Published in final edited form as:

Accid Anal Prev. 2013 January ; 50: 926–933. doi:10.1016/j.aap.2012.07.013.

Aging and Detection of Collision Events on Curved Trajectories

Zheng Bian, Amy H. Guindon, and George J. Andersen

Department of Psychology, University of California, Riverside, Riverside, CA 92521

Abstract

In the current study we examined age-related differences in the detection of collision events on a curved trajectory. Observers were presented with displays simulating an approaching object moving at a constant speed that was either on a collision or a non-collision path. The object disappeared before reaching the observer, and the task was to determine whether the object was on a collision path. In a series of three experiments, we manipulated the motion trajectory of the object (linear or curved), time-to-contact (TTC), and radius of the curvature. We found decreased performance with older as compared to younger observers when the object was traveling on a linear trajectory at long TTC. However, there was no age-related decrement in detecting a collision when the object was traveling on a curved trajectory. These results indicate a similar ability for older and younger observers in detecting collisions on a curved trajectory.

1. Introduction

An important task for driving safety is to avoid impending collisions. Failure to successfully perform this task may have serious consequences for the safety and health of drivers. Research has shown that older drivers (65 years of age or older), as compared to middle-age drivers, are more likely to be involved in a fatal crash (McKnight & McKnight, 1999). Evans (2004) examined data from the Fatality Analysis Reporting System and found that the rate of severe crashes and crash fatalities increased significantly for drivers older than 60. The risk of a crash increased with age even though older drivers tend to reduce the amount of driving (Raitanen, Tormakangas, Mollenkopf, & Marcellini, 2003). Although increased rate of fatal crashes has been shown to be associated with the fragility of older drivers (Cheung and McCartt, 2011) studies examining crash rates have found that older drivers have increased crash risk at intersections particularly when initiating left hand turns (FHWA report, Accident Analysis of Older Drivers at Intersections, 1994). These findings, considered together, suggest that age-related crash risk is an important issue for the safety of older drivers.

The increased risk for older drivers occurs when sensory and perceptual processing are declining with age. For example, research has found age-related declines in sensory processing including visual acuity (Corso, 1981; Owsley & Sloane, 1990) and contrast sensitivity at high spatial frequencies (Elliot, 1987; Owsley, Sekuler, & Siemsen, 1983). Decrements in performance with age have also been found in perceptual tasks, such as the perception of 2D coherent motion (Atchley & Andersen, 1998; Gilmore, Wenk, Naylor, &

© 2012 Elsevier Ltd. All rights reserved.

Address for correspondence: George J. Andersen, Department of Psychology, University of California, Riverside, Riverside, CA 92521, United States, Phone: 1-951- 827- 4383, andersen@ucr.edu.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Stuve, 1992), perceptual organization of 3D scenes (Bian & Andersen, 2008), structure from motion (Andersen & Atchley, 1995; Norman, Clayton, Shular, & Thompson, 2004), and collision detection of objects moving along linear trajectories (Andersen, Cisneros, Saidpour, & Atchley, 2000; Andersen & Enriquez, 2006; Delucia, Bleckley, Meyer, & Bush, 2003). Finally, studies have shown age related declines in the spatial extent of attention or useful field of view (Sekuler & Ball, 1986).

An important issue for driving safety of older drivers is what types of perceptual processing change with age that may account for the increased crash risk with age. One potential candidate is a decline in the ability to determine how much time remains before a collision will occur or time to contact (TTC). As an object approaches an observer, the projected size of the object increases or expands. TTC is specified by the inverse rate of expansion of an approaching object (Lee, 1976; Lee, Reddish, 1981). Studies have shown that TTC is widely used in actions such as intercepting an object (Lee, Young, Lough & Clayton, 1983) and reaching (Bingham & Zaal, 2004). Although previous studies found decreased accuracy for older drivers in judging TTC (Schiff, Oldak, and Shah, 1992; Hancock and Manser, 1997; Oxley, Fildes, Ihsen, Charlton, & Day, 2005), older drivers, as compared to younger drivers, tend to underestimate rather than overestimate TTC. For example, Oxley et al. (2005) found that older drivers were more conservative than younger drivers in selecting the safe time gap when crossing a road. In a related study, DeLucia et al. (2003) examined age-related differences in judging TTC between two objects, in detecting collision events between two objects, and in detecting collision events between the observer and an object. They found that older observers showed a greater underestimation of TTC than younger observers. An underestimation of TTC suggests that the driver believes less time is available for collision avoidance and is likely to result in an earlier reaction to avoid an impending collision as compared to a driver who does not underestimate TTC. The finding that older observers underestimate TTC suggests that they are more likely to respond to avoid a collision. Thus, TTC may not be the primary factor behind the increased crash risk for older drivers (e.g. McKnight & McKnight, 1999).

Before an observer can respond to avoid a collision they must first detect that a collision is imminent. As a result it is possible that the increased crash risk that occurs with age may due, in part, to a decreased ability to detect a collision. Collision events consisting of a moving observer and a moving object can occur under a variety of situations based on four factors: the motion trajectory of the object (linear or curved), the motion trajectory of the observer (linear or curved), the speed of object motion (constant or varying), and the speed of observer motion (constant or varying). These factors result in 16 different combinations of collision events (Andersen & Sauer, 2004). An additional eight combinations involve a stationary observer or a stationary object.

