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Aging and the Perception of Egocentric Distance

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Abstract

The present study examined whether there was an age-related difference in judging egocentric distances. In 4 experiments both younger and older observers judged the physical distance of an object on a ground plane and reported their judgments by verbal report and by blind rope-pulling. Overall, we found that: (1) younger observers in general underestimated egocentric distance and showed foreshortening; (2) older observers judged more egocentric distance than younger observers and did not show foreshortening; (3) this age-related difference was not due to an age-related difference in scaling or output calibration (Experiment 2), the use of eye height information (Experiment 3), or the use of texture gradient information (Experiment 4). These results may be accounted for by differences in perceived slant of the ground surface or a greater reliance on pictorial cues with increased age.

An extensive body of research has found that many aspects of vision change with age. For instance, research has found age-related declines in processing sensory information, including visual acuity (Corso, 1981; Owsley & Sloane, 1990), contrast sensitivity at high spatial frequencies (Owsley, Sekuler & Siemsen, 1983), and useful field of view (Sekular & Ball, 1986). Age-related decrements in performance has also been found in perceptual tasks, including structure from motion (Andersen & Atchley, 1995; Norman Clayton, Shular & Thompson, 2004), perception of 2D coherent motion (Atchley & Andersen 1998; Gilmore, Wenk, Naylor & Stuve, 1992), and collision detection (Andersen, Cisneros, Saidpour & Atchley, 2000; Andersen & Enriquez, 2006; Delucia, Bleckley, Meyer & bush, 2003). These age-related changes in vision can have a profound effect on mobility and overall quality of life among the elderly (Wahl, Schilling, Oswald, & Heyl, 1999; Menz, Morris & Lord, 2005).

In the current study, we examined an important aspect of visual perception and aging that has, to our knowledge, not been examined – age-related difference in judging egocentric distance (the perceived distance between an observer and some location in the 3D world). Egocentric distance perception is important for tasks such as locomotion (i.e. estimating how far one needs to walk) and driving (i.e. maintaining a safe distance during car following). Egocentric distance perception is also important for recovering information regarding the layout of objects in a scene. Although studies have examined age-related differences in the perception of layout and relative distance (the distance between objects in a scene), the perception of egocentric distance has not been examined. Two types of tasks have been used to assess perceived egocentric distance: non-action based tasks and action-based tasks. Non-action based tasks include a verbal report in physical units (e.g. Foley, 1977; Gibson, Bergman & Purdy, 1955; Gogel, 1976, 1981; Gogel & Tietz, 1973; Rogers & Gogel, 1975), magnitude estimation in which observers judged the perceived distance of a target in units of a standard modulus (Galanter & Galanter, 1973; Baird & Biersdorf, 1967;

Da Silva, 1985), fractionation and ratio estimation (Blank, 1961; Purdy & Gibson, 1955), and equal appearing intervals (Collins, 1976; Gilinsky, 1951; Harway, 1963). An excellent review can be found at Da Silva (1985). Recent studies have used perceptual matching tasks in which observers either positioned themselves such that their distance from a pole matched the height of the pole (Durgin, et. al., 2012) or positioned themselves such that their distance from one of two experimenters matched the frontal separation between the two experimenters (Li, Philips, & Durgin, 2011). A typical finding using non-action based tasks is that observers tend to underestimate egocentric distance with the magnitude of underestimating increasing with target distance. This decrease in perceived distance with increased distance, or foreshortening, was used as evidence that visual space is not Euclidean even under full cue conditions (e.g. Gilinsky, 1951; Harway, 1963; Wagner, 1985). For instance, Gilinsky (1951) had observers successively set equivalently appearing depth intervals on a ground plane, and found that greater intervals were needed as distance increased. Other studies, however, found that observers were rather accurate in judging egocentric distances (Da Silva, 1985).

Action-based tasks usually include visually-directed actions with visual information available only before the action is initiated (Foley & Held, 1972; Loomis, Da Silva, Fujita & Fukusima, 1992). In these tasks, observers viewed the stimulus and then were blind-folded when making responses by action. It is assumed that the action is controlled by the visual representation of the physical space and any error is a reflection of the perceived visual space. A widely examined task is blind-walking (e.g. Creem-Regehr, Willemsen, Gooch & Thompson, 2005; Thomson, 1980; Elliott, 1986, 1987; Loomis et al 1992; Sinai, Ooi & He, 1998) and variations of blind-walking, such as blind-walking through triangulation and blind pointing while walking (Fukusima, Loomis & Da Silva, 1997; He et al, 2004). Some other studies have used tasks such as blind rope-pulling (Mershon, Kennedy & Falacara, 1977; Philbeck, Woods, Kontra & Zdenkova, 2010) and blind throwing (Sahm, Creem-Regehr, Thompson & Willemsen, 2005; Woods, Philbeck & Danoff, 2009). A general finding from visually-directed actions is that observers are accurate in judging egocentric distances. For instance, Loomis et al (1992) found that observers could walk blind-folded to targets 12 meters away without systematic errors.

The reason for the discrepancy between these two types of measures may be due to the two tasks being processed by different cortical streams (Milner & Goodale, 1995; 2008). Given that previous research has found different results using the two tasks we employed both types of tasks in the present study. Specifically, we used a verbal report of distance and blind rope pulling to assess age-related differences in egocentric distance perception. Our decision to use blind rope-pulling as compared to blind walking was based on the potential concern of falls for older observers. Thus, both tasks are relatively easy to administrate with low risk. Most importantly, blind rope pulling has been found to produce responses that were highly correlated with responses from the blind walking task under a variety of viewing conditions (Philbeck & Loomis, 1997; Philbeck et. al., 2010). Using two tasks allowed us to examine whether any age-related difference in judging egocentric distance was indeed a reflection of difference in the visual space. As proposed by Foley (1977) and Philbeck and Loomis (1997), the perceived distance of an object in a 3-D scene is determined by a combination of different optical variables (depth cues) and is an internal variable that can only be accessed indirectly through various measures. If different behavioral measures are driven by the same underlying variable of perceived distance, then we should observe tight covariation of these measures as depth cues are manipulated (Foley, 1977; Philbeck & Loomis, 1997). If this is the case, then any age-related difference in judging egocentric distances should be due to a difference in perceived visual space.

