SPECIAL SECTION

Older Driver Failures of Attention at Intersections: Using Change Blindness Methods to Assess Turn Decision Accuracy

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A modified version of the flicker technique to induce change blindness was used to examine the effects of time constraints on decision-making accuracy at intersections on a total of 62 young (18–25 years), middle-aged (26–64 years), young-old (65–73 years), and old-old (74+ years) drivers. Thirty-six intersection photographs were manipulated so that one object (i.e., pedestrian, vehicle, sign, or traffic control device) in the scene would change when the images were alternated for either 5 or 8 s using the modified flicker method. Young and middle-aged drivers made significantly more correct decisions than did young-old and old-old drivers. Logistic regression analysis of the data indicated that age and/or time were significant predictors of decision performance in 14 of the 36 intersections. Actual or potential applications of this research include driving assessment and crash investigation.

INTRODUCTION

Older drivers are overrepresented in fatal traffic accidents on a per-mile basis (Evans, 1988; Hakamies-Blomqvist, 1993; Massie, Campbell, & Williams, 1995; McGwin & Brown, 1999; Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998; Stamatiadis & Deacon, 1998), most likely because of their fragility (Evans, 1988; Hauer, 1988). After age 75, the risk of intersection accident involvement for older drivers increases dramatically for most intersection maneuvers (Preusser et al., 1998; Staplin & Lyles, 1991). About one half of all driver fatalities for those 80 years of age and older are at intersections, compared with 23% for drivers younger than 50 years (Insurance Institute for Highway Safety, 2000). Typical citations by older drivers, once they are involved in an intersection accident, are failure to yield right of way and violation of traffic controls (Caird & Hancock, 2002). Failures of perception (Caird & Hancock, 2002; Schiff, Oldak, & Shah, 1992; Staplin, 1995), attention (Owsley, 2004), memory (Delorme & Martin-Lamellet, 1998; Guerrier, Manivannan, & Nair, 1999), cognition (Drakopoulos & Lyles, 1997), and action (Caird, Horrey, & Edwards, 2001; Hakamies-Blomqvist, 1994; Lerner, 1994) are frequently used to explain why older drivers are involved in accidents. Research that seeks to understand and predict why intersection accidents occur anticipates the unprecedented demographic shift that will swell the ranks of older drivers in the future (Caird & Hancock, 2002; Hakamies-Blomqvist & Henriksson, 2000; Owsley, 2004).

The current research examines the contribution of attentional failures at intersections. Attentional failures may result from the improper division of attention (Caird & Chugh, 1997; Ponds, Brouwer, & van Wolffelaar, 1988), visual search difficulties (McDowd & Shaw, 2000; Scialfa, Kline, & Lyman, 1987; Scialfa, Thomas, & Joffe, 1994), and/or inappropriate selective attention (Ball & Owsley, 1991; Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Owsley et al., 1998; Owsley, Ball, Sloane, Roenker, & Bruni, 1991; Parasuraman & Nestor, 1991). As

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such, failures of attention may result in drivers failing to detect a potential conflict with another object or detecting the conflict too late to respond appropriately (Caird & Hancock, 2002; Cairney & Catchpole, 1996; Rumar, 1990; Treat, 1980). Knowledge of the nature of visual attention may contribute to the understanding of attentional failures and, consequently, the understanding of driver errors at intersections.

In the current context, the inability of drivers to effectively detect changes in a rapidly changing and dynamic environment, such as a busy intersection, may represent an important attentional failure. Recent studies on change blindness have shed light on the understanding of visual attention. *Change blindness* is defined as the inability to detect changes made to an object or a scene during a saccade, flicker, blink, or movie cut (O'Regan, Rensink, & Clark, 1999).

In general, change blindness has implications for understanding how humans construct, link, and store visual representations. The long-held view is that people store detailed and coherent picture-like representations of the world from one view to the next. However, recent research into change blindness suggests this may not be the case (e.g., Mack & Rock, 1998; O'Regan et al., 1999; Rensink, O'Regan, & Clark, 1997, 2000; Simons & Levin, 1997). For example, Rensink (2000, 2002) suggested that focused visual attention provides spatiotemporal coherence for the stable representation of a single object or spatial location at a time. As such, accurate visual representations may exist only so long as attention is focused on the region or object in question. When attention is focused in one location, changes occurring in other parts of the visual scene may go unnoticed by observers, simply because there is no detailed representation of the changing location at that particular moment. If focused attention on hazardous objects is required to construct a coherent representation of a traffic scene, it follows that intersections that have increased complexity, traffic flow, and visual clutter will also have a higher incidence of missed changes (e.g., the appearance of a pedestrian from behind an initially occluding object) because drivers will fail to maintain a complete and accurate representation of each aspect of a visual scene.

Change blindness is especially pronounced when brief blank fields are placed between alternating displays of an original and modified scene, which is called the *flicker technique* (O'Regan et al., 1999; Rensink et al., 2000). In the standard or generic application of this technique, an image (A) and a modified image (A′) are presented for a short duration (typically 250 ms) separated by a blank field of 80 ms (i.e., the interstimulus interval, or ISI). The images are alternated repeatedly until the observer detects the changing element or a certain time has elapsed. The blank screen separating the two images simulates a saccade and is used to mask the appearance of new objects in the scene – changes that are readily detected when no such mask is present (Rensink et al., 1997). Importantly, these masks are effective even when they only partially occlude the scene (e.g., "mudsplats"; O'Regan et al., 1999).

