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Adaptive Response Criteria in Road Hazard Detection Among Older Drivers

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ABSTRACT

OBJECTIVES: The majority of existing investigations on attention, aging, and driving have focused on the negative impacts of age-related declines in attention on hazard detection and driver performance. However, driving skills and behavioral compensation may accommodate the negative effects that age-related attentional decline places on driving performance. In this study, we examined an important question that had been largely neglected in the literature linking attention, aging, and driving: can top-down factors such as behavioral compensation, specifically adaptive response criteria, accommodate the negative impacts from age-related attention declines on hazard detection during driving?

METHODS: In the experiment, we used the Drive Aware Task, a task combining the driving context with well-controlled laboratory procedures measuring attention. We compared younger (n = 16, age 21 – 30) and older (n = 21, age 65 - 79) drivers on their attentional processing of hazards in driving scenes, indexed by percentage of correct response and reaction time of hazard detection, as well as sensitivity and response criterion using the signal detection analysis.

RESULTS: Older drivers, in general, were less accurate and slower on the task than younger drivers. However, results from this experiment revealed that older, but not younger, drivers adapted their response criteria when the traffic condition changed in the driving scenes. When there was more traffic in the driving scene, older drivers became more liberal in their responses, meaning that they were more likely to report that a driving hazard was detected.

CONCLUSIONS: Older drivers adopt compensatory strategies on hazard detection during driving. Our findings showed that, in the driving context, even at an old age our attentional functions are still adaptive according to environmental conditions. This leads to considerations on potential training methods to promote adaptive strategies which may help older drivers maintain performance in road hazard detection.

***KEYWORDS*:** aging, driving, hazard detection, attention, adaptive, response criterion

INTRODUCTION

Age-related declines in attentional abilities have been identified as one of the major reasons for increased vehicle crash risks among older drivers (Clay et al. 2005). Yet, elevation in crash risks does not appear until the age of 75+ (Ryan et al. 1998; NHTSA 2012; Table 62), while attentional decline starts much earlier in the lifespan (Fortenbaugh et al. 2015). There are many older drivers who drive without an incident, despite that their attentional abilities, as measured by laboratory tasks, are likely not comparable to those of younger drivers. Given the strong link between attentional abilities and driving safety (Trick et al. 2004), it is unclear why such discrepancies exist between the laboratory measures and daily observations.

A plausible explanation is that older drivers utilize compensatory behaviors to accommodate age-related declines in cognition (Salthouse 2012). Older drivers adopt compensatory driving behaviors (for a review, see Staplin et al. 2012) such as traveling fewer miles (Langford et al. 2008), driving much more slowly (Bromberg et al. 2012; Kaber et al. 2012; Trick et al. 2010), keeping a longer headway distance (Andrews and Westerman 2012; Trick et al., 2010), and avoiding challenging driving situations such as left turns and heavy traffic (Andrews and Westerman 2012; Horberry et al. 2006). Some of these behaviors may have an impact on hazard detection. For example, Bromberg and her colleagues (2012) speculated that a slower driving speed may allow older drivers taking a longer time to perceive information, detect hazards, and react to them, although this compensatory behavior did not eliminate the difficulties that older drivers experience in hazard detection, particularly when hazards occurred in the visual periphery. Similarly, Romoser et al. (2013) hypothesized one contributor to older drivers' failure to scan before entering an intersection as older drivers being too engaged in monitoring the road in front of them (which may have helped them identifying hazards right in front of them), thus could not scan sufficiently for hazards in the periphery. Borowsky et al. (2010) found that older drivers relied greatly on signs and signals on the road to detect hazards. This reflects older drivers' strategy based on their understanding of the traffic environment from extensive driving experience.