Previous research has examined age-related decrements in collision detection during deceleration (Andersen, et al., 2000) and age-related decrements in collision detection with an object translating on a linear path at a constant speed (Andersen & Enriquez, 2006; DeLucia, et al., 2003). Specifically, Andersen et al. (2000) examined age-related decrements in detecting collision events during deceleration. They found that, compared to younger observers, older observers were less sensitive to collision events and tended to make more collision judgments, especially at higher driving speeds. They also found both age groups used speed and distance information, in addition to expansion information, to detect an impending collision during deceleration.

Andersen & Enriquez (2006) examined the effect of observer motion, display duration and TTC on age-related differences in collision detection. They presented observers with simulated 3-D scenes of an approaching object on a linear trajectory at a constant speed.

Under these conditions a collision event is defined by two factors: object expansions (the object is expanding because of reduced distance) and the bearing of the object (position in the visual field) remains constant. The object disappeared before reaching the observer, and the task was to determine whether the object would collide with the observer or pass by the observer. They found that the performance for both younger and older observers improved with decreased TTC. However, the improvement in performance was greater for younger than older observers. This suggests a decreased ability for older observers to use expansion information. They also found that older observers, as compared to younger observers, were less sensitive to collision events when the object was traveling at high speed.

These studies, considered together, indicate a decreased ability for older observers to detect collision events, which may lead to increased crash risk. It is important to note that these studies have only examined situations with an observer and/or an object translating on a linear trajectory. Many collision events involve an observer and/or object that is moving along a curved trajectory. For instance, a vehicle making a left turn at a four way intersection may crash into another vehicle (stopped and waiting to turn left in the opposite direction of traffic) if the driver initiates a steering angle that is too shallow (understeers) while negotiating the turn. Ni and Andersen (2008) showed that the optical information specifying a collision event for a curved trajectory was different than that for a linear trajectory. As discussed earlier, when an object traveling on a linear trajectory is about to collide with an observer, the bearing of the object is constant (Andersen & Kim, 2001). When an object is traveling on a curved trajectory, there is a constant rate of bearing change (see Ni & Andersen, 2008 for a detailed analysis). Specifically, under these conditions the rate of bearing change is determined solely by the angular speed of object motion along the curved trajectory. This suggests that when the angular speed is constant, the rate of bearing change is constant.

Ni and Andersen (2008) examined whether college-age observers used constant rate of bearing change in detecting collision events on a curved trajectory. In 3 experiments, they found decreased performance in detecting collision events moving along a curved trajectory as compared to a linear trajectory, and found that detection performance for a curved trajectory varied as a function of TTC and the radius of the curvature. In addition, when presented with non-collision stimuli with constant rate of bearing change (generated by systematically varying the angular speed of the object), observers were more likely to report a collision (false alarm) than when presented with non-collision stimuli with a variable rate of bearing change. These results suggest that younger observers used the constant rate of bearing change to detect collision events with an object moving along a curved trajectory.

In the present study we examined age-related differences in collision detection performance for curved and linear trajectories. Specifically, the purpose of the study was to determine the magnitude of age-related declines in collision detection performance for curved trajectories and to determine what changes in visual processing account for this decline. The present study examined two hypotheses. If age-related declines in collision detection performance are solely due to a decreased ability to use expansion information, then similar levels of performance should occur for both linear and curved path motions. However, if age-related declines are due to the ability to use bearing information, then collision detection performance may vary according to this information. Since bearing information is different for linear and curved path trajectories, it suggests that age related differences in the use of this information would be evident in detecting collision events for these two trajectories. Specifically, rate of bearing change is a higher order variable than constant bearing. Thus, we expect a greater age-related decline in performance for curved as compared to linear trajectories.

2. Experiment 1

The purpose of the first experiment was to examine age-related differences in detecting collisions of objects moving along curved and linear trajectories. The methodology was the same as the used in Andersen and Ni (2008). Observers were presented with simulated 3-D scenes with an approaching object at a constant speed either on a linear trajectory or on a curved trajectory. The object disappeared before reaching the projection plane and the observer's task was to indicate whether the object would eventually collide with the observer or would pass by the observer.

2.1. Method

2.1.1. Observers—The observers were 12 younger observers (6 male and 6 female) from the University of California, Riverside, and 12 older observers (5 male and 7 female) 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, and Wilkins, 1988), forward and backward digit span, perceptual encoding, and the Kaufman brief intelligence test (K-BIT). Demographic information of the observers who participated in the current study and the results of the screening tests are presented in Table 1.

2.1.2. Stimuli—The displays simulated 3-D scenes consisted of a 3.6 m wide roadway with a solid double-yellow line. The dimension of the simulated scene was 2400 m $\times$ 1200 m (calculation based on an eye height of 1.2 m). There was textured green grass on both sides of the roadway (see Figure 1). Within the scene there was a bright red sphere with a simulated diameter of 3.6 m translating towards the observer at a speed of 90 km/h from a distance of 175 m. The initial position of the sphere was chosen randomly from an arc with a radius of 175 m centering the observer within the field of view. The total travel time from the initial position of the sphere to the observer was 7.0 s.