Research on change detection has further shown that older adults miss more scene changes than do younger adults, suggesting age-related deficits in the ability to maintain a stable visual representation (Pringle, Irwin, Kramer, & Atchley, 2001). Furthermore, others have shown that changes made to objects of central interest are detected more readily than changes to objects of marginal interest (Pringle, 2000). Richard et al. (2002) extended these results to the driving domain, showing faster and more accurate detection of driving-related changes than of unrelated scene changes. These lines of research, however, adopt the typical flicker technique in which observers are instructed to look for changes. Although this approach effectively demonstrates the effects of change blindness, the task itself (i.e., detecting changes to scenes) is not representative of real-world tasks. Furthermore, it is not clear from past research whether age-related differences might be reduced when the task draws upon previous experience. Specifically, it is not known whether the poor detection performance of older adults might be reduced if they can draw on their driving experience (i.e., the practiced and appropriate allocation of visual attention). The current instantiation of the flicker technique does not afford such use of experience to guide task completion. One goal of the current research is to modify the flicker technique such that the observers' tasks are more representative of driving and that the (implicit) detection of changing features will have an impact on this task performance.

Present Study

In the current study, we modified the flicker method so that it could be used to test drivers' attentional capabilities at intersections. Typically, observers are asked to look for changes in two alternating images. Furthermore, observers are rarely under any time pressure in which to make a decision about whether a change is present. Drivers in a dynamic traffic environment rarely have more than a few seconds to observe a given scene or context. In contrast to the traditional approach, the modified flicker method (MFM) provides observers with a specific goal, rather than simply to monitor for changes, and also imposes some time constraints on observers such that their goal-oriented decision must take place rapidly. In the current study, drivers were asked to decide whether it was safe to complete a certain maneuver (i.e., making either a left or right turn, or continuing straight ahead) at each intersection. Although the MFM does not require participants to search actively for a changing feature, it is assumed that the correct detection of a safety-critical object will impact their decision of whether or not to proceed through the intersection. Imposing a directional goal (i.e., of travel) guides drivers' attention more efficiently and allows them to use prior experience to search for relevant information (Theeuwes, 1996; Yantis, 1998).

In the present study, the MFM was used to determine the effects of time constraints on the performance of younger and older drivers' decision making at intersections. Drivers examined a series of intersections for either 5 or 8 s in order to assess the safety of the intended path of travel. It was expected that a shorter viewing time would negatively impact decision accuracy. To the extent that older adults could draw on experience, there would be smaller age-related decrements in performance. However, if older adults were unable to draw upon related experience, these decrements would remain, suggesting that the impact of less stable visual representations sufficiently offset any benefit of experience.

METHOD

Participants

Sixty-two older and younger drivers were recruited from the following age groups: young (18–25 years, M = 22), middle-aged (26–64 years, M = 39), young-old (65–73 years, M = 69), and old-old (74+ years, M = 78). There were 8 men and 8 women in the first three age groups and 8 men and 6 women in the 74+ group. Older participants were recruited from senior community programs in Calgary. Younger volunteers were recruited from the University of Calgary. All groups were compensated for their participation. A valid driver's license and an active driving record were requirements for participation. All were screened for visual acuity and contrast sensitivity.

Participant responses to the background driver experience questionnaire and visual screening tests are shown in Table 1. The number of years driving is also somewhat indicative of age. The number of kilometers driven per year is slightly lower for the young-old age group (65–73) than for the other age groups. The number of violations per year is highest in the young (18–25) age group. The mean number of accidents for all age groups is between one and two. The youngest age group had the highest mean number of accidents in the past 5 years. Corrected visual acuity and contrast sensitivity declined and were somewhat more variable in the two older age groups.

Materials

Hardware and software. Intersection photographs were captured with a Nikon CoolPix 950 digital camera (at 800 × 600 resolution) and manipulated using Adobe Photoshop 5.5 on a Macintosh G3 computer. Toolbook was used to develop the software application that managed the presentation of images and data collection. The application ran on a 933 MHz Pentium III PC connected to an Epson data projector (Model 710C). Image sequences appeared on a 1.5- × 1.3-m screen (Model Da-Lite) positioned 3 m in front of participants; the projected image subtended 24.43° horizontally and 26.57° vertically. The participants were seated at a vehicle mock-up composed of a steering wheel, brake, and accelerator. Only the brake and accelerator inputs were recorded. Luminance measures

TABLE 1: Participant Sample Characteristics

	Age Group			
Descriptive Measure	18–25	26–64	65–73	74+
Mean age (*SD*)	21.75 (2.1)	38.81 (13.8)	69.25 (2.2)	78.4 (3.8)
Years driving (*SD*)	5.13 (1.7)	20.56 (11.8)	47.5 (6.3)	53.1 (11.5)
Km/year driven (*SD*)	14,812 (10,836)	15,013 (9,372)	10,718 (6,850)	13,285 (9,406)
No. of violations last 2 years (*SD*)	5.13 (1.7)	0.2 (0.4)	0.2 (0.4)	0.36 (0.6)
Total accidents (*SD*)	1.63 (1.4)	1.44 (1.1)	1.31 (1.2)	1.79 (1.5)
Accidents last 5 years (*SD*)	1.5 (1.5)	0.5 (0.6)	0.65 (0.3)	0.36 (0.6)
Corrected visual acuity (*SD*)	20.1 (3.5)	20.1 (4.1)	21.4 (6.4)	29.3 (6.5)
Mean contrast sensitivity values for spatial frequencies of 1.5, 3, 6, 12, 18 (cycles/°)	70, 127.5, 125, 71.5, 26	70, 85, 125, 55, 15	70, 85, 97.5, 55, 10	62.5, 85, 57.5, 32, 10

were collected using a Minolta LS110 photometer.

Driving images. Approximately 2500 digital pictures of signalized and nonsignalized intersections were taken in and around Calgary, Winnipeg, and Montreal. The final set of images was selected on the basis of image quality, position of the vehicle relative to the intersection, opportunities for image manipulation, and a variety of intrinsic image properties such as traffic control devices, signage, pedestrians, other vehicles, and hazards. Pilot testing determined that few, if any, participants could reliably tell where each image was filmed.

