Older Driver “Looked But Did Not See” Errors at Intersections: Using Change Blindness Methods to Assess Turn Decision Accuracy

J.K. Caird¹, C.J. Edwards¹, J.I. Creaser¹, & W.J. Horrey²

¹Cognitive Ergonomics Research Laboratory
Department of Psychology
University of Calgary
2500 University Drive NW
Calgary, AB T2N 1N4 Canada
(403) 220-5571 (Office)
(403) 282-8249 (Fax)
jkcaird@ucalgary.ca

²Human Perception and Performance Group
Beckman Institute
University of Illinois
405 North Mathews Avenue
Urbana, IL 61801 USA
(217) 244-4461
horrey@s.psych.uiuc.edu

Word Count: 5,473 (less references and abstract)
Number of Figures and Tables: 5
ABSTRACT

To examine why “looked but did not see” errors occur, a modified version of the flicker technique to induce change blindness was used to examine the effects of time constraints on decision-making at intersections on young (18-25), middle-aged (26-64), young-old (65-73), and old-old (74+) 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 using the modified flicker method. Sixty-two participants viewed the intersections for either five or eight seconds and were asked to decide whether it was safe to turn left, right or continue straight through each intersection. Younger and middle-aged drivers made more correct decisions than older drivers, with older drivers frequently failing to see changes that were relevant to a correct decision. Logistic regression analysis of the data indicated that age and time were significant predictors of decision performance in 14 of the 36 intersections. A qualitative analysis of drivers’ self-reported reasons for making a go or no go decision supported the quantitative finding that older drivers either failed to see important changes in the scene or to not see all the relevant information to make an accurate decision under time pressure. Overall, 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. The utility of the modified flicker method to assess driver performance and future research is discussed.
INTRODUCTION

Older drivers are over-represented in fatal traffic accidents on a per mile and per license basis (1-6), most likely due to their fragility (7). After age 75, the risk of intersection accident involvement for older drivers increases for most intersection maneuvers (5, 8). Typical citations, once involved in an intersection accident, are failure to yield right-of-way and violation of traffic controls (9). Failures of perception (10, 11), attention (12), memory (13, 14), cognition (15) and action (16-18) are frequently used to explain why older drivers miss signs, signals, and other vehicles at intersections.

Of interest to this research is the contribution of attentional failures to intersection accidents. Attentional failures may result from the improper division of attention (19, 20), visual search difficulties (21-23), and/or the switching of attention (24). For example, age-related declines in divided and selective attention, as measured by the Useful Field of View (UFOV™) test, have been related to intersection crashes (25-27). Three sub-tasks comprise the test for UFOV: visual processing speed, divided attention, and selective attention. UFOV research has been devoted to demonstrating the utility of the measures in predicting at-risk drivers for motor vehicle crashes, especially older drivers (e.g., 25-27) and as a driver screening or evaluation test. In particular, Owsley et al. (26) found that only the divided attention sub-task was associated with increased crash risk. Failures of attention at intersections are likely to result in not seeing the other vehicle at all or until it is too late to react appropriately (32). The common accident category of “looked but did not see” tends to be used to describe these kinds of driver errors (32, 33). Advances in visual attention research have used the change blindness paradigm to understand observers’ abilities to detect changes in complex scenes. Specifically, 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 (34).

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 method (35, 36). In the standard or generic application of this 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 inter-stimulus interval or ISI). The images are alternated repeatedly until a response is made or a certain time has elapsed.

