive. Both the younger and older observers had good visual acuity (acuity of younger and older observers measured at 1 meter was −0.089 and 0.044 LogMAR, respectively). All except two of the older observers (observers 1 & 2) had good stereoscopic vision and could readily identify and describe the shape of 3-D surfaces depicted by random-dot stereograms (i.e., could identify the same 3-D surfaces used by Norman et al., 2012). There shouldn't necessarily be any difference in results between the two stereoblind older observers (who could make head movements to generate motion parallax) and the other older adults in the current experiment, because it has been repeatedly shown that motion and binocular disparity are equally effective in providing 3-D information about environmental distances, surfaces, and objects (e.g., Norman & Raines, 2002; Norman, Todd, & Phillips, 1995; Rogers & Graham, 1982).

3. Results

The overall results are shown in Fig. 3; results concerning accuracy are presented in the left panel, while the precision (i.e., reliability) of the observers' repeated judgments for single lengths is shown in the right panel. In the left panel, adjusted (estimated) lengths as a proportion of the actual physical lengths are plotted for both the horizontal and in-depth intervals; a ratio of 1.0 indicates perfectly accurate length estimation. It is readily apparent from an inspection of the figure that the older observers' estimates of length were considerably more accurate than those of the younger observers ($F(1,16) = 6.9$, $p < .02$; $\eta^2_p = 0.30$). There was also a significant main effect of interval type, such that the length of horizontal intervals was perceived more accurately than the length of in-depth intervals ($F(1,16) = 39.7$, $p < .00002$; $\eta^2_p = 0.71$). The interaction between age and interval type was also significant ($F(1,16) = 10.5$, $p = .005$, $\eta^2_p = 0.40$): the improvement associated with increasing age was larger for the in-depth intervals and smaller for the horizontal intervals.

The younger and older observers' individual results are shown in Figs. 4 and 5, respectively. In interpreting the results of Figs. 4 and 5, it is helpful to discuss the earlier findings of a similar experiment (Experiment 4 of Norman et al., 1996). In this previous experiment, conducted with the same stimulus configuration, the observers' perceived extents of the horizontal intervals *increased* with increasing viewing distance (distance from observer to stimulus interval), while the perceived extents of the in-depth intervals *decreased* with increasing viewing distance. The results of a substantial proportion of the observers in the current experiment followed a similar pattern; for example, see results for observers 2, 3, and 6 (older adults) and observers 11, OCA, and AGC (younger adults). The judgments of a majority of the current observers (11 out of 18, 61.1 percent) were significantly correlated with viewing distance. Regardless of whether any particular observer's judgments were significantly correlated with viewing distance, almost

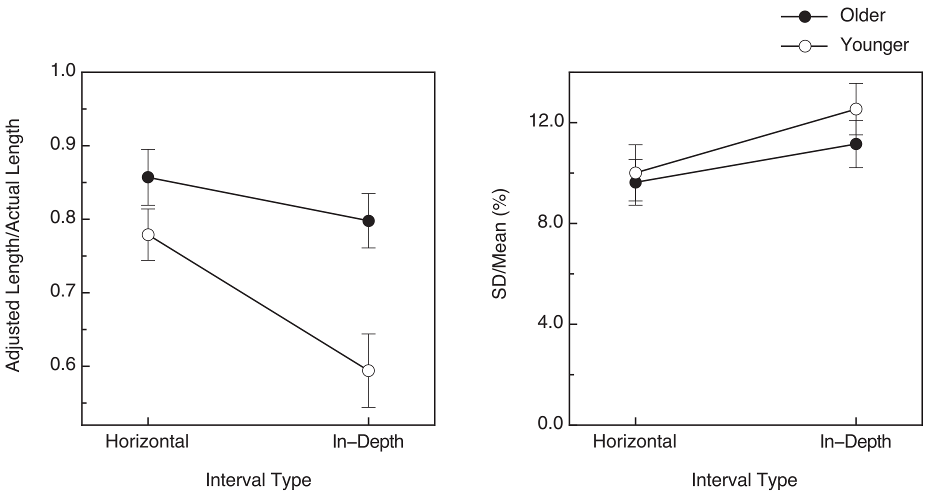

Fig. 3. The accuracy and precision of the observers' distance judgments are plotted in the left and right panels, respectively. The older observers' judgments are indicated by the filled circles, while the analogous judgments of the younger observers are indicated by the open circles. Perfectly accurate judgments would be indicated by a ratio of 1.0 (left panel). The precision (right panel) of the judgments is expressed as the standard deviation of an observer's repeated judgments divided by the mean (of those same judgments). The error bars indicate ± 1 SE.