A subset of images was duplicated and manipulated in Photoshop to create sets of paired images: Image A (unmanipulated) and Image A′ (manipulated). After a series of pilot studies, the images that were used for the experiment were reduced to 42 image pairs (i.e., A and A′). Of these, 6 were used for training and the remaining 36 were utilized for experimental trials. Of the latter, 26 included changing features and 10 did not contain any changes (i.e., A was the same as A′). The purpose of including unchanging images was to reduce participant expectancy of changes. Table 2 lists each intersection and associated information.

Modified change blindness paradigm. In the standard or generic application of the flicker technique, an image (A) and a modified image (A′) are presented for a short duration (typically 240 ms) separated by a blank field of 80 ms (i.e., the ISI; e.g., Rensink et al., 1997, 2000). The images are alternated repeatedly until a response is made or a certain time has elapsed.

This technique, however, was modified in the current study in order to introduce some time constraints as well as specific driver goals, features that are more typical of driving than those provided by the normal flicker paradigm. For example, the MFM creates a situation in which drivers have a limited time to decide whether or not an intended direction of travel is safe. In contrast, other applications of this paradigm have observers actively search scenes for a changing feature, regardless of the context.

The principal difference between the present study and previous flicker studies was that here each trial began with the presentation of one of three directional arrows centered on the screen, corresponding to the direction to turn left, right, or proceed straight ahead. The arrow indicated the desired direction of travel for the intersection that followed. For example, a left directional arrow indicated that a participant would be making a left-hand turn. Figure 1 illustrates the directional screen, intersection image, visual mask, participant directions, and variables. Once the directional arrow was memorized, participants initiated the trial. Each image in a pair was presented for 250 ms, and a gray mask was presented for 80 ms between the two (see Figure 1). Images A and A′ continued to flicker back and forth for either 5 or 8 s.

Procedure

At the beginning of a 75-min session, participants completed an informed consent form and a background questionnaire concerning age, gender, driving experience, and habits. Visual acuity was tested at a distance of approximately

TABLE 2: Intersection Characteristics

No.	Description	Go/ No Go	Travel Direction	Accuracy % (All Age Groups)
1	Signalized traffic lights, *car coming* toward viewer	No go	Left	57.33
2	Yellow light at intersection	Go	Straight	22.05
3	*Changing traffic signal* with a pedestrian	No go	Right	95.1
4	Light rail transit crossing, *train*	Go	Left	90.2
5	One way street with signalized traffic devices, *pedestrian*	Go	Left	42.93
6	Signalized intersection, vehicle turning ahead, *indicator light*	Go	Right	53.53
7	Signalized left turn, *car approaching* in opposite lane	No go	Left	85.4
8	Cars to the left, *pedestrian running* across road	No go	Straight	39.35
9	Pedestrian crosswalk, *pedestrian stepping* into crosswalk	No go	Straight	57.3
10	Left turn at signalized intersection	No go	Left	56.93
11	Right turn, signalized intersection, plethora of signage	Go	Right	67.8
12	One-way intersection, *pedestrian exiting* vehicle on far side	No go	Straight	31.33
13	*Yellow light change* at intersection	Go	Straight	75.68
14	Following vehicles in left turn maneuver	Go	Left	52.3
15	Two way intersection, *no-turn sign changing*	No go	Left	35.95
16	Intersection with construction, *vehicle ahead braking*	Go	Straight	72.55
17	Left turn, *vehicles* in opposing lane	No go	Left	93.55
18	Left turn lane, vehicles ahead, *store sign changing*	No go	Left	75.23
19	Traffic signal green, turn signal red	Go	Straight	88.25
20	Left turn, *oncoming vehicle,* view blocked by opposing turning traffic	No go	Left	84.05
21	One way street, *oncoming car*	No go	Left	82.83
22	Traffic signal green, one-way only to the left	No go	Right	70.68
23	Downtown intersection, *van turning* across view	No go	Straight	79.1
24	Vehicles ahead, *pedestrian crossing* street	No go	Straight	69.8
25	Multilane intersection, traffic signal red	No go	Right	38.48
26	Opposing vehicle turning right, *indicator lights changing*	Go	Left	64.8
27	Approaching one-way street to the left	No go	Right	55.3
28	Two lanes, *traffic control signal disappearing*	Go	Straight	93.15
29	Left turn lane, *pedestrian crossing* road	No go	Left	23.73
30	One way street, turn signal green	Go	Left	82.3
31	Two way intersection, *taxi incurring* from the left	No go	Straight	54.7
32	Two way intersection, *one way sign appearing* and *disappearing*	Go	Straight	83.68
33	Protected left turn, *green proceed signal,* opposing vehicles approaching	No go	Left	75.58
34	Left turn, green proceed signal, *vehicle appearing* on the right	Go	Left	91.83
35	Green proceed signal, opposing vehicle turning, *pedestrian crossing* from behind vehicle	No go	Straight	15.75
36	Green signalized intersection	Go	Straight	100

Note. Intersection changes are indicated in italics.

6 m (20 feet) using Landolt Cs, and contrast sensitivity was tested at a distance of about 3 m (9 feet) using the Vistech Vision Contrast Test System. Participants received a short verbal overview of the tasks and completed six practice trials. Practice trials included all three directions of travel. Following the practice trials, participants were randomly assigned to one of two separate experimental orders.

For the experimental block, drivers were presented with 36 intersections that varied in complexity and type of change present (see Table 2). For half of the trials, participants had 5 s to observe the scenes, and in the other half they had 8 s. The amount of time to observe the intersection varied randomly within the experimental block and was counterbalanced across the two experimental orders.