Linear trajectories were created using a method similar to that in Andersen and Kim (2001). The collision and non-collision trajectories both had a constant linear speed of 90 km/h. In collision events, the end point of the trajectory was the position of the observer. In non-collision events, the end point of the trajectory was either 4.8 m or 9.6 m to either side of the observer (these values are the same as that used in the Ni & Andersen (2008) study).

Curved trajectories were created using a method similar to that in Ni and Andersen (2008). The curvature of the trajectories was 225 m⁻¹. The collision and non-collision trajectories both had a constant angular speed of 6.1 °/s. For collision events, the end point of the trajectory was the position of the observer. For non-collision events, the trajectory was the same as that in the collision events except that it was rotated either $\pm 2.5^\circ$ or $\pm 5.0^\circ$ about the initial position of the sphere, such that the sphere would pass by the observer outside the field of view (these values are also the same valued used in the Ni & Andersen (2008) study).

The projected size of the sphere varied as a function of distance to the observer, with the smallest projected size as 0.8° and largest projected size as 6.6°. The average luminance was 12.06 cd/m². At the beginning of the motion trajectory, the contrast of the sphere was 0.04. At the end of the motion trajectory, the contrast of the sphere was 0.12, 0.09, 0.06 and 0.04, respectively for the time to contact (TTC) of 1.25 s, 2.5 s, 3.75 s, and 5.0 s.

2.1.3. Design—The 3-way mixed design included age as the between-subject variable and two within-subject variables: (1) motion trajectory of the object (linear or curved), and (2) TTC of the object at the last frame of display (1.25 s, 2.5 s, 3.75 s or 5.0 s). Each of the 8 combinations was presented for 80 replications (40 replications of collision events and non-collision events, respectively). A total of 640 trials were evenly divided into 4 blocks, which were completed within 1.5 hours. A practice block with 16 trials preceded the experimental blocks. The order of trials in each block for each observer was randomized individually.

2.1.4. Apparatus—The displays were presented on a 23-inch (58.4 cm) LCD monitor with a pixel resolution of 1024 by 768 and a refresh rate of 60 Hz, controlled by a Windows XP Professional Operating System on a Dell Dimension XPS workstation. The dimensions of the display on the monitor were 46.7 cm (W) × 35.1 cm (H), subtending a visual angle of $56.5^\circ \times 43.9^\circ$ at a viewing distance of 44 cm. A black viewing hood was placed in front of the monitor to cover the edges of the screen. A 19-cm diameter glass collimating lens, which magnified the images by approximately 19%, was located between the observer and the monitor. The purpose of the collimating lens was to remove accommodation differences between younger and older observers. The distance between the eyes and the collimating lens was approximately 10 cm and the distance from the eyes to the monitor was 44 cm. A chin rest was mounted at a position appropriate to this viewing distance.

2.1.5. Procedure—The experiment was run in a darkened room. The observer viewed the monitor binocularly through the collimating lens with their head in the chin rest. On each trial, a scene consisting of a roadway and a sphere was presented. The sphere traveled from distance to the observer either at a constant linear speed (linear trajectories) or at a constant angular speed (curved trajectories) and disappeared after sometime before reaching the projection plane. The observer then determined whether the sphere would eventually collide with or pass by the observer, and responded by pressing either the '4' button (collision) or the '6' button (non-collision) on a standard keyboard. Examples of the complete collision and non-collision events were shown to the observer during instructions. A practice block consisting of 16 trials was first conducted. In the practice block, the full path of the trajectory was presented (i.e. the sphere disappeared after reaching the projection plane) and observers could not make more than 1 error in order to proceed to the experimental blocks. Once the observer passed the practice block, four experimental blocks were then conducted. No feedback was given during the experimental blocks.

2.2. Results and discussion

We calculated the proportion of hits (a collision response for a simulated collision event) and false alarms (a collision response for a simulated non-collision event), which were used to derive a sensitivity score (d') and bias measure (β) for each observer in each condition.

The sensitivity score (d') is a measure of how drivers are able to discriminate signal (collision events) from noise (non-collision events) and was calculated using the function below:

$$d' = Z(\text{hit rate}) - Z(\text{false alarm});$$

where function $Z(p)$, $p \in [0,1]$, is the inverse of the cumulative Gaussian distribution (Green & Swets, 1966).