One possible form of compensatory strategy in hazard detection is an adaptive response criterion (i.e., liberal or conservative response biases). In target detection under uncertainty, a more liberal response criterion leads to a higher likelihood of reporting that a target is present. In contrast, a more conservative response criterion results in a higher likelihood of reporting that a target is absent. Adaptive response criteria have been observed among older adults in memory tasks (Cassidy and Gutchess 2015; Pendergrass et al. 2012) and auditory perception (Craik 1969). In driving, adapting response criteria according to the demand and context of the target detection task may benefit older drivers in detecting road hazards. For example, missing a stop sign could pose much more serious consequences on driving safety than missing a restaurant logo on a roadside panel. Therefore, when uncertain, drivers may be more likely to be biased to report seeing a stop sign than a restaurant logo. If a target is directly related to a potential driving hazard (e.g., a stop sign), older drivers may adopt a different response criterion and demonstrate much lower misses and higher false alarm rates. Indeed, a recent study (Zahabi et al. 2017; p.24, Table 3) found very high misses (45%) but extremely low false alarm rates (3%) among older drivers in identifying food signs when they performed a logo detection task during simulated driving. If the target is instead a driving hazard (e.g., a stop sign), older drivers may adopt a different response criterion. An empirical examination is needed on this speculation. As adaptive response criterion has been observed on perceptual and memory tasks among older adults, research should examine whether this is also present in driving hazard detection.

In this study, we used the Drive Aware Task (DAT) that combines the driving context and a well-controlled laboratory procedure of measuring target detection, to investigate whether adaptive response criteria are used by older drivers in the attentional processing of driving scenes. In particular, we aimed to examine whether older drivers adjust their response criteria when faced with various driving conditions (e.g., light traffic or heavy traffic).

METHODS

Participants

A total of 16 younger adults (age range: 21 – 30 years, mean age: 24.4 years, four men, 12 women; with an average of 5.1 years of driving experience) and 21 older adults (age range: 65 – 79 years, mean age: 70.6 years, nine men, 14 women; with an average of 44.1 years of driving experience) participated in this study. Every participant had a valid driver’s license and self-reported driving at least a few times a week. All participants self-reported normal or corrected-to-normal vision and no history of neurological or vision disorders. All participants were recruited from local communities in Toronto, Ontario, Canada, and were compensated at a rate of $10/h.

Drive Aware Task (DAT)

The Drive Aware Task (DAT) combined the driving context with a well-controlled laboratory procedure of measuring target detection. This task was developed to assess attentional processing of static driving scenes with a brief stimulus exposure (an earlier variation of the task was used in Feng et al. 2015). Sequence of image presentation in a typical trial of the task is shown in Figure 1. At the beginning of each trial, a travel direction followed by a static environment scene (an edited screen capture from driving simulation) was presented to provide the driving context (similar to the method used in Caird et al. 2005). After viewing the static stimulus scene, participants responded by indicating whether it was safe to travel the instructed direction and identified the particular hazard in the scene if it was unsafe ("Response 2", Figure 1). Half of the presented scenes included a driving hazard such as a red light, a vehicle turning onto the driver's path, and a jaywalking pedestrian that would prevent the driver from travelling the instructed direction (one hazard in each scene; conditions in the current studies listed in Table 1). The other half of the scenes were identical to those with the hazards except they do not contain any hazard. Only intersection scenes were used as intersections are particularly challenging for older drivers (Federal Highway Administration 1995; Romoser et al. 2013). Target presence (present, absent), travel direction (left, straight, right), traffic light position (low, high), and traffic load (low, high) were systematically varied among the intersection scenes. A detailed description of the task with example stimuli images for various conditions is provided in the Appendix of this paper (available online).

Procedure

Before the experiment, each participant was given a brief introduction to the study and signed a consent form. At the end of each DAT trial, participants were asked to indicate whether it was safe to travel the instructed direction and identify the hazardous object if reporting unsafe. Every participant completed eight practice trials of the DAT before the experiment session. None of the intersection scenes that appeared in the practice were included in the experiment session. Participants' response on each trial was recorded. Response time was calculated as the duration from the onset of the first response display ("Response 1" display, Figure 1) to a button click by the participant.