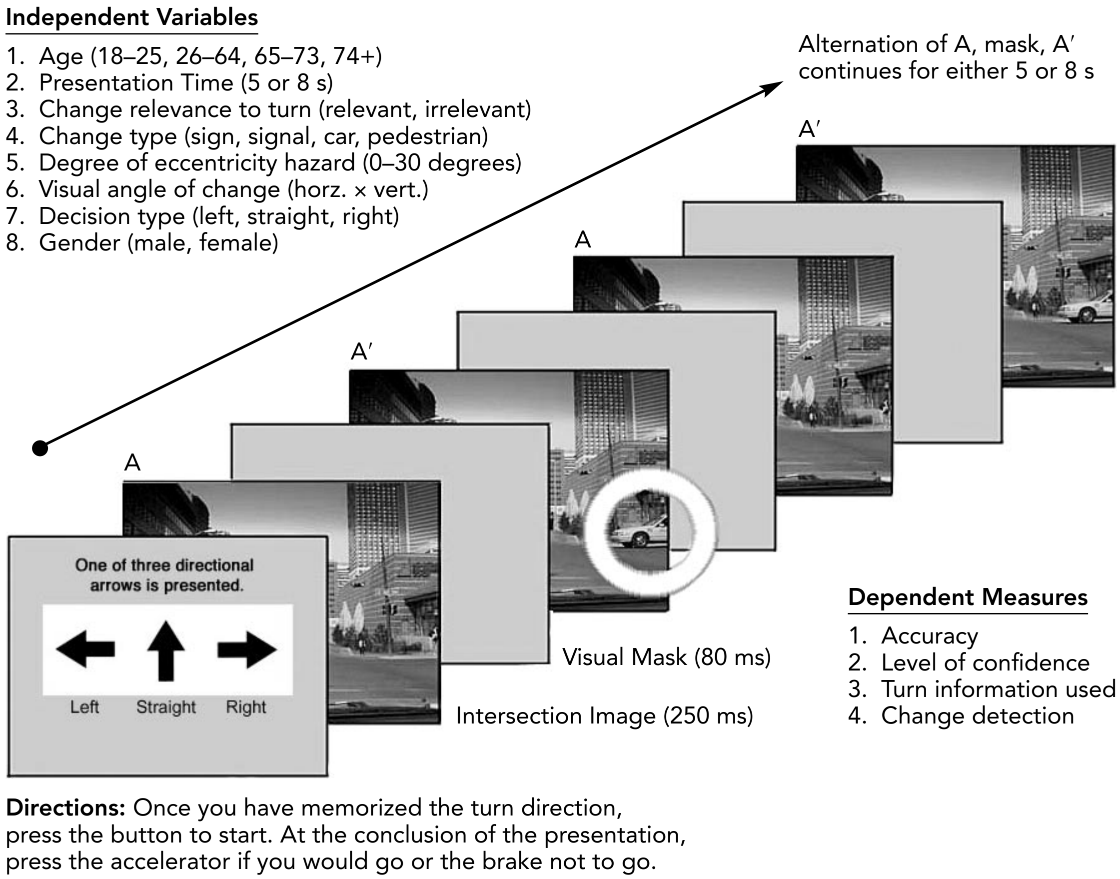

Figure 1. Modified flicker method with image sequence, timing, variables, and participant directions.

For each trial, participants were instructed to decide whether they would go or not go in the direction that was indicated in the first screen, based on the information they observed within each traffic scene. After the flickering stopped, a screen appeared that asked them to respond by pressing the accelerator to go or the brake not to go. Once they pressed either the brake or the accelerator, they were reminded to place their foot back on the ground.

Participants' responses were used to assess decision accuracy. Additionally, following the go/no-go response, another screen appeared that asked four questions – namely, "How confident are you in your decision to go or not to go?"; "State all of the elements (e.g., lights, other vehicles, signs, pedestrians) of the traffic scene that influenced your decision to go or not to go from the most important to the least important"; "Did you notice anything changing in the images that you saw?"; and "Did you make any assumptions about what you saw?" Following the experimental block, participants were debriefed and remunerated for their participation.

RESULTS

Accuracy

The 4 × 2 experimental design included the between-subjects variables of age (young, middle-aged, young-old, and old-old) and time (5 s, 8 s). Accuracy was determined by whether participants correctly chose to go or not to go at each intersection. Through several screening steps, in which ambiguous intersections were dropped from a larger set of 92 intersections, the experimenters determined the correct responses a priori. All 36 intersections were evaluated in terms of whether a decision to go would cause a collision or violate a traffic sign or signal.

Accuracy scores were analyzed using an analysis of variance (ANOVA) across age group and time. The main effect for time was not significant, $F(1, 58) = 0.169$, $p = .683$, nor was the Time × Age interaction, $F(3, 58) = 0.071$, $p = .975$. However, as shown in Figure 2, the main effect for age group was significant, $F(3, 58) = 18.778$, $p < .001$. Multiple comparisons (using a Bonferroni correction) showed that the young age group had greater accuracy ($M = 74.16$) than did the young-old ($M = 60.35$) and old-old ($M = 53.96$) age groups, although there was greater variability in the latter two groups (see Figure 2). (All noted differences were significant at $p < .01$.) Similarly, the middle-aged group ($M = 73.58$) showed significantly greater accuracy than did the young-old and old-old age groups ($p < .01$).

A multiple regression was run using contrast and size as the predictor variables of accuracy for each of the four age groups. A ratio calculation was used to provide the luminance percentage contrast of when an object appeared and disappeared using multiple measures. The calculation was then derived from the Michelson luminance contrast measure: $C = (l_{\max} - l_{\min})/(l_{\max} + l_{\min})$. Object size was computed using the product of the height and width visual angles.