A review of research on aging and visual perception suggests two different patterns of results for egocentric distance judgments. Previous research has found age-related decrements in various perceptual tasks, suggesting that older adults, compared to younger adults, may use different depth cues or assign different weights to the depth cues to determine perceived egocentric distances of objects in a scene. For instance, Bian and Andersen (2008) found that older observers depend less on the information on the ground surface in determining layout in 3-D scenes as compared to younger observers. Given the importance of the ground surface in perceptual organization of scene layout (Bian, Braunstein & Andersen, 2005, 2006; Bian & Andersen, 2010; Gibson, 1950; He & Ooi, 2000; He et al, 2004; McCarley & He, 2000, 2001), one possible pattern of results is that older observers, as compared to younger observers, will have decreased accuracy in judging egocentric distance. On the other hand, recent studies have found that older observers preserve their ability in many perceptual tasks related to distance perception, such as judgment of distance on a frontal-parallel plane (Norman, Holmin & Bartholomew, 2011), judgments of slant (Norman, Crabtree, Bartholomew & Ferrell, 2009), depth from motion parallax (Norman et. al., 2004), and judgments of size (Kavsek & Granrud, 2012). Of particular relevance was that Norman et al (2004) found that older observers were as accurate as younger observers in judging the depth of a surface defined by motion parallax, suggesting that older observers may have a preserved ability to perceive and judge distance. If this is the case, then we would expect similar judgments of egocentric distance for younger and older observers.

In the present study we examined the perception of egocentric distance by presenting older and younger observers with real world scenes and asked each observer to estimate the distance to a target in the scene that varied in distance. To assess performance we recorded judged distance and assessed performance using two different measures. One measure was the average judged distance to the object calculated for each observer. This measure allowed us to assess overall age-related differences in distance perception. The other measure was the slope of perceived to actual distance. This measure allows us to determine whether there are age-related differences in the compression or foreshortening of visual space.

Experiment 1

The purpose of the first experiment was to examine differences in judged egocentric distance for younger and older observers. Observers viewed an object located at various distances in an outdoor scene (see Figure 1) and judged its physical distance using either verbal report or blind rope pulling. In addition, to assess the role of binocular information we required observers to make judgments using either both eyes (binocular) or with one eye (monocular).

Method

Observers—The observers were 8 undergraduate students (4 male and 4 female, age = 22.8 ± 2.4) from the University of California, Riverside, and 9 older observers (5 male and 4 female, age = 70.2 ± 4.9) from the Life Society Program at the university. All observers were paid for their participation, were naive regarding the purpose of the experiment, and had normal or corrected-to-normal visual acuity. All observers were also screened using several perceptual and cognitive tests. The tests included Snellen acuity, contrast sensitivity (assessed using the Pelli-Robson contrast sensitivity chart; Pelli, Robson & Wilkins, 1988), forward and backward digit span, perceptual encoding, and the Kaufman Brief Intelligence Test. Demographic information of the observers who participated in the current study and the results of the screening tests are presented in Table 1.

Stimuli—The stimulus was a red brick measured $0.21\text{m} \times 0.10\text{m} \times 0.07\text{m}$ positioned at various distances from the observer on a grassy field.

Design—The four-way mixed design included age as the between-subject variable and three within-subject variables: (1) physical distance of the object (4m, 6m, 8m, 10m, or 12m); (2) viewing condition (binocular vs. monocular); and (3) the task observers used to indicate their judgment (verbal report vs. blind rope pulling).

The viewing condition was blocked and run on two separate days. All observers completed the monocular condition first in order to prevent potential carryover effects. On each day, observers completed two tasks in separate blocks. The order of task was counterbalanced across observers in each age group.

Each physical distance of the object was repeated twice for each combination of viewing condition and task. The order of physical distance was randomized and the distance varied from trial to trial.

Apparatus—The experiment was conducted on a grass field with a dimension of $35\text{m} \times 34.5\text{m}$ on campus at University of California, Riverside (see Figure 1). A yard stick (0.91m) was used to mark the location where the observers should stand. An eye patch was used to cover observers' eyes in the monocular viewing condition. A black nylon rope (24.4m long and 0.2m in diameter) was used in the blind rope pulling task.

Procedure—The observers were walked to the experimental location and were seated while instructions were given. On each trial, an experimenter positioned the object at one of the five locations while the observers faced in the opposite direction. In order to prevent the observers from using the duration an object was positioned as a cue to the distance, the experimenter always walked to the furthest distance (12m) and positioned the object on the way back. Once the object was positioned and the experimenter out of the field of view, the observer turned around and viewed the object either binocularly or monocularly (with an eye patch covering the weaker eye). Their task was to judge the physical distance (Carlson, 1977) from their feet to the front surface of the object as if they were using a measuring tape to measure this distance. They were encouraged to scan the ground plane between the target and their feet back and forth (He et al, 2004; Wu, Ooi & He, 2004).

