AGE-RELATED LIMITS OF 3D SPATIAL ATTENTION IN DUAL-TASK DRIVING

Russell Pierce, Zheng Bian, & George Andersen
Department of Psychology, University of California, Riverside
Riverside, California, USA
Email: Russell.Pierce@email.ucr.edu

Summary: A previous experiment by Andersen, Ni, Bian and Kang (2010) examined the limits of 3D spatial attention in younger drivers. In the current experiment, we examined age-related differences in the extent of 3D spatial attention by assessing participants' ability to detect a light-change target in an array of lights over a simulated roadway while performing a car following task. We found that reaction time to light-change targets presented during a car following task varied as a function of distance and horizontal position in younger adults, but only a function of distance in older adults. That is, the breadth of spatial attention for older drivers is constant across various depths. However, the depth of spatial attention may be somewhat less for older drivers as they respond to targets far away at approximately the same speed as younger drivers do for the lights at the same distance in the most extreme horizontal position. The results of the present study suggest that tests to assess crash risk, such as the UFOV, are limited in scope because such tests fail to consider the variation in attention as a function of distance.

OBJECTIVES

Driving safety is dependent on well functioning roadways, vehicles, and drivers. Measures that can assess drivers' spatial attention may help identify those who may have difficulty driving safely. In particular, the useful field of view (UFOV; Sekuler & Ball, 1986) has been identified as a predictor of accident risk among older drivers (Sims, McGwin, Allman, Ball, & Owsley, 2000; Owsley, Ball, Sloane, Roenker & Bruni, 1991; Owsley, Ball, McGuin, Sloane, & Roneker, 1998). However, the UFOV only assesses the extent of two-dimentional (2D) spatial attention, whereas driving is a task that takes place in three-dimentional (3D) space. The purpose of the current experiment was to determine whether an assessment of the scope of 3D spatial attention revealed age related differences that might be relevant to evaluating crash risk.

Measuring spatial attention in 2D, as the UFOV does, is in keeping with many theories of visual attention developed using 2D stimuli (e.g. Erikson & St. James, 1986; LaBerge & Brown, 1989). However, it has been demonstrated that depth is an independent and relevant dimension along which spatial attention can be allocated (e.g. Andersen, 1990; Andersen & Kramer, 1993) and that it stays relevant in older adults (Atchley & Kramer, 1998, 2000). Thus, it may be important to consider the extent of 3D spatial attention in relation to performance in driving tasks.

In fact, recent evidence demonstrates that attention is limited in 3D space while attending to a roadway scene (Andersen, Ni, Bian, & Kang, 2010). In Andersen et al.'s experiments participants engaged in a centrally presented simulated car following task while also detecting light changes above the simulated roadway at varying horizontal and depth positions. Participants responded

more rapidly to light changes that were closer in simulated depth than to those that were farther away, even though those light changes occurred further away from the central task in both horizontal position and projected height. These differences remained even after controlling for the changes in the projected size of the lights. Their results demonstrate that drivers' attention in a roadway scene is limited in the depth dimension with more attention directed to light changes nearby in depth than to light changes that were far away.

Atchley and Kramer (1998) conducted an experiment that examined the extent to which age influenced 3D spatial attention. In their experiment the only stimulus elements diagnostic for depth were size, vergence, and binocular disparity. They found that shifts of attention in depth occur at approximately the same speed for younger adults and older adults. However, in their experiment an advantage provided by valid attentional cues relative to neutral cues is present in younger adults but not in older adults. Atchley and Kramer suggest that the lack of an effect of depth may be due to older adults failing to tightly focus their attention along the depth axis. Consequently, we do expect differences in the extent of spatial attention of drivers as a function of age. However, the exact nature of the change remains an empirical question the answer to which will depend on real differences between younger and older drivers, the compensatory strategies they use, and the ways in which additional pictorial depth cues direct attention.

In summary, Andersen et al. (2010) examined the limits of 3D spatial attention in younger drivers. In the current experiment, we examined whether there are age-related differences in the extent of 3D spatial attention. The presence of age related differences in 3D spatial attention, and the nature of those changes, may have implications for how spatial attention is measured as a predictor of accident risk.

METHODS

Drivers

The drivers were 21 college students, 4 male and 17 female, (M age = 21.76 years; SD age = 2.75 years) and 20 older adults, 9 male and 11 female (M age =72.39 years; SD age = 4.98 years) who were paid for their participation. All drivers had normal or corrected-to-normal vision and were naïve to the purpose of the study.

Apparatus

A Dell XPS (Gen 2) desktop computer was used to present the displays on a 23 inch flat screen LCD monitor with a pixel resolution of 1024×768 and a refresh rate of 30 Hz. The nominal viewing distance was 91.5cm (36 inches) and was adjustable by the participant for their comfort. At this distance the visual angle of the display was $34.7° \times 25.8°$. A ECCI Trackstar 6000 wheel unit and pedal unit was used for closed loop control of the simulator.