The induction of change blindness through the use of the flicker technique has implications for understanding how we construct, link, and store visual representations. The long-held view is that we store detailed and coherent picture-like representations of our world from one view to the next. However, recent results using the change blindness paradigm suggest that this may not be the case (e.g., 34-38). For example, Rensink (39, 40) suggested that focused attention provides spatio-temporal coherence for the stable representation of a single object at a time. As such, accurate visual representations may exist only so long as attention is focused on the region or object in question. If focused attention on hazardous objects is required to construct a coherent representation of a traffic scene, it follows that intersections which have increased complexity, traffic flow, and visual clutter will also have a higher incidence of missed (i.e., failed to detect) objects. Thus, degraded detection performance in the change blindness paradigm may map onto failures of attention in the driving environment; specifically, “looked but did not see” accidents. Research on change detection has further shown that older adults miss more scene changes than younger adults, suggesting age-related deficits in the ability to maintain a stable visual representation—a finding which may help explain increased intersection accident representation (41, 50).
PRESENT STUDY

In this study, the goal was to modify the flicker method so that it could be used to test driver’s attentional capabilities at intersections. Typically, an original image and modified image are alternated repeatedly with blank fields (36) or “mudsplats” (34) presented between each successive image with minimal time constraints (e.g., 60 s) in which to make a decision about whether a change is present. In contrast, the modified flicker method (MFM) provides observers with a specific goal, rather than simply monitoring for changes. In the current study, drivers were asked to decide whether it was safe to complete a certain maneuver (i.e., either a left or right turn, or to continue straight ahead) at each intersection. While the MFM does not require participants to actively search for a changing feature, it is assumed that the correct detection of a safety-critical object will impact their decision to proceed through the intersection or no. 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 (42, 43).

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 (5, 14, 17). Drivers examined a series of intersections for either 5 or 8 seconds in order to assess the safety of the intended path of travel. It was expected that a shorter viewing time and increased age would reduce the number of relevant intersection changes detected, thus leading to poorer decision accuracy.

METHODS

Participants

Sixty-two older and younger drivers were recruited from the following age groups: young (18 to 25, M = 22), middle-aged (26 to 64, M = 39), young-old (65 to 73, M = 69), and old-old (74+, 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, Alberta. Younger volunteers were recruited from the University of Calgary and 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 kilometres driven per year is slightly lower for the age group of 65 to 73 than the other age groups. The number of violations per year is highest in the 16 to 25 year-old age group. The mean number of accidents for all age groups is between 1 and 2. The youngest age group had the highest mean number of accidents in the past 5 years. Corrected visual acuity and contrast sensitivity declined and was somewhat more variable in the two older age groups.

------------------------

Insert Table 1 Here
Materials

Hardware and Software

Intersection photographs were captured with a Nikon CoolPix 950 digital camera (at 800 x 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 m by 1.3 m screen (Model Da-Lite) positioned 3 m in front of participants. They were seated at a vehicle mock-up that was composed of a steering wheel, brake, and accelerator. Only the brake and accelerator provided input to the Toolbook application.

Driving Images

Approximately 2500 digital pictures of signalized and non-signalized 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, image manipulation opportunities, 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.

Each image was manipulated in Photoshop to create an image A (un-manipulated) and 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 & A’). Six of these were used for training and the remaining 36 were utilized for experimental trials.

Procedure

Overall Testing Procedures

At the beginning of a 75-minute session, participants completed an informed consent form and a background questionnaire concerning age, sex, driving experience, and habits. Visual acuity was tested at a distance of 20 feet using Landolt Cs and contrast sensitivity was tested at a distance of 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 and several intersections where uncertainty was present in a decision. Drivers were presented with 36 experimental intersection trials that varied in complexity and type of change present. The interpretation of whether to go or not to go was placed on the participant. Participants were randomly assigned to one of two separate experimental orders. They were then debriefed and remunerated for their participation.
Modified Change Blindness Paradigm

The flicker technique was modified so the tasks performed were more similar to those performed while driving. The principal difference of the present study and previous flicker studies was to begin each trial with one of three directional arrows centered on the screen that corresponded 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.

-------------
Insert Figure 1 Here
-------------

Once the directional arrow was memorized, participants indicated that they were ready to start a new trial. Each image in a pair was presented for 250 ms with a gray mask being presented for 80 ms between the two (see Figure 1). A and A’ continued to flicker back and forth for either 5 or 8 s. Once the intersection began to flicker, participants were instructed to decide whether or not they would go or not go in the direction that was indicated in the first screen. After the flickering stopped, a screen appeared that asked them to respond by pressing the accelerator to go, and 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.