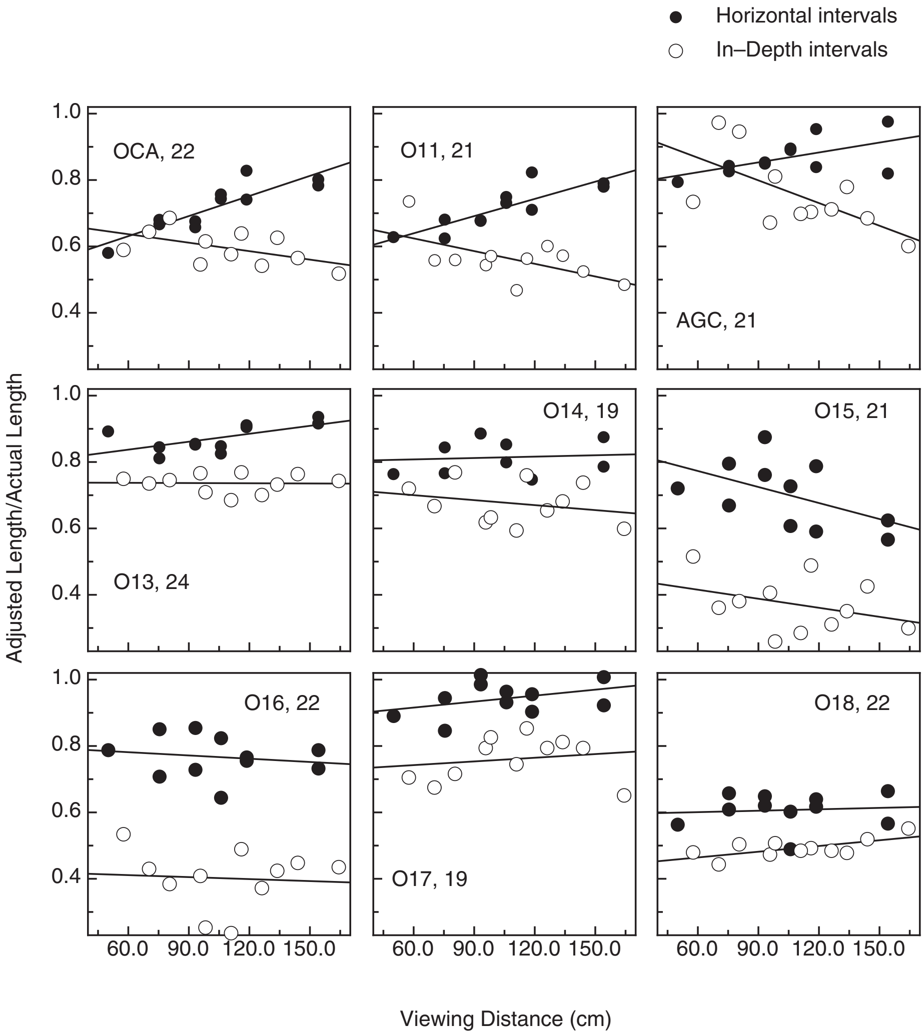

Fig. 4. Individual results for the younger observers. The adjusted/actual length ratios are plotted as a function of the distance between the observer and each stimulus interval (viewing distance). The filled circles indicate results obtained for the horizontal intervals, while the open circles indicate results obtained for the in-depth intervals. The best-fitting regression lines for the horizontal and in-depth intervals are also plotted for each observer. The ages (in years) of the individual younger observers (observers 10–18) are indicated for each plot.

all of the observers perceived the horizontal intervals to be longer than the in-depth intervals at farther viewing distances.

The precision (i.e., reliability) of the observers' repeated estimates of the length of the horizontal and in-depth intervals is shown in the right panel of Fig. 3. Unlike the results concerning accuracy, there was no significant effect of age upon the precision of the observers' judgments of distance ($F(1,16) = 0.4$, $p = .53$; $\eta_p^2 = 0.03$). However, there was a significant effect of the interval type (horizontal vs. in-depth intervals; $F(1,16) = 33.5$, $p < .00005$, $\eta_p^2 = 0.68$) such that the observers' judgments were more precise and reliable for the horizontal intervals.