In the verbal report task, the observers reported their judgment either in a combination of foot and inch or in any other unit system of their choice. Throughout the study most observers chose to report in feet and inches. Two observers (one in Experiment 2 and in Experiment 3, respectively) chose to report in meters and centimeters. Once the observers made their responses they were instructed to face away from the object while experimenters set up the object at a different location for the next trial. In the blind rope pulling task, observers put on a mask covering both eyes and received one end of a rope from an experimenter. They were instructed to pull the rope little by little so that the length of the rope they pulled matched the physical distance between the observer and the front surface of the object. Once the observers were satisfied with their responses, they signaled the experimenters. The experimenters then took the rope and measured the length of the rope that was pulled. The observers turned away from the object, took off the mask and took a break while waiting for the next trial.

Three practice trials were conducted at a different location before each task. This served to familiarize the observers with the procedure of the task. Two experimental blocks with five trials in each block were then conducted. Observers completed both tasks in the monocular condition on day 1 and both tasks in the binocular condition on day 2. A brief break was

given between blocks and upon request. Feedback was not provided throughout the experiment.

Results and discussion

We examined two dependent variables: mean judged distance and slope of judged distance as a function of physical distance. Each of them was then analyzed in a 2 (age group) by 2 (task) by 2 (viewing condition) by 5 (physical distance of the object) mixed analysis of variance (ANOVA).

Mean judged distance—For mean judged distance, we found a significant main effect of age ($F(1, 15) = 25.36, p < .01, \text{partial } \eta^2 = 0.64$), a significant main effect of physical distance ($F(4, 60) = 232.45, p < .01, \text{partial } \eta^2 = 0.94$) and a significant interaction between age and physical distance ($F(4, 60) = 15.69, p < .01, \text{partial } \eta^2 = 0.53$). According to this result, older observers judged greater distance than younger observers at 4m ($F(1, 15) = 17.08, p < .01, \text{partial } \eta^2 = 0.56$), 6m ($F(1, 15) = 27.58, p < .01, \text{partial } \eta^2 = 0.66$), 8m ($F(1, 15) = 25.18, p < .01, \text{partial } \eta^2 = 0.63$), 10m ($F(1, 15) = 25.06, p < .01, \text{partial } \eta^2 = 0.62$), and 12m ($F(1, 15) = 20.48, p < .01, \text{partial } \eta^2 = 0.61$), respectively (see Figure 2). There was no significant main effect of task ($F(1, 15) < 1, p > .05$) or viewing condition ($F(1, 15) = 2.44, p = .14$). No other interactions reached significance ($p > .05$). An important question is whether this age-related difference in egocentric distance judgment reflected an age-related difference in perceived egocentric distance or merely an age-related difference in response calibration. As discussed previously, one way to examine this issue is to examine whether the responses from two different tasks demonstrate tight covariation as depth cues were manipulated (Philbeck & Loomis, 1997). To examine this issue we examined the correlation of distance estimates based on the monocular and binocular viewing as well as the type of judgment. As shown in Figure 3, responses from verbal reports were highly correlated with responses from blind rope pulling for both viewing conditions and for both older and younger observers. This suggests that for both age groups, the judged egocentric distances were based on the same underlying variable of perceived egocentric distance. In addition, the results suggest overall greater accuracy for older observers as compared to younger observers in judging egocentric distance.

Slope—Judged distance for each observer in each combination of task and viewing condition was fit to a linear function of physical distance. The average r^2 value for all observers was above 0.89. The slope of this linear function was analyzed in a 2 (age group) by 2 (task) by 2 (viewing condition) analysis of variance. We found a significant main effect of age ($F(1, 15) = 18.48, p < .01, \text{partial } \eta^2 = 0.55$). While the average slope for younger observers was 0.56, the average slope for older observers was 0.95. This result indicates considerable foreshortening of visual space for younger observers but not for older observers. No other main effect or interaction reached significance ($p > .05$).

Experiment 2

The results of Experiment 1 were quite surprising. As noted earlier, there is an extensive literature on aging and vision showing decreased performance for older as compared to younger studies (see Andersen, 2012). Also as noted above, some studies have found that older observers perform as well as younger observers in judging perceived depth. What is particularly surprising is that older observers were more accurate than younger observers in the perception of egocentric distance, suggesting that they might not be subject to the same degree of compression of visual space as occurred with younger observers. The tight covariation of responses between two different tasks (verbal judgments and blind rope pulling) suggests that observers based their responses on an internal representation of

egocentric distance. In the current experiment, we directly examined whether the age effect observed in Experiment 1 was due to an age-related difference in scaling and output calibration between younger and older observers.

Method

Observers—The observers were 8 undergraduate students (4 male and 4 female, age = 22.1 ± 2.2) from the University of California, Riverside, and 8 older observers (4 male and 4 female, age = 74.8 ± 5.1) from the Life Society Program at the university. All observers were paid for their participation, were naive regarding the purpose of the experiment, and had normal or corrected-to-normal visual acuity. All observers were also screened using several perceptual and cognitive tests that were used in Experiment 1. Demographic information of the observers who participated in the current study and the results of the screening tests are presented in Table 1. None of the observers had participated in Experiment 1.

Stimuli—The stimuli were similar to that used in Experiment 1.

Design—Since viewing condition did not produce a significant main effect or interaction, it was not included in the current experiment. All observers viewed the stimuli binocularly. The three-way mixed design included age as the between-subject variable and two within-subject variables: (1) physical distance of the object (4m, 6m, 8m, 10m, or 12m); and (2) the task observers used to indicate their judgment (verbal report vs. rope pulling). The task was blocked and counterbalanced across observers in each age group. Each physical distance was repeated twice for each task. The order of physical distance was randomized and the distance varied from trial to trial.