The d' scores were analyzed in a 2 (age group) by 2 (motion trajectory) by 4 (TTC) mixed ANOVA with repeated measures. The main effect of age did not reach significance ($F(1, 22) = 0.46$, $MSE = 0.63$, $p = 0.50$). The average d' was 2.11 for younger observers and 2.00 for older observers. The main effect of motion trajectory was significant ($F(1, 22) = 76.6$, MSE

= 46.84, $p < .01$), with the average d' for the linear trajectory (2.55) significantly higher than the d' for the curved trajectory (1.56). This result suggests that overall detection of collision events on a curved trajectory is more difficult than on a linear trajectory, which is consistent with previous research (Ni & Andersen, 2008). The main effect of TTC was significant ($F(3, 66) = 482.2$, $MSE = 92.26$, $p < .01$). As TTC increased from 1.25 s to 5.0 s, the average d' decreased from 3.73 to 0.53. There was also a significant interaction between motion trajectory and TTC ($F(3, 66) = 52.3$, $MSE = 6.35$, $p < .01$) and a significant 3-way interaction of age, motion trajectory and TTC ($F(3, 66) = 3.37$, $MSE = 0.41$, $p < .05$). As shown in Figure 2, when the object was traveling on a linear trajectory, the mean sensitivity of older observers was similar to younger observers at short TTC (1.25 s and 2.5 s). When TTC increased to 3.75 s and 5 s, there was a greater decrease in sensitivity for older observers as compared to younger observers. That is, there is an age-related decrement in detecting collision events on a linear trajectory at long TTC, which is consistent with the findings of previous studies (Andersen & Enriquez, 2006). However, when the object was traveling on a curved trajectory, there was no difference in sensitivity between the two age groups for all levels of TTC. No other interactions reached significance.

An additional analysis was conducted to examine whether the detection performance was above chance level for each observer in each condition (Marascuilo, 1970). For linear trajectory collision events, the number of younger observers with sensitivity significantly greater than zero was 12, 12, 12, and 9 (out of 12) for the 1.25 s, 2.5 s, 3.75s, and 5.0 s TTC, respectively. The number of older observers with sensitivity greater than chance was 12, 12, 11, and 7 (out of 12) for the 4 levels of TTC, respectively. For curved trajectory collision events, the number of younger observers with sensitivity greater than chance was 12, 12, 2, and 0 (out of 12) for the 4 levels of TTC, and the number of older observers with above chance performance was 12, 11, 5, and 0 (out of 12) for the 4 levels of TTC. These results suggest that the age-related decrements in collision detection with linear trajectories at the 3.75 s and 5.0 s of TTC were due to a decreased sensitivity to detect collision rather than an inability to perform the collision detection task. For the curved trajectories, the majority of younger and older observers were unable to detect collisions with better than chance performance when TTC was 3.75 s and 5.0 s.

The response bias is a measure of criteria that drivers used to make a collision or non-collision response. It was calculated using the following function:

$$\beta = f(Z(\text{hit rate})) / f(Z(\text{false alarm}));$$

where function $f(x)$ is the probability density function of a normal distribution function $N(0, 1)$ and function $Z(p)$, $p \in [0, 1]$, is the inverse of the cumulative Gaussian distribution (Green & Swets, 1966).

The bias measure (β) was also analyzed in a 3-way mixed ANOVA. The main effect of age was not significant ($F(1, 22) = 0.65$, $MSE = 1.55$, $p = .43$). There was a significant main effect of motion trajectory ($F(1, 22) = 8.43$, $MSE = 8.05$, $p < .05$) and TTC ($F(3, 66) = 12.65$, $MSE = 10.84$, $p < .01$), that was mediated by a significant interaction between these two variables ($F(3, 66) = 9.42$, $MSE = 6.11$, $p < .01$). An examination of the simple effects for TTC indicated that, when the TTC was 2.5 s, observers were more likely to make a collision response to curved trajectories than to linear trajectories ($p < .05$). When the TTC was 1.25 s, 3.75 s, and 5.0 s, however, there was no significant difference between the linear and curved trajectories ($p > .05$). No other interactions reached significance.

3. Experiment 2

The result of Experiment 1 indicated that, although older observers showed decreased performance in detecting collision events on a linear trajectory than younger observers, their ability to detect collision events on a curved trajectory was similar to that of younger observers. This result suggests that older observers are able to use the constant rate of bearing change information as efficiently as younger observers, and is inconsistent with the hypothesis that recovering constant rate of bearing information is more difficult for older observers than recovering constant bearing information. As can be seen in Figure 2, average sensitivity for both younger and older observers significantly decreased when TTC increased from 2.5 s (average $d' = 2.25$) to 3.75 s (average $d' = 0.47$). This suggests that any age-related difference in detecting curved collisions may occur within this range of conditions. In Experiment 2, we examined this possibility by including three additional levels of TTC between 2.5 s and 3.75 s.

3.1. Method

3.1.1. Observers—The observers were 11 younger observers (5 male and 6 female) from the University of California, Riverside, and 11 older observers (5 male and 6 female) 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. Demographic information of the observers who participated in the current study and the results of the screening tests are presented in Table 1.

3.1.2. Stimuli—The stimuli were similar to that used in Experiment 1, except that only curved trajectories were examined.

3.1.3. Design—The 2-way mixed design included age as the between-subject variable. The within-subject variable was the TTC of the object at the last frame of display (2.5 s, 2.75 s, 3.0 s, 3.25 s and 3.5 s). Each of the five levels of the TTC was presented for 96 replications (48 replications with collision and non-collision events, respectively). A total of 480 trials were evenly divided into 3 blocks, which were completed within 1 hour. A practice block with 16 trials preceded the experimental blocks. The order of trials in each block for each observer was randomized individually.

3.1.4. Apparatus and Procedure—The apparatus and the procedure were the same as in Experiment 1. Feedback was not provided during the practice trials or the experiment.