4. Discussion

In the current experiment, younger and older observers viewed exocentric intervals in actual physical space and judged their extents. The results obtained for the younger adults showed that the perceived length of any given extent depended strongly upon its orientation in space – in-depth intervals, on average, were perceived to be substantially shorter than physically-equivalent horizontal intervals (e.g., see Fig. 4 and the open circle results in the left panel of Fig. 3). These results indicate that younger observers' near space is subject to affine compressions along the line of sight, a finding that is similar to those of previous studies (e.g., Baird & Biersdorf, 1967; Heine, 1900; Norman et al., 1996; Thouless, 1931). The overall pattern of results exhibited by the older observers was different. While it is true that the in-depth intervals were perceptually compressed (relative to the horizontal intervals) for the majority of the older observers at farther viewing distances (e.g., at 100–160 cm, see Fig. 5), the overall amount of compression was small (see left panel of Fig. 3, filled circles). For example, whereas the younger observers perceived the in-depth intervals to be only 59.4 percent of their actual length, the older observers perceived them to be 79.8 percent of their actual length – the older observers' perceptions of the in-depth intervals were much more accurate. The current results thus demonstrate that the geometry of visual space is significantly affected by increases in age. While the affine compression of in-depth intervals relative to horizontal intervals is quite large for younger adults, it is minimal for older adults (compare filled and open circles, left panel of Fig. 3).

The results of our experiment are both similar to, and different from, the large-scale outdoor experiments conducted by Bian and Andersen (2013). In their study, younger and older adults estimated egocentric distances in depth. These distances ranged from 4 m to 12 m. Their observers made estimates of viewed egocentric

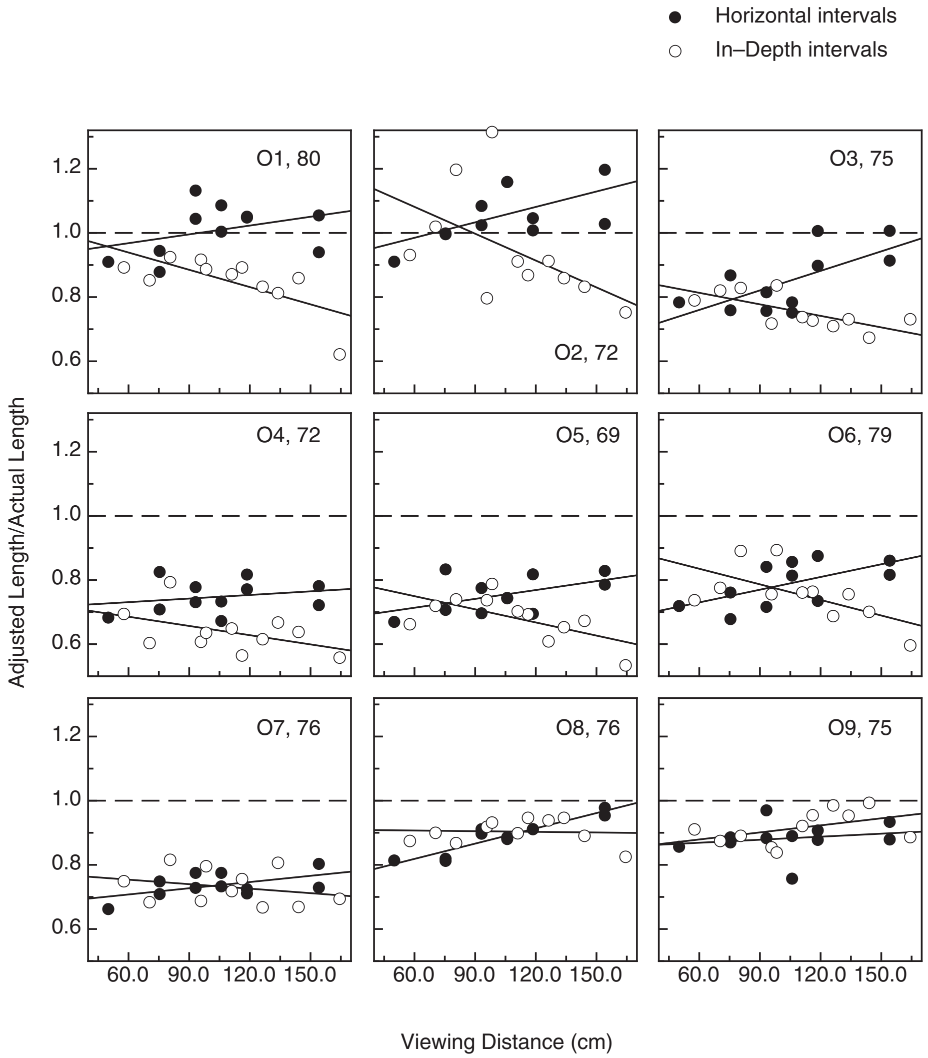

Fig. 5. Individual results for the older observers. The adjusted/actual length ratios are plotted as a function of the viewing distance. The filled circles indicate results obtained for the horizontal intervals, while the open circles indicate results obtained for the in-depth intervals. The best-fitting regression lines for the horizontal and in-depth intervals are also plotted for each observer. Accurate performance is indicated by the dashed line. The ages (in years) of the individual older observers (observers 1–9) are indicated for each plot.