Apparatus and Procedure—The apparatus and the procedure were the same as in Experiment 1 with the following exceptions. First, at the beginning of each block, observers were instructed to compare the size of the yard stick (0.91m) positioned right in front of their feet to the distance of the object when making distance judgments. The yard stick was positioned perpendicular to the line of sight. Second, in the blind rope pulling task, on each trial observers were instructed to use the rope to measure the yard stick before making responses. Third, at the end of the blind rope pulling task, observers were instructed to use the rope to measure 10 feet (3.05m), 20 feet (6.10m), and 30 feet (9.14m), respectively. These manipulations were included to examine whether the results from Experiment 1 were due to age-related differences in scaling or output calibration. For instance, if the age-related effect obtained in Experiment 1 was due to older observers having a larger internal scale of distance than younger observers, then we would expect similar performance between younger and older observers when observers were given a specific scale (i.e., the yardstick). If the results in Experiment 1 were due to an age-related difference in output calibration, then we would expect older observers to pull more rope than younger observers when trying to measure 10, 20, or 30 feet with rope. Feedback was not provided in the experiment.

Results and discussion

Similar to Experiment 1, mean judged distance and slope of judged distance as a function of physical distance were analyzed in a 2 (age group) by 2 (task) by 5 (physical distance of the object) mixed analysis of variance (ANOVA).

Mean judged distance—For mean judged distance, there was a significant main effect of age ($F(1, 14) = 5.46$, $p < .05$, partial $\eta^2 = 0.28$), a significant main effect of physical distance ($F(4, 56) = 96.54$, $p < .01$, partial $\eta^2 = 0.87$) and a significant interaction between age and physical distance ($F(4, 56) = 6.09$, $p < .01$, partial $\eta^2 = 0.30$). According to this result, there

was no significant difference between younger and older observers in judging egocentric distance at 4m ($F(1, 14) = 1.58, p = .23$) and 6m ($F(1, 14) = 1.14, p = .30$). However, older observers judged greater distance than younger observers when objects were positioned at 8m ($F(1, 14) = 5.60, p < .05$, partial $\eta^2 = 0.29$), 10m ($F(1, 14) = 5.97, p < .05$, partial $\eta^2 = 0.30$), or 12m ($F(1, 14) = 7.11, p < .05$, partial $\eta^2 = 0.34$) (see Figure 4). In addition, we found a significant main effect of task ($F(1, 14) = 12.05, p < .01$, partial $\eta^2 = 0.46$) and a significant interaction between task and physical distance ($F(4, 56) = 6.50, p < .01$, partial $\eta^2 = 0.32$). According to this result, observers in general judged greater distance using blind rope pulling task than verbal report. This difference was not significant at 4m ($F(1, 14) = 3.08, p = .10$) but reached significance at 6m ($F(1, 14) = 6.25, p < .05$, partial $\eta^2 = 0.41$), 8m ($F(1, 14) = 9.71, p < .01$, partial $\eta^2 = 0.34$), 10m ($F(1, 14) = 9.30, p < .01$, partial $\eta^2 = 0.40$), or 12m ($F(1, 14) = 14.32, p < .01$, partial $\eta^2 = 0.51$) (see Figure 5). This effect suggests that the re-calibration process improved response accuracy for the blind rope pulling task but not for the verbal report task. However, task did not interact with the age of the subjects, suggesting that the effect of re-calibration does not account for the age-related differences in judged egocentric distance obtained in Experiment 1 or Experiment 2. No other main effect or interaction reached significance ($p > .05$).

In order to examine output scaling between younger and older observers, at the end of the blind rope pulling task, we had observers pull 10 feet, 20 feet, and 30 feet of rope while blindfolded. This served as an informal observation since each observer pulled each distance only once, and the order of distance was not counterbalanced. The actual length pulled for each observer at each distance was then analyzed in a 2 (age group) by 3 (distance) ANOVA. We did not find a significant main effect of age ($F(1, 14) < 1, p > .05$). For younger observers, the length pulled was 9.85 feet, 19.5 feet, and 29.1 feet for 10 feet, 20 feet and 30 feet, respectively. For older observers, the length pulled was 9.27 feet, 18.4 feet, and 27.7 feet for 10 feet, 20 feet and 30 feet, respectively. The interaction between age and distance did not reach significance, either ($F(2, 28) < 1, p > .05$). There was a main effect of distance ($F(2, 28) = 1378.31, p < .01$). This result suggests that the output calibration was similar for older and younger observers.

Slopes—Judged distance for each observer in each task was fit to a linear function of physical distance. The average r^2 value for all observers was above 0.90. The slope of this linear function was analyzed in a 2 (age group) by 2 (task) analysis of variance. We found a significant main effect of age ($F(1, 14) = 6.86, p < .05$, partial $\eta^2 = 0.33$). While the average slope for younger observers was 0.60, the average slope for older observers was 1.00. There was also a significant main effect of task ($F(1, 14) = 11.91, p < .01$, partial $\eta^2 = 0.46$), suggesting higher slopes for the blind rope pulling task (0.86) than the verbal report task (0.74). The interaction between age and task did not reach significance ($F(1, 14) = 3.91, p = .07$).

Taken together, our results confirmed the findings of Experiment 1 and indicate that age-related differences in judging egocentric distance is not due to scaling or output calibration.