3.2. Results and discussion

For each observer, the proportion of hits and false alarms in each condition were calculated, and a sensitivity score (d') and bias measure (β) were derived.

The d' scores were analyzed in a 2 (age group) by 5 (TTC) mixed ANOVA with repeated measures. The main effect of age did not reach significance ($F(1, 20) = 0.12$, $MSE = 0.27$, $p = 0.73$). The average d' was 1.50 for younger observers and 1.60 for older observers. The main effect of TTC was significant ($F(4, 80) = 57.58$, $MSE = 6.77$, $p < .01$). As TTC increased from 2.5 s to 3.5 s, the average d' decreased from 2.33 to 0.92. The interaction between age group and TTC was not significant ($F(4, 80) = 0.76$, $MSE = 0.09$, $p = .55$). As can be seen from Figure 3, at all 5 levels of TTC, the d' of older observers was similar to that of younger observers.

We also examined whether the detection performance was above chance level. The number of younger observers with sensitivity greater than chance was 11, 11, 9, 8, and 5 (out of 11)

for TTC of 2.5 s, 2.75 s, 3.0 s, 3.25 s and 3.5 s, respectively. The number of older observers with greater than chance was 11, 10, 10, 7, and 6 (out of 11) for the 5 levels of TTC. These results suggest that majority of the observers were able to significantly detect collision events in the current experiment and replicate the primary finding in Experiment 1 that older and younger observers had similar performance in detecting curved collision events.

The bias measure (β) was also analyzed in a 2-way mixed ANOVA. The main effect of age was not significant ($F(1, 20) = 1.09$, $MSE = 4.43$, $p = .31$). The main effect of TTC was significant ($F(4, 80) = 4.39$, $MSE = 7.20$, $p < .01$). As TTC increased from 2.5 s to 3.5 s, the bias measure (β) increased from 1.46 to 2.97. Post hoc comparisons (Tukey HSD test) indicated that observers were more likely to report collision events in the 3.5 s TTC condition as compared to 2.5 s, 2.75 s, and 3.25 s TTC conditions ($p < .05$). The interaction between age group and TTC did not reach significance ($F(4, 80) = 0.77$, $MSE = 1.27$, $p = .55$).

4. Experiment 3

The results of Experiments 1 and 2, considered together, showed similar sensitivity to detect a curved trajectory collision event for older and younger observers. This suggests a similar ability of younger and older observers to use the constant rate of bearing change information to detect collision events along a curved trajectory. However, in Experiment 1 and 2, only one level of curvature (225 m^{-1}) was examined. As discussed previously, the rate of bearing change is determined by the curvature of the trajectory. In Experiment 3, we systematically examined the use of rate of bearing change by manipulating the curvature of the motion trajectories.

4.1. Method

4.1.1. Observers—The observers were 9 younger observers (4 male and 5 female) from the University of California, Riverside, and 9 older observers (5 male and 4 female) 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. Demographic information of the observers who participated in the current study and the results of the screening tests are presented in Table 1.

4.1.2. Stimuli—The stimuli were similar to that used in Experiment 2, except that 5 different curved trajectories (225 m^{-1} , 255 m^{-1} , 315 m^{-1} , 410 m^{-1} , or 550 m^{-1}) were examined.

4.1.3. Design—The 3-way mixed design included age as the between-subject variable. The within-subject variables included: (1) curvature of the motion trajectories (225 m^{-1} , 255 m^{-1} , 315 m^{-1} , 410 m^{-1} , or 550 m^{-1}); and (2) TTC of the object at the last frame of display (2.0, 2.75, 3.5, 4.25 or 5.0 s). Each of the 25 combinations between the two variables was presented for 48 replications (24 replications for collision and non-collision events, respectively). A total of 1200 trials were evenly divided into 3 blocks, which were completed in two 1.5-hour sessions. A practice block with 16 trials was first conducted followed by the experimental blocks. The order of trials in each block for each observer was randomized individually.

4.1.4. Apparatus and Procedure—The apparatus and the procedure were the same as in Experiment 1. Feedback was not provided during the practice trials or the experiment.

4.2. Results and discussion

For each observer, the proportion of hits and false alarms in each condition were calculated, and a sensitivity score (d') and bias measure (β) were derived.

The d' scores were analyzed in a 2 (age group) by 5 (curvature) by 5 (TTC) mixed ANOVA with repeated measures. The main effect of age did not reach significance ($F(1, 16) = 0.45$, $MSE = 1.6$, $p = .51$). There was a significant main effect for the curvature level ($F(4, 64) = 24.39$, $MSE = 13.95$, $p < .01$), a significant main effect for the TTC ($F(4, 64) = 456.19$, $MSE = 101.31$, $p < .01$), and a significant interaction between these two variables ($F(16, 256) = 4.05$, $MSE = 0.66$, $p < .01$). As shown in Figure 4, the mean sensitivity (d') increased as a function of decreasing curvature and decreasing TTC. Most importantly, the pattern of performance was almost identical between younger and older observers at each level of curvature, even at the smallest level of curvature (550 m^{-1}) when the motion trajectory was very similar to a linear trajectory. No other interactions were found to be significant ($p > .05$).