After the decision to go or not go was made, another screen appeared that asked four additional questions; namely:

1. How confident are you in your decision to go or not to go?
2. 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.
3. Did you notice anything changing in the images that you saw?
4. Did you make any assumptions about what you saw?
RESULTS

Accuracy Results

Accuracy was determined by whether participants correctly chose to go or not to go at each intersection. The experimenters determined accuracy \textit{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. Unique characteristics of each intersection, such as traffic control devices, vehicles present, pedestrians and so forth, confound collapsing accuracy across intersections. Therefore, each intersection was assumed to possess unique information that drivers use to determine whether to turn and, therefore, intersections were analyzed individually for effects.

Analysis of age group accuracy differences for the 14 significant intersections (see Logistic Regression Results below) was performed using an analysis of variance (ANOVA). A significant difference was found for correct accuracy between each age group, $F(3,52)= 11.42$, $p<0.0001$. Four follow up t-tests were conducted using a Bonferroni correction at $\alpha = 0.0125$ (i.e., $0.05/4$), to control for the error rate. The youngest age group (i.e., 18-24) had significantly higher accuracy scores ($M=17.05, SD=5.50$) on the 14 intersections than the young-old (i.e., 65-73) age group ($M=9.22, SD=7.76$), $t(26)= 3.08$, $p<0.005$, and the old-old (i.e., 74+) age group ($M=6.10, SD=6.01$), $t(26)= 5.01$, $p< 0.0001$. The middle age group (i.e., 25-63) had significantly higher accuracy scores ($M=17.28, SD=5.38$) on the 14 intersections than the young-old age group ($M=9.22$), $t(26)= 3.19$, $p= 0.004$ and the old-old age group, $t(26)= 5.18$, $p< 0.0001$. Overall accuracy percentages calculated for the 14 significant intersections are shown in Figure 2. The low level of accuracy is indicative of the difficulty of the task constraints in MFM.

------------------------
Insert Figure 2 Here
------------------------

Logistic Regression Results

Logistic Regression (LR) provides a means to predict outcomes when using a set of variables that are continuous, dichotomous/discrete or a mixture (44). 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, the outcome variable was decision accuracy. Age was used as a continuous predictor due to insufficient cell sizes across all age groups when left as a categorical variable. In total, 62 cases were entered into each of the logistic regressions. 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. Tables 2 shows the significant intersection numbers, a brief description of the intersection, and associated statistics. In particular, the Wald statistic is a test of the individual contribution of a predictor to the model and follows a standard normal distribution. A value of +/- 2 was considered significant for the Wald test (i.e., 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 easier to interpret (45). Note, that percent increases are based on an exponential function.

Intersection Decision Accuracy with Changing Pedestrians

Space limitations constrain the number of significant intersections that can be described and interpreted. 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 is in a straight-ahead lane. Both traffic lights are green and there is one vehicle just before the intersection in the lane to the right of the participant. This vehicle is braking. The change incorporated in this intersection is a pedestrian running out in front of oncoming traffic, from behind the vehicles stopped in the left turn lane. The odds ratio for intersection 8 indicated that for every 1-unit increase in age, the odds of being inaccurate increased by 7%. Older drivers did not see the pedestrian. Attention was, most likely, directed towards the line of vehicles stopped on the left and the state of the lights based on verbal reports. As with other intersections, detecting the pedestrian was critical for making the correct decision to stop. Time was also a significant predictor at this intersection. The odds of being accurate were 5 times greater for the 8-second category than the 5-second category. The longer viewing time increased the likelihood of detecting the pedestrian.

The size, obscuring vehicles, and contrast of a pedestrian in intersections 5, 9, 24, 29 and 35 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 ($\theta = 1.16^\circ \times 2.24^\circ$). Intersection 12 is a one-way street and the lights were green. There is a cyclist on the left, with his foot down on the road indicating he is stopped. The intersection is sunny, but it is shadowed on either side of the intersection. 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 = $0.26^\circ \times 1.08^\circ$). For this intersection, a 1-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 7 times greater for the 8-second condition than the 5-second condition. The pedestrian crossing lights in intersection 24 showed the crossing was potentially in use. There were stationary vehicles ahead of the participant’s vehicle, 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. The lack of contrast between the pedestrian and the background may have obscured the change. The change associated with intersection 35 was relatively small (visual angle = 0.49º x 1.50º).