Neither contrast nor size predicted decision accuracy in any of the models. Of particular note, the young-old and old-old age group accuracy was not predicted by object contrast and size, $F(2, 33) = 0.953$, $p = .3696$, young-old; $F(2, 33) = 0.44$, $p = .957$, old-old. Despite these two age groups having worse visual acuity and contrast sensitivity than the middle-aged and young groups (see Table 1), object size and contrast did not reliably predict decision accuracy.

Logistic Regression

To understand the impact of each intersection on turn decision accuracy, we used logistic regression (LR) to explore individual intersections for diagnostic purposes. LR provides a means to predict outcomes when using a set of variables that are continuous, dichotomous/discrete, or a mixture (Tabachnick & Fidell, 2001). LR produces a log-linear function that describes results in a more complex manner than the usually understood methods (e.g., linear regression). A series of 36 direct (i.e., predictors entered simultaneously) logistic regressions were computed using SPSS 11.0. The two predictors used were age and time, and the outcome variable was decision accuracy. Age was used as a continuous predictor because of insufficient cell sizes

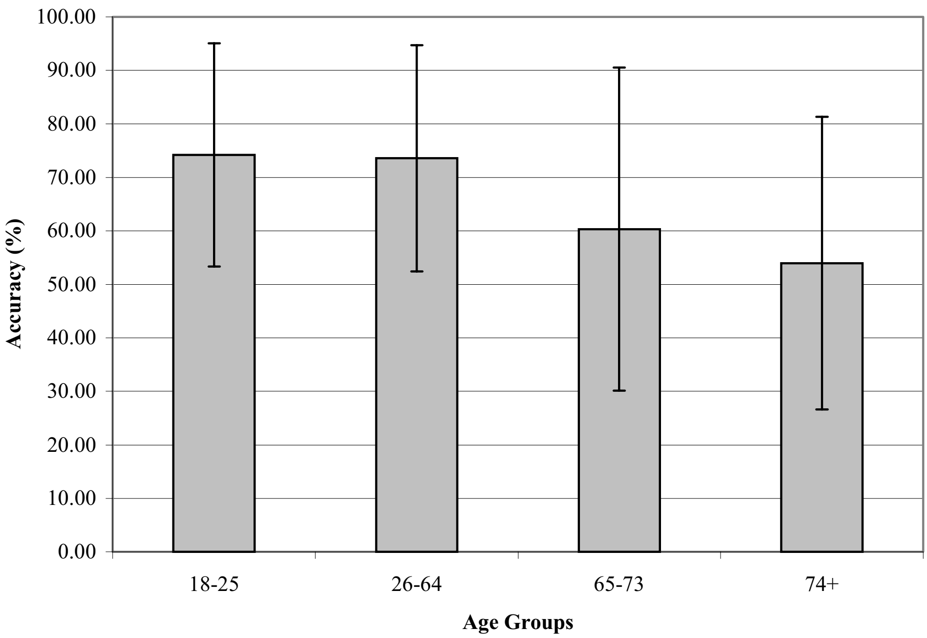

Figure 2. Mean decision accuracy (%) by age group for all 36 intersections. Error bars indicate 1 *SD*.

across all age groups when left as a categorical variable.

Insufficient cell sizes can lead to highly inflated parameter estimates, which in turn lead to erroneous results. Unique characteristics of each intersection (traffic control devices, vehicles present, pedestrians, etc.) confound collapsing accuracy across intersections. Each intersection is assumed to possess unique information that drivers use to determine whether to turn, and therefore intersections were analyzed individually for effects. In total, 62 cases were entered into each of the logistic regressions. The 62 cases represent individual participants, and the 36 models represent one intersection each.

Of the 36 logistic regression analyses, 14 provided statistically significant predictions of accuracy. Age was a significant accuracy predictor in 10 intersections, time was a significant predictor for accuracy in 1 intersection, and both age and time were significant predictors in 3 intersections. Table 3 shows the intersections with significant age and time predictors, a brief description of the intersection, and associated statistics. LR results are typically reported to show the significance of each predictor (χ^2), Wald (*z* ratio), and parameter estimates (*B*). Additional analyses include odds ratios – Exp(*B*) is an expression particular to SPSS – and interpretations.

Significant chi-squared values indicate that either predictor reliably predicts turn accuracy. Whether time or age is a significant predictor of decision accuracy is indicated by the Wald statistic. A value of ±2 is considered significant for the Wald test with a confidence interval of 95% for a standard normal distribution. When the Exp(*B*) or odds ratio is less than 1.0, 1 divided by the Exp(*B*) coefficient is the odds ratio (Menard, 1995; Pedhazur, 1997). Note that percentage increases are based on an exponential function.

We further examined some of these significant

TABLE 3: Logistic Regression of Accuracy with Driver Age and Time to View an Intersection