We also examined whether the detection performance was significantly different from chance level. When the TTC was 2.0 s and 2.75 s, all younger and older observers were able to detect collision events with greater than zero sensitivity. When TTC was 3.5 s, the number of younger observers with above chance performance for the five levels of curvatures was 5, 8, 9, 9 and 9 (out of 9), respectively. For older observers, the number of observers with above chance performance for the 5 levels of curvature was 7, 8, 9, 9 and 8 (out of 9). When TTC was 4.25 s, the number of younger observers with above chance performance for the five levels of curvatures was 3, 6, 8, 8, and 9 (out of 9). For older observers the number of observers was 2, 4, 8, 9, and 9 (out of 9). When TTC was 5.0 s, the number of younger observers with better than chance performance for the five levels of curvature was 0, 1, 2, 3, and 6 (out of 9), and for older observers these numbers were 0, 1, 1, 4, and 4 (out of 9). These results are consistent with the results of the d' scores that indicated that sensitivity to detection collision events decreases as a function of increasing TTC as well as increasing curvature level of the trajectories.

The bias measure (β) was also analyzed in a 3-way mixed ANOVA. The main effect of age was not significant ($F(1, 16) = 0.16$, $MSE = 1.03$, $p = .70$), nor was the main effect of curvature level ($F(4, 64) = 0.93$, $MSE = 0.46$, $p = .45$). The main effect of TTC, however, was significant ($F(4, 64) = 2.78$, $MSE = 2.60$, $p < .05$), which was mediated by an interaction with the curvature level ($F(16, 256) = 4.75$, $MSE = 1.93$, $p < .01$). According to this result, observers were more likely to make collision judgments with increased TTC when the curvature level was 225 m^{-1} , ($F(4, 72) = 12.39$, $p < .01$) or 255 m^{-1} ($F(4, 72) = 6.42$, $p < .01$). When the curvature level was 315 m^{-1} , 410 m^{-1} , or 550 m^{-1} , however, the observers' collision judgments did not vary as a function of TTC ($F(4, 72) = 1.87$, $p > .05$; $F(4, 72) = 1.08$, $p > .05$; and $F(4, 72) = 0.73$, $p > .05$). No other interactions reached significance ($p > .05$).

5. General Discussion

In the present study we examined age-related decrements in detecting collision events on curved trajectories. In Experiment 1 we presented observers with objects translating on either a linear or curved trajectory that would either collide with or pass by the observer. Several different levels of TTC were examined. We found decreased performance in detecting a collision on a curved as compared to a linear trajectory, a finding consistent with the results of previous research with college age observers (Ni & Andersen, 2008). The sensitivity to detect a collision event decreased with increasing TTC for both age groups. Although there was an age-related decrement in detecting a collision for a linear trajectory at

longer TTC conditions, there was no age-related difference in detecting a collision for a curved trajectory. In Experiment 2, we included more intermediate levels of TTC to determine whether age-related differences might exist for intermediate values of TTC not examined in Experiment 1. The results indicated that the detection performance was similar for both age groups at all levels of TTC. These results suggest that sensitivity decreases with increased TTC at the same rate for younger and older observers. In Experiment 3, we systematically manipulated the curvature of the trajectories and examined whether there was an age-related difference in detection performance as a function of curvature. Again, our results indicated similar sensitivity for the two age groups in collision detection at all levels of curvature. These results, taken together, suggest that the ability to use constant rate of bearing change information does not change with age.

These results are somewhat surprising given the results of previous research that found decreased performance of older observers in motion perception (e.g. Atchley & Andersen, 1998; Norman, et. al., 2004), TTC judgments (Oxley, et. al., 2005), and collision detection on a linear trajectory (Andersen & Enriquez, 2006). This difference is probably due to the use of optical information specifying a collision event. As discussed previously, the optical information specifying collision events on a linear trajectory is the fixed angular direction or position of the object's projection in the flow field, or constant bearing (Andersen & Kim, 2001). In order to correctly detect a collision event, observers have to differentiate the trajectories with constant bearing from those with variable bearing. On the other hand, the optical information for curved path collision events is a constant rate of bearing change. In order to accurately detect a collision event, observers need to differentiate the trajectories with a constant rate of bearing change from those with variable bearing change (Ni & Andersen, 2008). Andersen and Enriquez (2006) proposed that older observers were less sensitive to the expansion information and thus had difficulty in performing tasks requiring the detection of bearing change. This conclusion was based on the results of their research indicating that age-related declines in collision detection performance were greater at higher speeds of observer motion. Our results suggest age-related declines in using constant bearing information but no age-related decline in using constant rate of bearing change information.

So what might account for the discrepancy between the present results and the results of previous research? Constant bearing information is static information because the approaching collision object is stationary in the visual field. In contrast, constant rate of bearing information is dynamic information because the approaching collision object is moving in the visual field. This suggests that the age-related declines in performance for linear path collision events may be due to illusory motion of a stationary object in the visual field. Specifically, the motion of the surrounding scene may result in miss-perceived motion of a static collision object (with constant bearing) for older drivers whereas younger drivers are less susceptible to this illusion. Furthermore, the likelihood of misperceived motion would increase with an increase in driver speed (which increases the velocity of the surrounding driving scene). An important issue for future research would be to examine this explanation.