**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%. The sign was a relatively small change ($\theta = 0.71^\circ \times 0.71^\circ$). Failing to detect the sign meant that many older drivers continued to proceed through an otherwise safe intersection.

In intersection 13, the traffic lights changed from green to yellow. Time was a significantly reliable predictor of accuracy, age, however, was not. The results indicate that the odds of being accurate were almost 4 times greater in the 8-second versus the 5-second presentation time. Participants in the 8-second 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 & 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 towards 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 = 4.2º x 2.25º) 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. In intersection 23 the traffic lights were green, 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 = 2.23º x 1.97º). 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.
Intersections without Changes

For intersections 2 and 27, no changes were present, but the complexity of the intersection affected decision accuracy. Age predicted accuracy for intersection 2 and age and time predicted intersection 27 performance. 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 is 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-second condition than the 5-second condition. More time allowed participants to better scan the scene before making a decision.

Qualitative Analysis

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 analysis of reported items collapsed across young (18 to 64) and old (65+) age categories provide interesting information for future eye movement analysis and strategic compensation research (17, 48).

Intersections with Pedestrians

Seven of the 14 significant intersections (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. 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 intersections 8 and the yellow pedestrian lights for intersection 24. The time effects for intersections 12 and 24 may be due to more young participants in the eight-second condition seeing the pedestrian than those in the five-second condition. More young participants also 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 due 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 them 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 four 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 as the lights were green in six of the seven intersections.
Intersections with Changing Traffic Control Devices

Intersections 15 and 21 both required drivers to make a left-hand turn when a “no turns” sign (15) or a “no left turns” sign (21) was the relevant change. 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 failed to use the important “no turns” sign to make their decision and instead proceeded to turn when they were not supposed to.

Intersections with Changing Vehicles

Intersections 23 and 31 had vehicles as a relevant change. In 23, a van turned left in front of the participant and in 31 a taxi ran the red light from the right. The age effect in intersection 23 could be due to a larger number of younger participants than older participants citing the van as most influential in their decision-making. For intersection 31, nine younger participants cited the taxi as most influential, nine cited the green light and eight cited the pedestrians in the crosswalk. Sixteen older participants cited the green as most influential and eight cited the pedestrians as influential. The age effect is probably due to more younger pedestrians using the taxi or the pedestrians (29 in total) to make their decisions.
DISCUSSION

This study used a modified flicker method (MFM) to assess the effects of decision accuracy at intersections under imposed time constraints. Complex intersections are encountered on a daily basis and depending on what is present at the intersection different environmental elements can compete for a driver’s attention. The MFM is a unique way to generate “looked but did not see” errors and made participants undertake an effortful search when viewing scenes. Moreover, imposing a restricted time limit to make an appropriate turn decision resembled real-world examples of daily driving. Declining abilities and time restrictions in the present study allowed insights into driver errors made at complex intersections.

More accurate by younger drivers may be due, in part, to age differences in scanning capabilities (23). If attention is required to construct stable object representations, maintenance of multiple hazardous objects is critical. In busy or complex intersections, the observer may not be able to adequately construct a stable and coherent representation for all the important hazards. If drivers cannot attend to all salient traffic environment features, then high-demand intersections may prove overwhelming and hazards may go unnoticed. In a limited viewing time, older drivers are likely to execute fewer eye movements (46), and once objects are fixated, more time is required to process information (23). Younger drivers, in the same time constraints, are likely to make more eye movements and fixate for shorter periods of time (23, 46). Thus, older drivers are less likely to scan and process as many objects in the traffic scene.