Intersection	Description	$\chi^2(2)$	χ^2 *p* Values	Predictors	*B*	Wald (*z* Ratio)	Exp(*B*) (Odds Ratio)
2	Yellow light, parked cars, pedestrians	7.58	.023	Age	–0.034	2.32	0.967
				Time	–0.882	1.32	0.414
5	Green light, left turning vehicle, pedestrian	10.21	.006	Age	–0.034	2.78	0.967
				Time	0.796	1.41	2.218
8	Stopped traffic, green light, pedestrian	27.65	.0001	Age	–0.067	3.99	0.935
				Time	1.67	2.21	5.332
9	Clear intersection, pedestrian, green lights	12.00	.002	Age	–0.037	2.89	0.964
				Time	–0.964	1.67	0.382
12	Green lights, pedestrian, bicyclist	33.03	.0001	Age	–0.087	3.98	0.964
				Time	1.89	2.18	6.633
13	Vehicles ahead, yellow light, oncoming turning vehicles	4.457	.045	Age	0.001	0.11	1.001
				Time	1.31	2.00	3.711
15	Bus, no-left-turn sign, green lights	14.20	.001	Age	–0.044	3.37	0.957
				Time	–0.584	0.97	0.558
21	Green lights, one-way, no-left-turn sign	18.28	.0001	Age	–0.142	2.24	0.868
				Time	–0.272	0.33	0.762
23	Commercial truck, turning van, green lights, one-way	8.17	.011	Age	–0.044	2.44	0.957
				Time	–0.196	0.29	0.822
24	Traffic, pedestrian, pedestrian crossing lights	12.43	.002	Age	–0.041	2.77	0.959
				Time	1.12	1.76	3.069
27	Vehicles ahead, one-way sign, green light	15.60	.0001	Age	–0.034	2.56	0.967
				Time	1.75	2.86	5.758
29	Stopped vehicle, pedestrian, signs	12.05	.002	Age	–0.043	2.84	0.958
				Time	1.01	1.49	2.735
31	Pedestrians, taxicab, green lights	8.61	.013	Age	–0.033	2.78	0.967
				Time	0.016	0.03	0.985
35	Turning vehicle, green lights, pedestrian	13.89	.001	Age	–0.063	2.66	0.939
				Time	1.09	1.35	3.001

intersections to determine some of the factors contributing to the differences in performance across age and/or time. The following sections break down these intersections by the type of change occurring in the scene.

Intersection decision accuracy with changing pedestrians. Space limitations constrain the number of intersections that can be described and interpreted. Seven of the 14 intersections showing significant predictors (5, 8, 9, 12, 24, 29, 35) had pedestrians as the relevant change, and all showed age effects, with Intersections 12 and 24 also showing time effects. Figure 3 (top left) shows Intersection 8 with the change in it highlighted. In Intersection 8, four vehicles were stopped in the left-turn lane next to the participant, who was in a straight-ahead lane. Both traffic lights were green, and there was one vehicle just before the intersection in the lane to the right of the participant. This vehicle was braking. The change incorporated in this intersection was a pedestrian running out in front of oncoming traffic, from behind the vehicles stopped in the left-turn lane.

For Intersection 8 the *B*-value result was negative, indicating that as age increases, the probability that the participant will be accurate declines. In particular, because the *B* value for age is negative, the odds ratio value associated with it is less than 1.0, Exp(*B*) = 0.935. When the Exp(*B*) is less than 1.0, 1 divided by the Exp(*B*) coefficient is easier to interpret (Pedhazur, 1997). In our sample for this intersection, 1/0.935 yields a value of 1.07. The odds ratio for Intersection 8 indicated that for every one-unit (1-year) increase in age, the odds of being inaccurate increased by about 7%. Note, however, that this 7% increase is based on an exponential function, which means that a 2-year increase in age does not equal a 14% increase in inaccuracy. Results from the participant self-reports suggested that older drivers did not see the pedestrian. Time was also a significant predictor at this intersection. The odds of being accurate were five times greater for the 8-s category than for the 5-s category. The longer viewing time increased the likelihood of detecting the pedestrian.

Participants were asked to state all of the elements (e.g., lights, other vehicles, signs, pedestrians) of the traffic scene that influenced their decision to go or not to go from the most important to the least important. A frequency

Figure 3. Examples of significant intersections. Top left: Intersection 8, pedestrian. Top right: Intersection 15, traffic sign. Bottom left: Intersection 31, vehicle (bottom left). Bottom right: No change. White circles are used to highlight changes here and did not appear in the image presented to participants.

analysis of reported items collapsed across young (18–64) and old (65+) age categories provide interesting information for future eye movement analysis (Ho, Scialfa, Caird, & Graw, 2001) and strategic compensation research (Chu, 1994). Based on the verbal reports of participants, attention was most likely directed toward the line of vehicles stopped on the left and the state of the lights. As with other intersections, detecting the pedestrian was critical for making the correct decision to stop. Qualitative analyses are mixed with LR analyses to add insight through the rest of the results.

The size, obscuring vehicles, and contrast of a pedestrian in Intersections 5, 9, 24, 29, and 35 may have contributed to the difficulty of detection. Time and size contributed to detection difficulties for Intersection 12. In Intersection 5, the pedestrian was moderately obscured by the turning vehicle. The correct decision was to stop because the pedestrian had a walk signal, which was visible. The change in Intersection 9 was the appearance of a pedestrian crossing the road from the right on a pedestrian crosswalk. The size of the pedestrian may have contributed to older drivers failing to detect it (visual angle = $1.16° \times 2.24°$). Intersection 12 was a one-way street, and the lights were green. On the left, there was a cyclist with his foot down on the road, indicating he was stopped. The intersection was sunny but was shadowed on each side. A pedestrian, exiting from a vehicle into the street next to the participant's lane, appeared on the other side of the intersection in the shadows. The pedestrian was small (visual angle = $0.26° \times 1.08°$). For this intersection, a one-unit increase in age increased the odds of being inaccurate by 9%. Time was positively related and indicated that the odds of being accurate were almost seven times greater for the 8-s condition than for the 5-s condition.

The pedestrian crossing lights in Intersection 24 showed that the crossing was potentially in use. Ahead of the participant's vehicle there were stationary vehicles, of which only the car in front had its brake lights on. The change associated with this intersection involved the appearance of a pedestrian on a crosswalk in front of the stopped vehicles. Intersection 29 contained a turn lane with roadway markings, a stopped vehicle to the right, and a series of traffic flow signs that indicated lane designation. A pedestrian appeared on a crosswalk in front of a stopped car just to the right of the participant's viewpoint; only the top half of the pedestrian was visible behind the car.