These results suggest two important conclusions regarding traffic safety. First, our results show decreased sensitivity to detect a collision on a curved trajectory as compared to on a linear trajectory for both younger and older drivers. This suggests that collision events involving a left turn (such as when the driver of a vehicle making a left turn under compensates when steering) are more difficult to detect than collisions with upcoming traffic, leaving drivers with a higher crash risk. The design and implementation of a collision warning system should take this consideration in order to improve driving safety.

Second, our results, together with previous findings (Andersen & Enriquez, 2006; De Lucia, et. al., 2003), indicate that older drivers have decreased ability to detect collisions than younger drivers. In order for older drivers to achieve the same level of detection performance as younger drivers, a shorter TTC is needed, leaving less time for older drivers to make appropriate responses to avoid collisions. However, for collisions events involving a curved path (such as a left turn), there is no age-related difference. Recent studies have provided evidence showing that training programs could potentially improve vision for both younger and older observers (e.g., Andersen, Ni, Bower, & Watanabe, in press; Ball & Sekuler, 1986; Richards, Bennett, & Sekuler, 2006). It has also been found that the training of Useful Field of View could improve driving safety for older drivers (e.g., Roenker, Cissell, Ball, Wadley, & Edwards, 2003). An interesting topic for future research is to examine whether training could improve the ability of drivers to use the optical information specifying a collision event (e.g. constant bearing information and constant rate of bearing change information) and whether this can lead to improved driving safety for both age groups.

Another interesting topic for future research would be to examine information from other sources that may be used to detect collision events on a curved trajectory. Previous studies have found that, in addition to TTC, edge rate information and relative size were also used to detect collision events during deceleration (Andersen, et. al., 1999; Andersen, et. al., 2000). An important issue for future research will be to examine whether there is an age-related difference in using different sources of information other than the expansion information to detect collision events on a curved trajectory.

One potential limitation with the methodology in the present study is that collision detection performance was assessed using a driving simulator. An important issue for future research will be to validate the present findings using real world driving conditions. In addition, previous studies have found that older drivers tend to self-regulate their driving behaviors in order to reduce crash risk (Evans, 2004). The present study examined age-related differences in detection performance when the only task was to identify collision events. Thus, older drivers did not have an opportunity to self-regulate driving performance. An important issue for future research will be to examine the effect of self-regulation of driving, by older drivers, on collision detection when engaged in more complex driving tasks.

In summary, the results of the current study indicate that older observers, as compared to younger observers, have a decreased ability to detect collision events on a linear trajectory particularly at long TTCs. However, there is no age-related decrement in detecting collision events on a curved trajectory. These results suggest that older observers, in addition to difficulty detecting expansion information, have more difficulty in detecting constant bearing information but not in detecting constant rate of bearing change.

Acknowledgments

This research was supported by NIH AG031941 and EY18334.

References

- Andersen GJ, Atchley P. Age-related differences in the detection of three-dimensional surfaces from optic flow. *Psychology and Aging*. 1995; 104:650–658. [PubMed: 8749592]
- Andersen GJ, Enriquez A. Aging and the detection of observer and moving object collisions. *Psychology and Aging*. 2006; 21:74–85. [PubMed: 16594793]
- Andersen, GJ.; Sauer, CW. Optical information for collision detection during deceleration. In: Hecht, H.; Savelsbergh, GJP., editors. *Time-to-contact*. Amsterdam: Elsevier; 2004. p. 93-108.