Experiment 3

In Experiments 1 and 2 we found that older observers, as compared to younger observers, judged greater egocentric distance and were more accurate in judging distance. One possible explanation for this age effect is the use of visual information for perceiving distance. The results of Experiment 1 suggest that binocular information does not account for the difference in performance for older and younger observers. However, there are two other sources of information available in the viewing conditions and scenes used in Experiments 1 and 2. One source of information concerns eyeheight. Previous research has found that

egocentric distance could be determined by using eye height (the height of the observer) and angle of declination (the angle subtended by the observer and the line of sight when viewing an object; Sedgwick, 1986; Ooi, Wu & He, 2001; Ooi & He, 2007). For instance, Ooi, Wu and He (2001) found that observers underestimated distances when viewing through a base-up prism which increased the angular of declination. After adapting to the prism, observers misperceived their eye height and overestimated egocentric distances, suggesting both eye height and angle of declination were used in judging egocentric distance. Ooi and He (2007) also found that underestimation of egocentric distance decreased with increasing eye height. In the current experiment, we examined whether the age effect observed in Experiments 1 and 2 was due to age-related difference in using eye height information. To examine this issue we had observers view the scene under three different eye conditions – seated, standing, and standing on a platform. Since the verbal report task and the blind rope pulling task produced similar results (see Experiment 1), only verbal report task was used. If the age-related difference in judging egocentric distance was due to difference in using eye height information, then we would expect that older and younger observers would show different responses to the manipulation of eye height information.

Method

Observers—The observers were 12 undergraduate students (5 male and 7 female, age = 21.9 ± 2.3) from the University of California, Riverside, and 12 older observers (6 male and 6 female, age = 76.2 ± 6.2) from the Life Society Program at the university. All observers were paid for their participation, were naive regarding the purpose of the experiment, and had normal or corrected-to-normal visual acuity. All observers were also screened using several perceptual and cognitive tests that were used in Experiment 1. Demographic information of the observers who participated in the current study and the results of the screening tests are presented in Table 1. None of the observers had participated in previous experiments.

Stimuli—The stimuli were similar to that used in Experiment 1.

Design—The three-way mixed design included age as the between-subject variable and two within-subject variables: (1) physical distance of the object (4m, 6m, 8m, 10m, or 12m); and (2) eye height of observers (seated, standing, or standing on a platform). The eye height viewing condition was blocked and counterbalanced across observers in each age group.

In each block, each physical distance of the object was repeated twice. The order of physical distance of the object was randomized for each observer in each block. Three practice trials were inserted at the beginning of each block at a different location to familiarize the observers with the procedure of the experiment.

Apparatus and Procedure—The apparatus and the procedure were the same as in Experiment 1 with the following exceptions. In the seated condition, observers sat on a folding chair. In the standing on a platform condition, observers stood on top of a Zorin platform (1.1m above the ground) with their hands grabbing the safety rail of the platform. They were instructed to judge the physical distance from the ground right under their feet to the object. Feedback was not provided in the experiment.

Results and discussion

Similar to Experiment 1 and Experiment 2, mean judged distance and slope of judged distance as a function of physical distance were analyzed in a 2 (age group) by 3 (eye height) by 5 (physical distance of the object) mixed analysis of variance (ANOVA).

Mean judged distance—For mean judged distance, there was a significant main effect of age ($F(1, 22) = 7.71, p < .05$, partial $\eta^2 = 0.26$), a significant main effect of physical distance ($F(4, 88) = 240.97, p < .01$, partial $\eta^2 = 0.96$), and a significant interaction between age and physical distance ($F(4, 88) = 9.83, p < .01$, partial $\eta^2 = 0.31$). According to this result, there was no significant difference between younger and older observers in judging egocentric distance at 4m ($F(1, 22) = 3.18, p = .09$). However, older observers judged greater distance than younger observers when objects were positioned at 6m ($F(1, 22) = 4.94, p < .05$, partial $\eta^2 = 0.18$), 8m ($F(1, 22) = 5.62, p < .05$, partial $\eta^2 = 0.20$), 10m ($F(1, 22) = 9.18, p < .01$, partial $\eta^2 = 0.29$), or 12m ($F(1, 22) = 9.39, p < .01$, partial $\eta^2 = 0.30$) (see Figure 6). The main effect of eye height was not significant ($F(2, 44) = 2.95, p = .06$). However, the non-significant trend indicated greater judged distance for the platform condition as compared to the seated or standing condition.

If the age-related difference in judging egocentric distances was due to difference in using eye height information between younger and older observers, then we would expect older and younger observers show different responses when their eye height was manipulated. However, as can be seen from Figure 6, this was not the case. There was a consistent age effect in all three levels of eye height. The interaction between age and eye height did not reach significance ($F(2, 44) = 2.10, p = .13$), suggesting that the use of eye height information was not different between younger and older observers. No other interaction reached significance.

Slopes—Judged distance for each observer in each eye height level was fit to a linear function of physical distance. The average r^2 value for all observers was above 0.89. The slope of this linear function was analyzed in a 2 (age group) by 3 (eye height) analysis of variance. We found a significant main effect of age ($F(1, 22) = 11.14, p < .01$, partial $\eta^2 = 0.33$). While the average slope for younger observers was 0.65, the average slope for older observers was 0.98. The main effect of eye height was not significant ($F(2, 44) < 1, p > .05$), nor was the interaction between age and eye height ($F(2, 44) < 1, p > .05$). Again, this suggests that the use of eye height information was not different between younger and older observers.

Experiment 4

In the previous experiments we found that older observers judged greater egocentric distance than younger observers, and that this effect was not due to an age-related difference in output scaling or the use of eye height information. In this experiment, we examined a second source of information for egocentric distance – the texture gradient on the ground surface. The importance of texture gradient as a depth cue was proposed by J. J. Gibson (1950). On a receding or slanting surface, the projected size of the texture elements and the space between the elements decrease systematically as a function of distance. Previous studies have found that disruption of a continuous texture gradient on the ground surface would result in decreased perceived distance (Feria, Braunstein & Andersen, 2003; Sinai, Ooi & He, 1998). Egocentric distance along a textured ground surface can be specified as

$$d = H \times (\cos \alpha_1 / \sin \alpha_2) \times \tan(\beta_1 / \beta_2),$$

where H is the eye height of the observer, α_1 and α_2 are the projected angles from the observer to two texture elements on the ground surface and β_1 and β_2 are the projected extents of the texture elements (i.e. the calculation of $\tan(\alpha_1 / \alpha_2)$ is the texture gradient of the

surface) (Bian & Andersen, 2010). With some approximation, egocentric distance could also be determined by

$$d=(H \times G)/3,$$

where H is the eye height of the observer and G is the texture gradient of size at the object's location on the ground surface (Sedgwick, 1983). In the current experiment, we examined whether the age effect observed in previous experiments was due to an age-related difference in using texture gradient information. To examine this issue we had observers make egocentric distance judgments in a long indoor corridor. We manipulated ground texture by creating three different texture patterns on a uniform surface (white canvas). The patterns examined were a random texture pattern, a regular texture pattern, and a no texture pattern condition. If older observers use texture information more efficiently than younger observers, then their performance should be greater when a ground texture pattern is present as compared to when it is absent.