In Intersections 8 and 24, the pedestrian was cited as the most influential decision-making factor by younger participants, whereas the older participants' most influential factor was the green light for Intersection 8 and the yellow pedestrian lights for Intersection 24. The time effects for Intersections 12 and 24 may be attributable to more young participants seeing the pedestrian in the 8-s condition than in the 5-s condition. Also, more young participants cited the pedestrian as the most influential factor than did older participants for Intersection 9. It appears that the age differences in these intersections are attributable to the younger participants reacting correctly to the presence of a pedestrian in the roadway, whereas the older participants were less likely to either see pedestrians or say they were influential in their decisions to go or not go. In Intersections 5, 12, 29, and 35, the green lights were the most common first response for most younger and older participants; however, the second most common first response for younger participants was the pedestrian for all four intersections. Only 4 older participants noted the pedestrian as most influential to their decision making for Intersection 5, and none noted it as most influential for Intersections 12, 29, and 35. These responses suggest that older participants may have focused their attention more on the traffic lights than on scanning the rest of the intersection for hazards, which possibly resulted in fewer correct decisions to stop, given that the lights were green in six of these seven intersections.

Intersection decision accuracy with traffic control devices. Three intersections (3, 15, 21) with traffic light or sign changes were significant. For example, Intersection 15 contained traffic lights showing a green proceed signal and a bus located to the right (see Figure 3, top right). Vehicles were present in the opposite flow of traffic but were beyond the intersection. A no-turns sign on the overhanging light pole changed in this intersection. The correct decision was to adhere to the sign and not proceed with the left turn. For every one-unit increase in age, the odds of being inaccurate were 5%. Failing to detect the sign meant that many older drivers continued to proceed through an otherwise safe intersection. For Intersection 15, older participants most often cited oncoming vehicles or the green lights as their most influential decision-making factor. Younger participants cited the no-turns sign most commonly, followed by green lights. Therefore, it appears that older participants may have failed to use the important no-turns sign to make their decision and instead proceeded to turn when they were not supposed to.

In Intersection 13, the traffic lights changed from green to yellow. Time was a significantly reliable predictor of accuracy, but age was not. The results indicate that the odds of being accurate were almost four times greater with the 8-s versus the 5-s presentation time. Participants in the 8-s condition had more time to assess the intersection and make a correct decision. Intersection 21 contained vehicles directly in front and to the right of the participant's viewpoint. The intersection was controlled, and the lights were green. A truck was present on the one-way street at which the participants were asked to turn left. The truck's location on the side street clearly indicated that the street was a one-way and that a left turn could not be made. Furthermore, the change in the intersection was a no-left-turn sign on the traffic light pole.

Intersection decision accuracy with changing vehicles. Two intersections had vehicles that were not detected (23 and 31). In Intersection 31, a yellow taxi was positioned just ahead of the field of view on the right-hand side (see Figure 3, bottom left). The taxi was the change in this intersection, and it was clearly over the stop line and into the intersection. The traffic lights for the participant were green, and pedestrians were just finishing crossing the intersection toward the left side of the image. A vehicle was also stopped on the other side of the intersection in the opposing lane. The correct decision here was to stop because the taxi appeared to be violating the intersection. The change was large (visual angle = 4.2° × 2.25°), but older drivers often missed it and chose to proceed. Others, who saw the taxi, may have assessed the likelihood of it violating the traffic signals to be relatively low and chose to proceed as well. For Intersection 31, 9 younger participants cited the taxi as most influential, 9 cited the green light, and 8 cited the pedestrians in the crosswalk. Of the older participants, 16 cited the green light as most influential and 8 cited the pedestrians. The age effect is probably attributable to more younger participants (29 in total) using the taxi or the pedestrians to make their decisions.

In Intersection 23 the traffic lights were green and the one-way sign and no-turns sign were clearly visible on the light pole. The change inserted into the image was a van in the opposite flow of traffic, which appeared to be turning left in front of the participant's vehicle. The change was relatively large (visual angle = 2.23° × 1.97°). A commercial truck was also stopped on the opposite side of the road, next to where the van appeared, and pedestrians were visible on the right-hand sidewalk, across the intersection. The age effect in Intersection 23 could be attributable to a larger number of younger participants than older participants citing the van as most influential in their decision making.

Intersections without changes. No changes were present in Intersections 2 and 27, but the complexity of the intersection affected decision accuracy. Age predicted accuracy for Intersection 2, and age and time predicted accuracy for Intersection 27. Intersection 2 contained parked cars on both sides of the road, a yellow traffic light, and pedestrians to the right (see Figure 3, bottom right). Intersection 27 was congested, with vehicles in all three lanes in front of the participant. The traffic light was green. There was a moving van in the lane directly in front of the participant, next to the pole containing a one-way sign pointing left. There were also trees and buildings on both sides of the street. Drivers were asked to decide whether it was safe to turn right at this intersection. Older drivers often failed to see the one-way sign and decided it was safe to turn right. The odds of being accurate were almost six times greater for the 8-s condition than for the 5-s condition. More time allowed participants to better scan the scene before making a decision.

DISCUSSION

This study used a modified flicker method to assess the effects of age and time on intersection turn decision accuracy. Overall, young and middle-aged participants were more accurate in their decisions than were those in the young-old and old-old age groups, a finding that is consistent with previous studies in change blindness (Pringle et al., 2001). Object size and contrast, when used as predictor variables in multiple regression, did not reliably predict decision accuracy for any age group; this has also been found by previous research (Guerrier et al., 1999; Staplin, 1995).

The logistic regression and qualitative analysis lend some insight into the difficulties experienced by older participants. Older drivers had especially low accuracy scores for the pedestrian events. Failure to detect the pedestrians may have led older drivers to decide the intersection was clear and the turn maneuver was safe to complete. Traffic sign changes were also more difficult to detect with age (Ho et al., 2001), which was also suggested by Preusser et al. (1998) as a primary reason for older driver intersection accidents. Although the sign changes were relatively small, they were critical to safe intersection maneuver decisions. Older drivers appeared to overlook both forms of information provided and made incorrect decisions. Similarly, in two intersections older participants tended to miss relevant vehicles that were relatively large and conspicuous (visual angles = $2.23° \times 1.97°$ and $4.2° \times 2.25°$).