Stimuli

The stimuli were computer generated 3-D scenes composed of a one-way road with three lanes, a lead vehicle, and buildings on both sides of the road. The lane widths were 3.8 meters, demarked

by dashed lines (2 meters in length positioned every 2 meters along the roadway). Asphalt was simulated using black and white gravel texture pattern. The driver and the lead vehicle were located in the center lane. A white sedan was used to represent the lead vehicle subtending a horizontal visual angle of 5.5° at a headway distance of 20.5m. Digital photographs of real buildings and vehicles were used as texture maps for the roadway scenes. The images were digitally altered to increase the realism of the simulator scene (e.g., remove specular highlights, add shading) and were scaled to be appropriate for the 3D geometry of the simulation. The average luminance of the driving scene was 24.7 cd/m^2.

In the car following task, the lead vehicle's average speed was 60 kmph (37.3 mph). It varied velocity according to a sum of 3 equal energy sinusoids (i.e., each sine wave's peak accelerations and decelerations were equivalent). The three frequencies used were .033, .083, and .117 Hz. The initial phase of the high and middle frequency sine waves was selected randomly with the phase value of the low frequency sine wave selected to produce a sum of zero. This manipulation ensured that the velocity profile of the lead vehicle varied smoothly. In the low workload condition, the amplitudes for the three sine waves were 9.722, 3.889, and 2.778 kmph, respectively. The average range of speed produced by the sum of sinusoidal functions was ±14.3 kmph about the mean speed. In the high workload condition, the amplitudes for each sinusoid were 220% the size of those in the low amplitude condition, resulting in an average speed variation of ±31.5 kmph about the mean speed.

In the light detection task, a light array with 21 lights was simulated, each of which randomly presented in red or green color. The simulated size of the light array was 12.68m × 0.60m, and it was placed at 2.7m above the roadway. Each light had a simulated diameter of 0.5m. The potential targets were the 3rd, the 6th, and the 9th to either side from the center. They represented a horizontal eccentricity of approximately 2.86°, 5.71°, and 8.53°.

Procedure

The experiment was run in a darkened room. The drivers were seated in front of the display with their hands on the steering wheel and feet on the pedals as if they were operating a vehicle. At the beginning of each trial, a stationary lead vehicle was presented on the display at a simulated distance of 20.5 meters from the drivers. When the drivers were ready to start the trial, they pulled a paddle on the steering wheel, and then both vehicles began moving down the roadway.

Each trial consisted of two stages. In the first stage, both the lead vehicle and the drivers' vehicle were moving at a constant speed of 60 kmph with a constant separation of 20.5m. Control input (acceleration/deceleration) was not allowed during this phase and the drivers were instructed to remember this distance as the desired headway distance for the rest of the trial. After 5 seconds, drivers heard a tone which indicated the start of the second stage. During the second stage the lead vehicle varied its speed according to the experimental design. The drivers were instructed to maintain a following distance that was indicated during the first phase by using the acceleration and brake pedals despite speed variations of the lead vehicle. Feedback for the car following task was used by activating a horn sound if the distance headway (the distance between the drivers' vehicle and the lead vehicle) exceeded 27.3 meters. The purpose of the horn was to simulate an impatient driver behind the drivers' vehicle and to ensure that the drivers closely attend to the

speed variation of the lead vehicle. If participants stayed 27.3 meters or further back for 15 seconds or more the trial terminated and they were asked to repeat the trial. If participants failed to respond to four or more banners during a trial, or if participant's vehicle closed within 2.35 meters of the lead vehicle, they were asked to repeat the trial.

While driving down the roadway the drivers would pass a light array every 75 meters with 21 red or green colored lights. Each array had a different random order of red and green lights. When the drivers' vehicle was 24 ± 4 meters away from the light array, one of the lights would change to yellow. The distance variation was used to prevent the drivers from predicting the light change event according to the visual angle of the light array. The target was the 3rd, 6th, or 9th light located on either side from the center. The drivers were instructed to indicate whether the target was on the left-hand or right-hand side of the light array. They made a response by pulling on the left or right paddle on the steering wheel. Feedback on the light detection task was given by activating a high-tone sound (indicating a correct response); no feedback was given for incorrect responses. If the drivers failed to make a response before passing the light array, a neutral sound was activated as a reminder to the drivers. On each trial, each of the 6 target positions (2 sides $\times$ 3 positions) was repeated twice, resulting in a total of 12 light detection responses. The order of the target position was randomized. Once the 12 light detection responses were completed, the trial was over and the drivers were instructed to start the next trial.