Method

Observers—The observers were 12 undergraduate students (6 male and 6 female, age = 23.2 ± 2.8) from the University of California, Riverside, and 12 older observers (6 male and 6 female, age = 71.8 ± 4.8) from the Life Society Program at the university. All observers were paid for their participation, were naive regarding the purpose of the experiment, and had normal or corrected-to-normal visual acuity. All observers were also screened using several perceptual and cognitive tests that were used in Experiment 1. Demographic information of the observers who participated in the current study and the results of the screening tests are presented in Table 1. None of the observers had participated in previous experiments.

Stimuli—The stimuli were similar to that used in Experiment 1.

Design—The three-way mixed design included age as the between-subject variable and two within-subject variables: (1) the physical distance of the object (4m, 5m, 6m, 7m, 8m, 9m, 10m, 11m or 12m); and (2) the texture on the ground (blank, random texture or regular texture). The texture variable was blocked and counterbalanced across observers in each age group.

In each block, each physical distance of the object was repeated twice. The order of physical distance of the object was randomized for each observer in each block. Three practice trials were inserted at the beginning of each block at a different location to familiarize the observers with the procedure of the experiment.

Apparatus and Procedure—The experiment was conducted in the hallway of Psychology building in University of California, Riverside. The hallway was 4.8 meters wide and 34 meters long. Observers sat in front of a table with their chin supported by a chin rest. An eye height of 1.2m was used. They viewed the object monocularly through a black rectangular viewing hood that occluded side walls and the ceiling but not the ground surface. The horizontal visual angle was 17.1° . The vertical visual angle was 12.3° above line of sight and 29.0° below line of sight, respectively. An eye patch was used to cover one of the observers' eyes.

In each block, one of three pieces of canvas ($4.8 \text{ m} \times 12.0 \text{ m}$) was used to cover the ground surface, each with a different texture gradient (see Figure 7). At the beginning of each trial,

the viewing hood was blocked. An experimenter walked to the end of the canvas and then positioned the object on the way back. The viewing hood was then unblocked and the observer was able to look at the object on the ground through the viewing hood. Observers were instructed to judge the physical distance from their feet to the object. Similar to Experiment 3, verbal report task was used. Feedback was not provided in the experiment.

Results and discussion

Similar to Experiment 1 through Experiment 3, mean judged distance and slope of judged distance as a function of physical distance were analyzed in a 2 (age group) by 3 (texture gradient) by 9 (physical distance of the object) mixed analysis of variance (ANOVA).

Mean judged distance—For mean judged distance, there was a significant main effect of age ($F(1, 22) = 13.95, p < .01, \text{partial } \eta^2 = 0.39$), a significant main effect of physical distance ($F(4, 88) = 277.14, p < .01, \text{partial } \eta^2 = 0.93$) and a significant interaction between age and physical distance ($F(4, 88) = 12.95, p < .01, \text{partial } \eta^2 = 0.37$). According to this result, older observers judged greater distance than younger observers when objects were positioned at 4 m ($F(1, 22) = 5.93, p < .05, \text{partial } \eta^2 = 0.21$), 5 m ($F(1, 22) = 8.32, p < .05, \text{partial } \eta^2 = 0.27$), 6 m ($F(1, 22) = 9.02, p < .01, \text{partial } \eta^2 = 0.29$), 7 m ($F(1, 22) = 12.51, p < .01, \text{partial } \eta^2 = 0.36$), 8 m ($F(1, 22) = 15.35, p < .01, \text{partial } \eta^2 = 0.41$), 9 m ($F(1, 22) = 14.93, p < .01, \text{partial } \eta^2 = 0.40$), 10 m ($F(1, 22) = 13.63, p < .01, \text{partial } \eta^2 = 0.38$), 11 m ($F(1, 22) = 13.50, p < .01, \text{partial } \eta^2 = 0.38$), or 12 m ($F(1, 22) = 15.07, p < .01, \text{partial } \eta^2 = 0.41$) (see Figure 8).

The main effect of texture was not significant ($F(2, 44) = 1.60, p = .21$), nor was its interaction with age ($F(2, 44) < 1, p > .05$). As can be seen in Figure 7, observers' responses did not vary as a function of texture on the ground, which could be due to the use of other optical variables in judging egocentric distances (e.g. height in the visual field). There was a significant interaction between physical distance and texture gradient ($F(16, 352) = 1.78, p < .05, \text{partial } \eta^2 = 0.07$). According to this result, there was no difference between the three textures when objects were positioned at 4 m ($F(2, 44) = 1.79, p = .18$), 5 m ($F(2, 44) < 1, p > .05$), 6 m ($F(2, 44) < 1, p > .05$), 7 m ($F(2, 44) < 1, p > .05$), 8 m ($F(2, 44) = 1.12, p = .33$), 10 m ($F(2, 44) = 3.02, p = .059$), 11 m ($F(2, 44) = 1.47, p = .24$), or 12 m ($F(2, 44) = 1.36, p = .27$). When the objects were positioned at 9 m, the judged distance of a random texture was significantly greater than that of a regular or a blank texture ($F(2, 44) = 3.73, p < .05, \text{partial } \eta^2 = 0.14$).