Older drivers had lower accuracy scores for the pedestrian events. Failure to detect the pedestrians led older drivers to decide the intersection was clear and the turn maneuver was safe to complete. The relatively small size of the pedestrian, low contrast, and limited time to view an intersection affected detection performance. Time to view an intersection was also a predictor of accuracy and was significant for 4 of the 36 intersections tested. Accuracy was 5 to 8 times greater for the 8-second condition than the 5-second condition in these intersections.

Traffic sign changes were more likely to be missed with age (46) which is also suggested by Preusser et al. (5) 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. Older participants were also more likely to miss relevant vehicles. Two intersections had vehicles that were relatively large and conspicuous (visual angles = 2.23º x 1.97º, 4.2º x 2.25º, respectively). One intersection had a mini-van in the opposing lane of traffic and the other intersection had a yellow taxicab to the right of the participant’s vehicle that changed in the scene. With the taxi present, the perceived brightness is greater than when the vehicle is absent. The vehicle in each intersection intentionally violated established traffic laws. When visually scanning the scene, from one flicker to the next, attention may have been focused on what they expected to encounter, such as lights and signs (42, 43), and not the vehicles violating the traffic code.

The qualitative analysis provides additional insight into the quantitative results. 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 is present at the intersection. However, younger drivers appeared to scan additional locations in the images before making a turn decision. In most instances, older drivers fixated on traffic lights and occasionally additional signage, whereas younger drivers were able to identify other hazards in addition to the light information. Extension of this research with eye movement analysis would confirm whether these reported observations are accurate.
Twenty-two of the intersections that participants judged did not yield age or time as significant predictors. Thus, intersection decision performance was not appreciably different across age for two-thirds of the intersections tested. This result suggests that older drivers are able to make effective decisions in many circumstances. However, when exceptional events occur, such as the sudden appearance of a pedestrian, detection may suffer. Oftentimes, these exceptional events have the greatest implications for safety (19, 49). Similarly, where many potential hazards co-occur, the capability to scan all objects in a limited time may also hinder detection. Complex intersections containing multiple signs, traffic control devices, and increased traffic congestion are examples of multiple objects. Drivers of all ages successfully navigate complex intersections on a daily basis.

FUTURE RESEARCH

The modified flicker method (MFM) was developed to understand driver selective attention at intersections. The MFM provides a driver a maneuver goal (i.e., right, left or straight) and a limited time to determine if the turn is safe. The 14 intersections, where age and/or time are predictive of turn decision accuracy, could be used as a diagnostic test for older drivers. In contrast, the flicker method when used to understand visual attention and cognition does not provide the observer with a relevant goal or limit the time to view alternating images. Instead, the focus is on whether or not a change is detected. If the 14 significant intersections were collapsed into a screening test, it could be further tested for validity and reliability. The complexity of intersections tends to evolve with the addition of new signs and signals and as traffic flow increases and structural modifications are made. The MFM could be also adapted to determine the ease with which drivers could process the overall attention load of intersection modifications to make safe turn decisions.

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. 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 means the potential to miss unexpected hazards.

How do attentional limitations interact with compensation strategies? Do older drivers tend to look for signs and signals, and thus are less likely to see other important, but unexpected, cars and pedestrians? Does the strategy lead to potential intersection conflicts? If many older driver intersection crashes are the result of failing to see traffic lights and signs, does this indicate a failure to adopt a strategy or other events in the intersection momentarily cause the search strategy to be suspended or forgotten?
ACKNOWLEDGMENTS

The technical report (47) has many additional details about the intersection images and methods that could not be included due to space constraints. Ling Suen served as the contract monitor and guided this research for the Transportation Development Centre of Transport Canada. Brad Johnson developed the Toolbook application for the change blindness study. Bob Dewar and Don Kline provided invaluable comments at critical junctures. Tak Fung helped with the logistic regression. Funding from the Canadian Foundation for Innovation, Alberta Science and Innovation, and the Centre for Transportation Engineering and Planning (C-TEP) provided support for the hardware and software development.