The experiment contained 9 sessions. The first 4 sessions were for the purpose of familiarizing participants with the two tasks as well as the dynamics of the driving simulator and each lasted 1 minute. In the first session participants only responded to the light detection task. In the second session participants only controlled the vehicle with the lead variation of the lead vehicle determined by one sine wave function with a frequency of 0.083 and an amplitude of 3.889 kmph. The third session was the same as the 2nd except that participants were asked to perform the light detection task as well. In fourth session participants were asked to perform both the car following task and the light detection task. During this session the lead vehicle moved according to a complex waveform designed to produce low workload. The fifth session consisted of a single trial which took about 65 seconds to complete successfully. In this session the lead vehicle moved according to a complex waveform designed to produce high workload. The remaining sessions were experimental sessions, each of which contained 3 trials for a total of 12 trials per experimental session. Workload was counterbalanced across blocks. In each experimental trial, the drivers did both the car-following task and the light-detection task and were instructed to perform both tasks equally well. A break was given after each session. Each trial lasted about 65 seconds and the duration of the whole experiment, including breaks, was about 60 minutes.
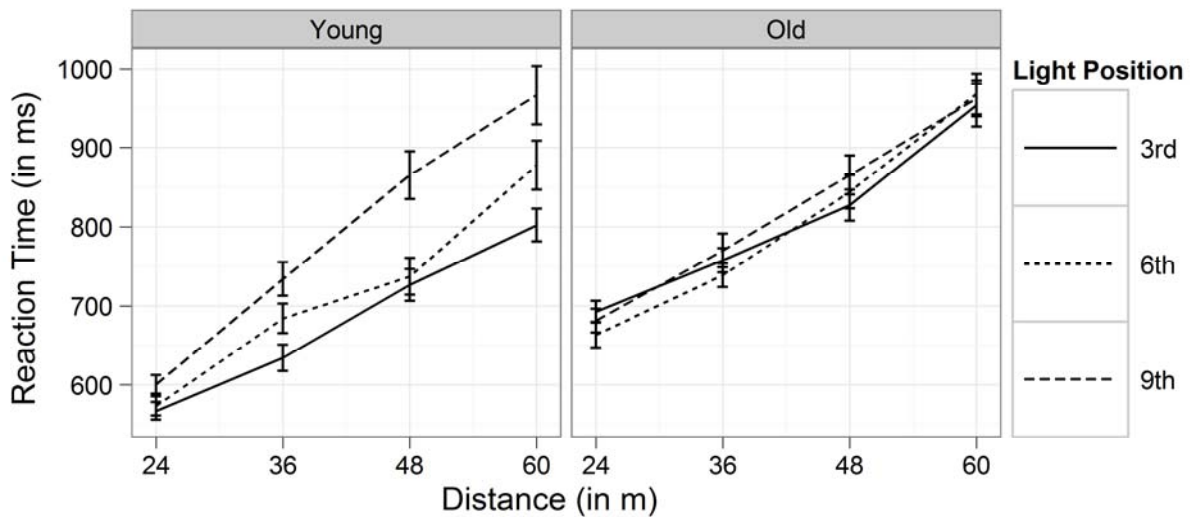
RESULTS

Throughout our analyses we reported Greenhouse-Geisser corrected p values, where appropriate, and the original degrees of freedom. To confirm that the workload manipulation was successful we examined root mean square (RMS) error of following distance in an Age x Workload mixed ANOVA. We observed separate main effects of age, $F(1, 39) = 5.58$, $p = .02$, and of workload, $F(1, 39) = 447.48$, $p < .001$. There was no interaction between these factors, $p > .05$, suggesting that the workload manipulation affected younger and older adults to a similar extent. See Table 1 for details.

Table 1. Mean RMS Error in Car Following

Workload	Age	
	Younger Drivers	Older Drivers
Low	5.11 (1.43)	6.16 (1.97)
High	8.64 (2.06)	9.74 (1.92)

Note: standard deviations in parentheses

We conducted separate Age x Light Distance x Light Position x Workload mixed ANOVA analyses for reaction time and accuracy on the light detection task. We observed differences across our independent variables in terms of accuracy and reaction time. Though there was a main effect of workload on accuracy, $F(1, 39) = 7.12$, $p = .01$, no other effects of workload reached significance, $ps > .05$.