These results suggest that the age-related difference in egocentric distance judgment was not due to an age-related difference in using the texture gradient information on the ground plane. No other interaction was significant.

Slopes—Judged distance for each observer in each combination of texture gradient was fit to a linear function of physical distance. The average r^2 value for all observers was above 0.92. The slope of this linear function was analyzed in a 2 (age group) by 3 (texture gradient) analysis of variance. We found a significant main effect of age ($F(1, 22) = 15.09, p < .01, \text{partial } \eta^2 = 0.41$). While the average slope for younger observers was 0.86, the average slope for older observers was 1.33. The slopes for both younger and older observers were considerably higher than what we observed in previous experiments.

The main effect of texture gradient was not significant ($F(2, 44) = 2.88, p = .07$), nor was the interaction between age and texture gradient ($F(2, 44) < 1, p > .05$). Again, this suggests that the use of texture gradient information was not different between younger and older observers.

General Discussion

In the present study we examined age-related differences in perceived egocentric distance. In Experiment 1 we manipulated the presence of binocular cues and used both verbal report and blind rope-pulling tasks. We found that while younger observers underestimated egocentric distance, older observers were quite accurate and judged greater distance than younger observers. In Experiment 2, we examined whether this age effect was due to a difference in scaling and output calibration between younger and older observers. We found that older observers judged greater distance than younger observers even when both age groups were calibrated on the same scale. In Experiment 3 and 4, we examined whether this age effect was due to a difference in the use of two different information sources for egocentric distance – eye height and texture gradients. Again we found an age-related improvement in judging egocentric distance with older observers more accurate than younger observers. Although there was evidence that eye height and texture were used to judge distance, it did not interact with the age of the subjects, suggesting that the use of these two sources of information were not differentially used by older and younger observers.

These results were surprising given numerous studies showing age-related declines in sensory, perceptual and cognitive tasks. Thus, an important question is what age-related factors might account for the present results? There are several possible factors that might account for the present findings. Let us consider these factors separately. First, could our results be due to older observers utilizing a cognitive correction when responding? Specifically, could older observers be aware of errors in the judgments and thus cognitively correct their response? In order to examine this issue, in Experiment 1 and 2, we used two tasks: verbal report and blind rope pulling. A strong covariation between responses from two tasks as depth cues are manipulated would suggest that both responses are derived from the same underlying mechanism of perceived distance (Foley, 1977; Philbeck & Loomis, 1997). In our experiments, the data from both younger and older observers showed a strong correlation with both response types regardless of monocular or binocular viewing. This suggests that the results could not have been due to a difference in cognitive corrections or output scaling. Moreover, this hypothesis was directly assessed in Experiment 2 by providing observers with an explicit scale to use in estimating distance. The results indicated the same interaction of age and distance obtained in Experiment 1. In addition, asking subjects to estimate specific lengths using blind rope pulling did not produce an age difference in performance. These results, considered together, suggest that the age-related difference in distance judgments is not based on age related differences in the underlying concept of spatial distance or output scaling.

A second possibility is that older observers may have more knowledge about egocentric distance in real world scenes as a result of greater experience. As a result, they may be more aware of errors in estimation of distance during their lifetime and thus correct for this underestimation by increasing their responses either consciously or unconsciously. Evidence does exist of the role of experience in egocentric distance judgments. For instance, Durgin et. al. (2012) compared egocentric distance judgments between athletes and non-athletes. Using verbal report, they found that when a target was positioned at distances greater than 10 meters athletes judged greater and more accurate distance than non-athletes. At distances less than 10 meters, there was no significant difference between the two groups. However, when observers matched perceived egocentric distance of a pole with the height of the pole, similar performance was found between athletes and non-athletes at various physical distances. Durgin et. al. (2012) concluded that athletes were simply making cognitive corrections in their verbal report at far distances rather than perceiving greater distances than non-athletes. We did not collect information about the experiential factors that may

potentially affect the judged egocentric distances, such as the degree of mobility and athleticism of older and younger subjects. Thus, an important issue would be to examine this possibility by collecting specific information on this topic. However, there is indirect evidence that this interpretation may not account for the present findings. Consider the processes involved in the finding for athletes. One process is a perceptual process of determining distance. A second process is a cognitive process of correcting one's estimate. Both of these processes would contribute some degree of variability in a response. Thus, an observer using a cognitive correction in their judgments should have greater variability in responding when compared to an observer that does not use a cognitive correction. In order to examine this hypothesis, we conducted a t-test on the standard errors between younger and older observers in all 4 experiments. None of the t-tests were significant, suggesting that an analysis of standard errors does not provide support for this explanation. An important goal in future research would be to examine this explanation more directly.

A third explanation is that older observers were more engaged in the experiment than younger observers? There are two reasons to dismiss this hypothesis. First, if the results reflect a difference in attention between younger and older observers, then we should have observed a simple main effect of age. However, in Experiment 1, 3, and 4, we observed a significant interaction between age and physical distance of the objects, suggesting that the age-related difference in judging egocentric distance existed only at medium and far distances (6m and beyond), but not at near distance (4m). Moreover, if younger observers were less engaged in the tasks as compared to older observers, then we should have expected a difference in the consistency from trial to trial between age groups. That is, older observers should exhibit higher consistency in their responses. As mentioned previously, none of the t-test comparisons between younger and older observers on standard errors was significant, suggesting that older and younger observers were not differentially engaged in the experiments.