Although time to view an intersection was a significant predictor of accuracy for 4 of the 36 intersections tested, but not in the overall ANOVA, why time was not a more potent variable requires consideration. We suspect that a floor effect for the 5-and 8-s intervals did not permit participants to perform differentially. The choice of 5 and 8 s was based on the approximate time required to approach an intersection at posted speed limits. However, within the MFM, time to detect and to determine if a turn was safe probably followed a longer time course because the mask made visual search much more effortful. A wider range of values that permits more time to integrate information into a decision may reveal additional insights into age-related differences in intersection decisions.

The qualitative analysis provides deeper insight into the quantitative results and suggests an additional avenue of research. In general, older drivers appeared to rely heavily on the traffic control devices (e.g., lights) in the intersection to make decisions, often to the exclusion of other important objects, such as pedestrians and vehicles. For a large portion of the results, both older and younger drivers used the traffic light as a basis for a turn decision, if one was present at the intersection. However, younger drivers appeared to scan additional locations in the images before making a turn decision. Extension of this research with eye movement analysis would confirm whether these reported observations are accurate.

Although drivers of all ages successfully navigate complex intersections on a daily basis, the sudden appearance of hazard events may impact decisions to a greater degree for older drivers if the events are not part of their typical scan pattern. Often these exceptional events have the greatest implications for safety (Caird et al., 2001; Wickens, 2001). Similarly, when many potential hazards co-occur, the capability to scan all objects and formulate a decision to turn in a limited time may impact the accuracy of performance. Complex intersections containing multiple signs, traffic control devices, and increased traffic congestion are examples of multiple objects.

Limitations and Future Research

The modified flicker method was developed to explore older driver decision failures at intersections. Because this study was the first to use the new method, and in spite of extensive pilot testing, the selection of intersections may have not been ideal in terms of clear and unambiguous information for the participants to use in deciding whether or not to turn. The advantage of the MFM appears to be for testing the detectability and maintenance of attention to fixed objects such as traffic lights, signs, and/or related infrastructures that are intended to support driver decisions. Alternative methods such as video, driving simulation, and on-road testing are perhaps more useful in examining objects that are moving and require vehicular control or a particular reaction.

Nevertheless, the MFM is an interesting means to experiment with and potentially test drivers' decisions guided by experience and visual search for salient information in a limited time. The

MFM provides a driver a maneuver goal (i.e., right, left, or straight) and a limited time to determine whether it is safe to turn at the intersection. Accuracy was the central measure, and all participants received the same length of exposure – that is, either 5 or 8 s. In contrast, when used in other studies to explore visual attention and cognition, the flicker method does not provide the observer with a relevant goal, nominally limits the time to view alternating images, and focuses on response time to detected changes. The flicker method has focused on time to change detection and the theoretical implications that may or may not logically follow. Because driving experience is fundamental to understanding driver performance limitations, we argue that the modification to the flicker method is essential.

Accumulation of results from additional studies is required to determine the efficacy of the method to predict accident involvement. In this study, the Pearson correlation between self-reported participant accidents in the past 5 years and decision accuracy for the 14 significant intersections using LR was .32, which was significant at $p = .012$. With further refinement of the methods and images, the MFM might achieve a modest predictive relationship with accidents. If the 14 significant intersections were collapsed into a diagnostic test and combined with others, they could be further developed and tested for validity and reliability. A range of individual difference tests – most importantly, a working memory test – would further identify what processes may limit decision performance. Of the possible performance constraints that are remaining, working memory and integration of multiple objects into an accurate decision are implicated. The relationship between MFM and useful field of view is another avenue of potential research. If attention is required to construct stable object representations, maintenance of multiple hazardous objects is critical to accurate decision making. In busy or complex intersections, the observer may not be able to adequately construct a stable and coherent representation for all the important hazards in order to form an accurate decision.

Intersection complexity tends to evolve with the addition of new signs and signals and as traffic flow increases and structural modifications are made. The overall difficulty drivers experience with an intersection is not ordinarily a consideration of the traffic engineers who make these incremental changes. The MFM could be adapted to determine the ease with which drivers could process the overall intersection at various decision points to determine if safe turn decisions could be made. Hypothetical as well as actual intersection modifications could be tested. Secondary task interactions could also be added to MFM testing, once baseline performance is measured, to determine a first approximation of the safety of interaction with an in-vehicle technology (Caird, 2004). Other methods are also required to determine the distractibility of in-vehicle telematic devices.

The relative risk of being in an intersection accident increases dramatically after the age of 75. Why this occurs from a driver performance level of analysis requires additional research. Aging drivers, in particular, are susceptible to missing important items at intersections. These "looked but did not see" errors are difficult to observe in the field (Keskinen, Ota, & Katila, 1998) but are a common inference in accident investigations (Cairney & Catchpole, 1996; Treat, 1980). A means to generate surrogate errors through the use of the MFM may aid in the identification of sources of age-related decline and possible countermeasures. For example, it appears that older drivers have adopted particular strategies of coping with complex intersections. By focusing on specific items such as traffic, traffic control devices, and the roadway ahead, older drivers have adapted a means of identifying the most relevant items immediately. Unfortunately, concentration on these elements alone may increase the potential to miss unexpected hazards. How do attentional limitations interact with compensation strategies? For example, slowed vehicle approaches to intersections, which are used by some older drivers as a compensation strategy, may permit consideration of multiple hazards for a longer period of time.

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