REFERENCES


FIGURES AND TABLES LIST (Order of Appearance)

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

Table 1. Participant sample characteristics (means, SD); mean age, number of years driving, kilometres driven per year, number of violations in the past 2 years, total number of accidents across all driving, accidents in previous 5 years, visual acuity, and contrast sensitivity.

Figure 2. Overall decision accuracy (%) by age group for the 14 significant intersections. Error bars indicate 1 standard deviation (SD).

Table 2. Logistic Regression of Accuracy with Driver Age and Time to View an Intersection; Intersection Numbers, Description and Associated Statistics.

Figure 3. Examples of significant intersections: 8) Pedestrian (top left), 15) Traffic sign (top right), 31) Vehicle (bottom left), and 2) No change (bottom right).
Independent Variables:
1. Age (18-25, 26-64, 65-73, 74+)
2. Presentation time (5 or 8s)
3. Change relevance to turn (relevant, irrelevant)
4. Change type (sign, signal, car, pedestrian)
5. Degree of eccentricity hazard (0-30 degrees)
6. Visual angle of change (horiz. x vert.)
7. Decision type (left, straight, right)
8. Gender (male, female)

Dependent Measures:
1. Accuracy
2. Level of confidence
3. Turn information used
4. Change detection

Figure 1. Modified flicker method with image sequence, timing, variables, and participant directions. In this example, the participant was instructed to travel straight through the intersection. The taxi is not present in A and appears in A'. If they indicated that they would not go, their response was correct because the taxi was in their way.
Table 1. Participant sample characteristics (means, SD); mean age, number of years driving, kilometres driven per year, number of violations in the past 2 years, total number of accidents across all driving, accidents in previous 5 years, visual acuity, and contrast sensitivity.

<table>
<thead>
<tr>
<th>Descriptive Measure</th>
<th>Age Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16 to 25</td>
</tr>
<tr>
<td>Mean Age (SD)</td>
<td>21.75 (2.1)</td>
</tr>
<tr>
<td>Years Driving (SD)</td>
<td>5.13 (1.7)</td>
</tr>
<tr>
<td>Km/Year Driven (SD)</td>
<td>14,812 (10,8336)</td>
</tr>
<tr>
<td>Number of Violations, Last 2 Years (SD)</td>
<td>5.13 (1.7)</td>
</tr>
<tr>
<td>Total Accidents (SD)</td>
<td>1.63 (1.4)</td>
</tr>
<tr>
<td>Accidents Last 5 Years (SD)</td>
<td>1.5 (1.5)</td>
</tr>
<tr>
<td>Corrected Visual Acuity (SD)</td>
<td>20.1 (3.5)</td>
</tr>
</tbody>
</table>
Figure 2. Overall decision accuracy (%) by age group for the 14 significant intersections. Error bars indicate 1 standard deviation (SD).
Table 2. Logistic Regression of Accuracy with Driver Age and Time to View an Intersection; Intersection Numbers, Description and Associated Statistics.