Figure 1. Interaction between age, light distance, and light position on reaction time

There was an interaction between age, light distance, and light position on reaction time, $F(6, 234) = 3.55$, $p = .005$, the results of which are plotted in Figure 1. Simple effects analyses split by age reveled that there was an interaction between light distance and position for younger drivers, $F(6, 120) = 9.16$, $p < .001$, but that there was no interaction for these factors among older drivers, $F(6, 114) = 1.25$, $p = .29$. Specifically, younger drivers had a main effect of light distance, $F(3, 60) = 115.53$, $p < .001$, and light position, $F(2, 40) = 66.87$, $p < .001$, whereas older drivers had a main effect of light distance $F(3, 60) = 202.60$, $p < .001$, but no effect of light position, $p = .23$.
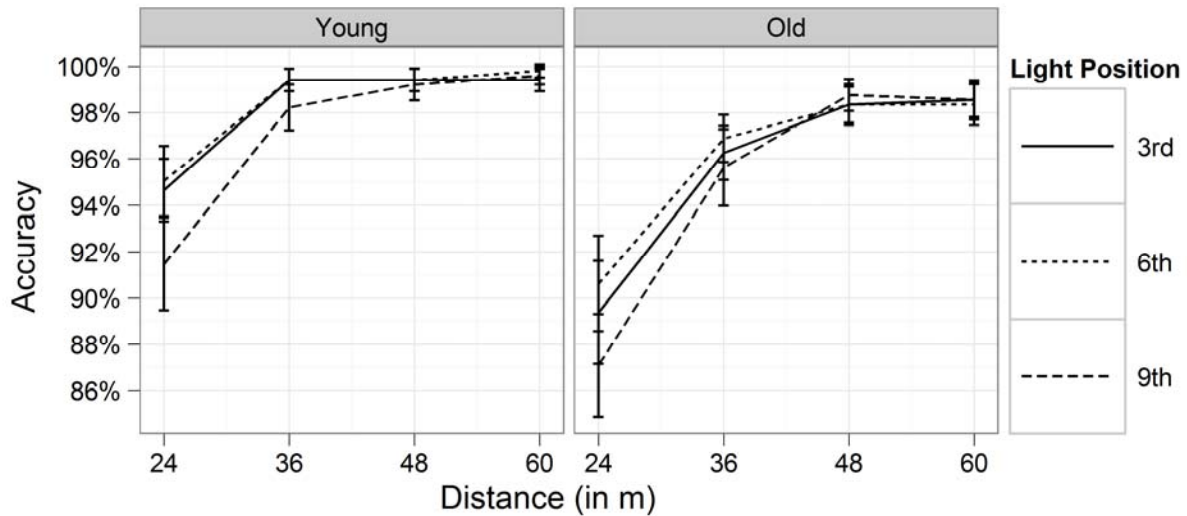
Figure 2. Interaction between age, light distance, and light position on accuracy

There was a light distance by light position interaction on accuracy, $F(6, 234) = 2.97$, $p = .02$. Specifically, simple effects analyses revealed that though there was an effect of light position at the closest distance, $F(2,80) = 5.14$, $p = .008$, that there were no significant differences at distances further away, all $ps > .05$. There was also a main effect of age on accuracy, $F(1,39) = 15.38$, $p < .001$. However no other factors significantly interacted with age, all $ps > .05$. See Figure 2.

As predicted, the extent of 3D spatial attention for older drivers is different than it is for younger drivers. Specifically, for younger drivers reaction time is a function of light position and distance whereas for older drivers it is only a function of distance. That is, the spread of spatial attention for older drivers is constant across various depths. Furthermore, the depth of spatial attention may be somewhat less for older drivers as they respond to light targets 60m away in all light positions at approximately the same speed as younger drivers do for the light in the 9th position.

CONCLUSION

A 2D model of spatial attention would predict two patterns that were not observed in our data. First, it would predict that reaction times to near objects would be the same as far objects. Second, because far objects appear more towards the center of the display, it would predict that light position should matter less for far objects than near objects. However, our data demonstrated the exact opposite pattern for younger adults. These results are similar to those reported by Andersen et al. (2010) who demonstrated that spatial attention during a driving task is affected by distance and by horizontal position. Specifically, our results indicate that the scope of spatial attention for young drivers is broad in space near the vehicle and reduces in spatial extent as it increases in depth. That is, among younger drivers spatial attention is directed asymmetrically in 3D space.

However, there are age-related differences in the extent of 3D spatial attention. Specifically, the horizontal spatial extent of attention at near distances was the same for younger and older drivers. However, the horizontal spatial extent of attention decreased at greater distances for

younger drivers but not for older drivers. Interestingly, the largest age related cost occurred at the greatest distance and for targets in close horizontal proximity to the lead vehicle. The results of the present study suggest that tests to assess crash risk, such as the UFOV, are limited in scope because such tests fail to consider the variation in attention as a function of distance. The available data did not allow us to assess the relationship between 3D spatial attention and crash risk. Nor did we develop a measure of spatial attention for the individual task performer. We recommend that as new procedures are developed to assess spatial attention for the purpose of predicting individual crash risk that researchers consider including a test of 3D spatial attention to augment already well established 2D measures.

ACKNOWLEDGMENTS

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