depth either by verbal report or through the use of an action measure (blind rope pulling). Bian and Andersen consistently found the judgments of older adults to be remarkably accurate – e.g., when older adults viewed a target 10 m from themselves, they accurately judged that the target was located at a 10 m distance. Such accurate estimation of distances did not occur for the older adults in our experiment. While it is true that the older observers in the current experiment performed more accurately than the younger observers (see left panel of Fig. 3), their performance was nevertheless inaccurate (in absolute terms), with adjusted length/actual length ratios considerably smaller than 1.0. There are three significant differences between the current study and that of Bian and Andersen: (1) our study evaluated the perception of small distances (10–20 cm in extent) located in near visual space, while their study evaluated much larger extents (4–12 m), (2) our study required observers to judge *exocentric* spatial intervals, whereas their task required the judgement of *egocentric* intervals, and (3) our study employed a visual matching task, whereas their observers either made verbal estimates or used blind rope pulling to make their judgments of distance. Any of these differences could potentially be responsible for the difference in outcomes.

A primary finding of the current experiment is that older adults are more accurate than younger adults in their estimations of exocentric distance. The finding that older adults perceive environmental distances more accurately than younger adults is somewhat surprising, because most studies investigating aging and perception have either found no difference between the abilities of younger and older adults (e.g., McIntosh et al., 1999; Norman, Holmin, & Bartholomew, 2011) or found negative effects of increasing age (e.g., Andersen & Atchley, 1995; Betts, Sekuler, & Bennett, 2007; Norman et al., 2003, 2013; Sekuler, Hutman, & Owsley, 1980; Snowden & Kavanagh, 2006). The explanation of why older adults are more accurate in their judgments of distance is certainly not obvious at this point. Older adults' stereoscopic vision is no better than younger adults (e.g., Norman et al., 2012) – binocular vision did not even make a difference in the current exocentric distance estimation task (e.g., the pattern of results for the stereoblind older adults, observers O1 & O2, was essentially equivalent to other observers, such as O3, O11, OCA, & AGC, who do possess effective stereopsis). Our own laboratory has shown that older and younger adults perceive identical extents in depth from patterns of motion parallax (Norman et al., 2004a). In addition, we have shown that older and younger adults can both effectively utilize texture gradients (Norman et al., 2009). In short, as far as we are aware, there is no type of optical information to support the perception of environmental distances which older adults can utilize more effectively than younger adults (thus there is no optical reason for this age-related superiority).

One potential explanation for the age-related superiority in accuracy for the distance judgments obtained in the current experiment (e.g., see left panel of Fig. 3) involves the inhibitory neurotransmitter GABA (gamma-aminobutyric acid). GABA agonists, such as baclofen and muscimol, are known to impair performance on spatial tasks (i.e., tasks requiring perception of spatial position; Brioni et al., 1990; Deng et al., 2009; also see Terunuma et al., 2014). GABA antagonists, in comparison, facilitate performance for spatial tasks (Froestl et al., 2004; Helm et al., 2005; Mondadori, Jaekel, & Preiswerk, 1993). This research demonstrates that increased activity at GABA receptors impairs performance on tasks requiring the perception of spatial information, while decreased activity at GABA receptors facilitates performance. The effects of aging are interesting, because increases in age are known to result in lowered GABA activity in visual cortex (e.g., Leventhal et al., 2003; Schmolesky et al., 2000; Yang et al., 2009). Thus, the consequences of aging (decreased GABA activity) are similar to the effects of a GABA antagonist applied to a younger animal. Our current finding of improved (i.e., more accurate) performance for older adults on a task requiring spatial perception may therefore not be surprising, given that reductions in GABA activity are known to facilitate performance on spatial tasks (e.g., Mondadori, Jaekel, & Preiswerk, 1993). Similar age-related improvements presumably caused by a reduction in GABA activity in visual cortex have occurred for tasks requiring visual motion discrimination (Betts et al., 2005). It is interesting that age-related changes in cortical functioning apparently lead not only to deficits in visual performance (e.g., Andersen & Ni, 2008; Norman et al., 2013), but also to enhancements, such as those found in the current study.

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