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Description</th>
<th>$\chi^2(2)$</th>
<th>$\chi^2$ sig. values</th>
<th>Predictors</th>
<th>B</th>
<th>Wald (z-ratio)</th>
<th>Exp(B) (odds ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Yellow Light, parked cars, pedestrians.</td>
<td>7.58</td>
<td>0.023</td>
<td>Age</td>
<td>-.034</td>
<td>2.32</td>
<td>0.967</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time</td>
<td>-.882</td>
<td>1.32</td>
<td>0.414</td>
</tr>
<tr>
<td>5</td>
<td>Green light, left turning vehicle, pedestrian.</td>
<td>10.21</td>
<td>0.006</td>
<td>Age</td>
<td>-.034</td>
<td>2.78</td>
<td>0.967</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time</td>
<td>.796</td>
<td>1.41</td>
<td>2.218</td>
</tr>
<tr>
<td>8</td>
<td>Stopped traffic, green light, pedestrian.</td>
<td>27.65</td>
<td>0.0001</td>
<td>Age</td>
<td>-.067</td>
<td>3.99</td>
<td>0.935</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time</td>
<td>1.67</td>
<td>2.21</td>
<td>5.332</td>
</tr>
<tr>
<td>9</td>
<td>Clear intersection, pedestrian, green lights.</td>
<td>12.00</td>
<td>0.002</td>
<td>Age</td>
<td>-.037</td>
<td>2.89</td>
<td>0.964</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time</td>
<td>-.964</td>
<td>1.67</td>
<td>0.382</td>
</tr>
<tr>
<td>12</td>
<td>Green lights, pedestrian, bicyclist</td>
<td>33.03</td>
<td>0.0001</td>
<td>Age</td>
<td>-.087</td>
<td>3.98</td>
<td>0.964</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time</td>
<td>1.89</td>
<td>2.18</td>
<td>6.633</td>
</tr>
<tr>
<td>13</td>
<td>Vehicles ahead, yellow light, oncoming turning vehicles.</td>
<td>4.457</td>
<td>0.045</td>
<td>Age</td>
<td>.001</td>
<td>1.11</td>
<td>1.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time</td>
<td>1.31</td>
<td>2.00</td>
<td>3.711</td>
</tr>
<tr>
<td>15</td>
<td>Bus, no-left turn sign, green lights.</td>
<td>14.20</td>
<td>0.001</td>
<td>Age</td>
<td>-.044</td>
<td>3.37</td>
<td>0.957</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time</td>
<td>-.584</td>
<td>0.97</td>
<td>0.558</td>
</tr>
<tr>
<td>21</td>
<td>Green lights, one-way, no-left turn sign.</td>
<td>18.28</td>
<td>0.0001</td>
<td>Age</td>
<td>-.142</td>
<td>2.24</td>
<td>0.868</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time</td>
<td>-.272</td>
<td>0.33</td>
<td>0.762</td>
</tr>
<tr>
<td>23</td>
<td>Commercial truck, turning van, green lights, one-way.</td>
<td>8.17</td>
<td>0.011</td>
<td>Age</td>
<td>-.044</td>
<td>2.44</td>
<td>0.957</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time</td>
<td>-.196</td>
<td>0.29</td>
<td>0.822</td>
</tr>
<tr>
<td>24</td>
<td>Traffic, pedestrian, pedestrian crossing lights.</td>
<td>12.43</td>
<td>0.002</td>
<td>Age</td>
<td>-.041</td>
<td>2.77</td>
<td>0.959</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time</td>
<td>1.12</td>
<td>1.76</td>
<td>3.069</td>
</tr>
<tr>
<td>27</td>
<td>Vehicles ahead, one-way sign, green light.</td>
<td>15.60</td>
<td>0.0001</td>
<td>Age</td>
<td>-.034</td>
<td>2.56</td>
<td>0.967</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time</td>
<td>1.75</td>
<td>2.86</td>
<td>5.758</td>
</tr>
<tr>
<td>29</td>
<td>Stopped vehicle, pedestrian, signs.</td>
<td>12.05</td>
<td>0.002</td>
<td>Age</td>
<td>-.043</td>
<td>2.84</td>
<td>0.958</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time</td>
<td>1.01</td>
<td>1.49</td>
<td>2.735</td>
</tr>
<tr>
<td>31</td>
<td>Pedestrians, taxi-cab, green lights.</td>
<td>8.61</td>
<td>0.013</td>
<td>Age</td>
<td>-.033</td>
<td>2.78</td>
<td>0.967</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time</td>
<td>.016</td>
<td>0.03</td>
<td>0.985</td>
</tr>
<tr>
<td>35</td>
<td>Turning vehicle, green lights, pedestrian.</td>
<td>13.89</td>
<td>0.001</td>
<td>Age</td>
<td>-.063</td>
<td>2.66</td>
<td>0.939</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time</td>
<td>1.09</td>
<td>1.35</td>
<td>3.001</td>
</tr>
</tbody>
</table>
Figure 3. Examples of significant intersections: 8) Pedestrian (top left), 15) Traffic sign (top right), 31) Vehicle (bottom left), and 2) No change (bottom right). Red circles are used to highlight changes here and did not appear in the image presented to participants.