- Andersen GJ, Cisneros J, Saidpour A, Atchley P. Speed, size and edge rate information for the detection of collision events. *Journal of Experimental Psychology: Human Perception & Performance*. 1999; 25:256–279. [PubMed: 10069034]
- Andersen GJ, Cisneros J, Saidpour A, Atchley P. Age-related differences in collision detection during deceleration. *Psychology and Aging*. 2000; 15:241–252. [PubMed: 10879579]
- Andersen GJ, Ni R, Bower JD, Watanabe T. Aging and Neural Plasticity in Early Stages of Visual Processing. *Journal of Vision*. (in press).
- Atchley P, Andersen GJ. The effect of age, retinal eccentricity, and speed on the detection of optic flow components. *Psychology and Aging*. 1998; 13:297–308. [PubMed: 9640589]
- Ball K, Sekuler R. Improving Visual Perception in older observers. *Journal of Gerontology*. 1986; 41(2):176–182.
- Bian Z, Andersen GJ. Aging and the perceptual organization of 3-D scenes. *Psychology and Aging*. 2008; 23:342–352. [PubMed: 18573008]
- Bingham, GP.; Zaal, FT. Why tau is probably not used in guide reaches. In: Hecht, H.; Savelsbergh, GJP., editors. *Time-to-contact*. Vol. Vol. 135. Amsterdam: Elsevier; 2004. p. 371–388. *Advances in Psychology*
- Cheung I, McCartt AT. Declines in fatal crashes of older drivers: changes in crash risk and survivability. *Accident Analysis & prevention*. 2011; 43(3):666–674. [PubMed: 21376853]
- Corso, JF. Aging sensory systems and perception. New York: Praeger Publishers; 1981.
- DeLucia PR, Bleckley MK, Meyer LE, Bush JM. Judgments about collisions in younger and older drivers. *Transportation Research Part F: Traffic Psychology & Behaviour*. 2003; 6:63–80.
- Elliot DB. Contrast sensitivity decline with aging: A neural or optical phenomenon? *Ophthalmic and Physiological Optics*. 1987; 7:415–419. [PubMed: 3454919]
- Evans, L. Traffic Safety. Bloomfield Hills, MI: Science Serving Society; 2004.
- Federal Highway Administration (FHWA). FHWA-RD-94-021. Accident Analysis of Older Drivers at Intersections. Turner Fairbanks Highway Transportation Research Center. 1994 1994.
- Green, DM.; Swets, JA. Signal detection theory and psychophysics. New York: Wiley; 1966.
- Gilmore GC, Wenk HE, Naylor LA, Stuve TA. Motion perception and aging. *Psychology and Aging*. 1992; 7:654–660. [PubMed: 1466834]
- Hancock PA, Manser MP. Time-to-contact: more than tau alone. *Ecological Psychology*. 1997; 9:265–297.
- Lee DN. A theory of visual control of braking based on information about time to collision. *Perception*. 1976; 5:437–459. [PubMed: 1005020]
- Lee DN, Reddish PE. Plummeting gannets: A paradigm of ecological optics. *Nature*. 1981; 293:293–294.
- Lee DN, Young DS, Reddish PE, Lough S, Clayton TMH. Visual timing in hitting an accelerating ball. *Quarterly Journal of Experimental Psychology*. 1983; 35:333–346. [PubMed: 6571315]
- McKnight AJ, McKnight AS. Multivariate analysis of age-related driver ability and performance deficits. *Accident Analysis & prevention*. 1999; 31(5):445–454. [PubMed: 10440541]
- Ni R, Andersen GJ. Detection of collision events on curved trajectories: optical information from invariant rate-of-bearing change. *Perception & Psychophysics*. 2008; 70(7):1314–1324. [PubMed: 18927013]
- Norman JF, Clayton AM, Shular CF, Thompson SR. Aging and the perception of depth and 3-D shape from motion parallax. *Psychology and Aging*. 2004; 19:506–514. [PubMed: 15383000]
- Owsley, C.; Sloane, ME. Vision and aging. In: Bolter, F.; Grafman, J., editors. *Handbook of neuropsychology*. Vol. Vol. 4. Amsterdam: Elsevier; 1990. p. 229–249.
- Owsley C, Sekuler R, Siemsen D. Contrast sensitivity throughout adulthood. *Vision Research*. 1983; 23:689–699. [PubMed: 6613011]
- Oxley JA, Ihnen E, Fildes BN, Charlton JL, Day RH. Crossing roads safely: An experimental study of age differences in gap selection by pedestrians. *Accident Analysis and Prevention*. 2005; 37:962–971. [PubMed: 15993827]

- Raitanen T, Tormakangas T, Mollenkopf H, Marcellini F. Why do older drivers reduce driving? Findings from three European countries. *Transportation Research Part F: Traffic Psychology & Behavior*. 2003; 6:81–95.
- Richards R, Bennett PJ, Sekuler AB. Age related differences in learning with the useful field of view. *Vision Research*. 2006; 46:4217–4231. [PubMed: 17027061]
- Roenker DL, Cissell GM, Ball KK, Wadley VG, Edwards JD. Speed-of-processing and driving simulator training result in improved driving performance. *Human Factors*. 2003; 45(2):218–233. [PubMed: 14529195]
- Schiff W, Oldak R, Shah V. Aging persons' estimates of vehicular motion. *Psychology and Aging*. 1992; 7:518–525. [PubMed: 1466820]
- Sekuler R, Ball K. Visual localization: Age and practice. *Journal of the Optical Society of America A*. 1986; 3:864–867.

Figure 1.
A single frame of the stimuli used in the experiments.

Figure 2.
Sensitivity to collision events as a function of trajectory, TTC, and age in Experiment 1.

Figure 3.
Sensitivity to collision events as a function of TTC and age in Experiment 2.

Figure 4. Sensitivity to collision events as a function of TTC, curvature, and age in Experiment 3.

Table 1

Means and Standard Deviations of Participants' Demographic Information and Results From Perceptual and Cognitive Tests in Experiment 1 through 3

<i>Variable</i>	<i>Younger</i>		<i>Older</i>	
	M	SD	M	SD
Age (years) ^a	21.8	1.0	74.6	7.2
Years of education ^a	14.9	0.9	16.1	2.4
Snellen Letter Acuity ^a	10/10.3	4.3	10/19.0	8.4
Log Contrast Sensitivity ^b	1.58	0.1	1.59	0.2
Digit Span Forward	10.3	1.9	11.2	2.6
Digit Span Backward	6.9	2.8	7.4	2.0
Perceptual Encoding Manual ^a	89.1	15.3	58.8	13.3
Kaufman Brief Intelligence Test ^a	23.9	5.0	29.7	6.1

^a Differences between age groups were significant ($p < .05$) for both sets of age groups.

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