A fourth explanation is that older observers anticipate greater effort (as if imagining that they were walking to the target) and thus bias their responses consistent with expected effort. Several studies found that the perceived distance was influenced by the energy expenditure or anticipated effort required to perform the task and by the physiological status of the observers (Proffitt, Stefanucci, Banton & Epstein, 2003; Witt, Proffitt & Epstein, 2004). For instance, in Proffitt et. al. (2003), observers wearing a heavy backpack judged greater distances than observers without a backpack. However, recent studies have reported failures to replicate this effect (Hutchison & Loomis, 2006a, 2006b; Woods, Philbeck & Danoff, 2009) and suggested that this effect was due to recalibration of responses or experimental demand (Woods, Philbeck & Danoff, 2009; Durgin, et. al., in press). Could this effect account for the age-related differences in perceived distance observed in the present study? If perceived egocentric distance is affected by the effort required to perform the task, then we should have observed a differential age effect when observers responded with a verbal report or rope pulling task. That is, the age-related difference measured with a blind rope pulling task, which involved a motor response, should be larger than that measured with a verbal report task. Yet this interaction was not observed in Experiment 1 or Experiment 2. Considered together, we believe that the present results cannot be due to effort, energy expenditure or other related cognitive factors.

A fifth possibility is that the effect of age and distance to the target is due to a perceptual factor not examined in the present study. For example, one possible interpretation of the results is that the effect is due to age-related differences in the perceived slant of the ground plane. Previous research has suggested that the compression of space in egocentric distance judgments by college age observers may be due to the misperceived slant of the ground plane (Ooi & He, 2007). Specifically, if the ground plane is perceived as slanted towards the

observer then judged distance will be compressed. Our result for younger observers is consistent with this interpretation. Thus, for older observers to perceive greater distance the perceived slant should be perceived as closer to the slant of the ground surface, resulting in greater accuracy. Norman et al. (2009) found similar performance in judging slant varying from 20° to 65° between younger and older observers. However, perceived slant might be quite different when close to a ground plane (90°). An alternative theory, the angular expansion hypothesis, suggests that the compression of perceived distance on the ground is due to incorrectly perceived gaze angle and optical slant (Durgin & Li, 2011; Li & Durgin, 2012). We did not require subjects to judge gaze angle in the present study and thus an important goal for future research will be to examine the relationship among perceived slant, perceived gaze angle and perceived distance on a ground surface.

A sixth possibility concerns the use of pictorial cues when viewing real world scenes. In a well-lit environment, there are many pictorial cues that may be used to determine egocentric distance. These cues include perspective, texture gradients, shading, height in the visual field, to name a few. It is possible that older observers may rely more on pictorial cues when judging distance because of declines in other information sources for distance perception such as accommodation and stereopsis. In Experiment 3 and 4, we examined whether the age effect was due to a difference in the use of some of these information sources such as eye height and texture gradients. We found that the pattern of responses as a function of eye height and texture gradient was similar between younger and older observers, suggesting that if this hypothesis is correct then the age-related differences in judging egocentric distances may be due to the use of other pictorial cues not examined in the present study. That is, other information sources might be used differentially by older and younger observers or the assignment of weights to different depth cues (to estimate distance) might vary based on age. Understanding the use of other pictorial cues and the possible reweighted use of these cues based on age would be an important direction for future research.

In summary, the results of the present study demonstrate a surprising age-related difference in vision – the perception of egocentric distance. Overall the results suggest that increased age is associated with more accurate distance estimates. This effect is not dependent on information sources such as eyeheight or texture, and the results are not likely the results of strategic or attentional differences based on age. These results indicate that not all aspects of vision decline or remain constant with age. Indeed, performance in some visual tasks, such as egocentric distance, improves with increased age. The improved performance for older observers may serve an important role for the health and wellbeing of older observers. Egocentric distance is likely to be important in motor tasks such as walking or climbing steps. Thus, an improved ability to judge distance may decrease the likelihood of a fall when moving in the world.

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Figure 1.
Scene used in Experiment 1 and 2.

Figure 2. Judged distance as a function of age, viewing condition and physical distance from Experiment 1. Error bars represent ± 1 standard error.

Figure 3. Responses from blind rope pulling task as a function of responses from verbal report from Experiment 1.

Figure 4. Judged distance as a function of age, task and physical distance from Experiment 2. Error bars represent ± 1 standard error.

Figure 5. Judged distance as a function of task and physical distance from Experiment 2. Error bars represent ± 1 standard error.

Figure 6. Judged distance as a function of age, eye height and physical distance from Experiment 3. Error bars represent ± 1 standard error.

Figure 7.
Photo of actual texture gradient used in Experiment 4: (a) random texture; (b) regular texture.

Figure 8. Judged distance as a function of age, texture and physical distance from Experiment 4. Error bars represent ± 1 standard error.

Table 1

Means and Standard Deviations of Participants' Demographic Information and Results From Perceptual and Cognitive Tests in Experiment 1 to 4

Variable	Younger		Older	
	M	SD	M	SD
Age (years) ^a	22.5	2.2	73.4	5.4
Years of education ^a	14.0	1.2	16.1	2.5
Snellen Letter Acuity	10/10.6	1.4	10/13.1	2.4
Log Contrast Sensitivity ^{a, b}	1.81	0.15	1.66	0.22
Digit Span Forward	11.1	2.4	11.6	2.6
Digit Span Backward	8.2	1.5	7.3	1.4
Perceptual Encoding Manual ^a	88.6	14.7	56.2	16.1
Kaufman Brief Intelligence Test	23.5	3.1	26.3	5.6

^aDifferences between age groups were significant ($p < .05$).

^bContrast sensitivity was measured using the Pelli Robson test (Pelli, Robson, & Wilkins, 1988).