RESULTS

We conducted a 2 (target presence: present, absent) × 2 (traffic load: low, high) × 2 (age: younger, older) mixed analysis of variance on the percentage of correct response on the DAT. Percentage of correct response for each combination of target presence by traffic load condition was calculated by the number of correct trials divided by the total number of trials for that combination of condition (12 trials for each combination) for each participant. Visual inspection of normal Q-Q plots of studentized residuals indicated normal distributions. In general, participants were more accurate when the target was absent (present: 75.1%, absent: 91.8%), $F(1,35) = 38.33$, $p < .001$, and when there was less traffic in the driving scenes (low traffic: 85.3%, high traffic: 81.6%), $F(1,35) = 12.51$, $p = .001$. Older participants were less accurate than younger participants (older: 77.4%, younger: 89.4%), $F(1,35) = 14.89$, $p < .001$. There was a trend of greater age difference in the driving scenes with higher traffic ([older] low traffic: 80.2%, high traffic: 74.7%; [younger] low traffic: 90.4%, high traffic: 88.5%), as indicated by a marginally significant age × traffic load interaction, $F(1,35) = 3.07$, $p = .089$. In addition, there was an overall significant target presence × traffic load interaction, $F(1,35) = 13.88$, $p = .001$. Subsequent analyses showed that, with an increasing amount of traffic in the driving scenes, participants had more false alarms (i.e., reporting a target when the target was absent) thus a lower percentage of correct response (percent correct on target-absent trials: low traffic: 95.4%, high traffic: 88.3%), $F(1,35) = 30.37$, $p < .001$, but comparable misses (i.e., reporting no target when the target was present; percentage of correct response on target-present trials: low traffic: 75.2%, high traffic: 75.0%), $F(1,35) = .02$, $p = .894$. This finding indicates that the participants were more likely to report seeing a target with the higher traffic load. There was also a significant three-way interaction (Figure 2), target presence × traffic load × age, $F(1,35) = 5.41$, $p = .026$, suggesting that older participants ([target-absent] low traffic: 92.8%, high traffic: 81.8%; [target-present] low traffic: 67.5%, high traffic: 67.6%) were more likely to commit false alarms (i.e., reporting a target when the target was absent) with the higher traffic load, while younger participants' performance ([target-absent] low traffic: 97.9%, high traffic: 94.8%; [target-present] low traffic: 82.8%, high traffic: 82.3%) was comparable between low and high traffic load conditions. No other interactions were significant.

To compare participants' response criteria between the two traffic loads, we also calculated the sensitivity (*d'*) and criterion (*c*), based on the signal detection method for Yes/No tasks (Stanislaw and Todorov 1999). To enable the conversion of probability scores into z-scores using the inverse phi function, we raised all false alarm rates of 0 to 0.01 and reduced all hit rates of 1 to 0.99 (same method used in Cowan et al. 2006; Pfeifer et al. 2014). We compared sensitivity and criteria between the two traffic load conditions using a paired-sample t-test in both age groups. Among the younger participants, no change was found in neither sensitivity (*d'*) (low traffic: 3.13, high traffic: 2.88), $t(15) = 1.61$, $p = .264$, nor criterion (*c*) (low traffic: .49, high traffic: .36), $t(15) = 1.40$, $p = .182$. In contrast, among the older participants, there was a significant decrease on sensitivity from the low traffic load condition ($d' = 2.12$) to the high traffic load condition ($d' = 1.53$), $t(20) = 5.97$, $p < .001$, and also a shift of criterion (*c*) to become more liberal in the high traffic condition (low traffic load: .54, high traffic: .26), $t(20) = 4.75$, $p < .001$.

We also analysed participants' response times, which were calculated as the durations from the onset of the first response display ("safe" or "unsafe", Figure 1) to a button click by a participant. Given the considerations of the distribution of response time data (Parmet et al. 2014), a logarithmic transformation was applied to the data. An average transformed response time was calculated based on all trials for each combination of traffic load by target presence condition of each participant. We conducted a 2 (target presence: present, absent) × 2 (traffic load: low, high) × 2 (age: younger, older) mixed analysis of variance on the log transformed DAT response times. In the following description of statistics, we present the mean transformed response times for each significance statistic; in addition, we also display the means in the inverse-log form (therefore in the unit of ms) to assist with interpretation. As Participants responded more quickly when there was less traffic in the driving scenes (low traffic: 3.24 [1738 ms], high traffic: 3.28 [1905 ms]), $F(1,35) = 20.05$, $p < .001$. Older participants responded more slowly than younger participants (older: 3.30 [1995 ms], younger: 3.23 [1698 ms]), $F(1,35) = 4.33$, $p = .045$. There was a significant interaction between target presence and traffic ([target absent] low traffic: 3.23 [1698 ms], high traffic: 3.29 [1949 ms]; [target present] low traffic: 3.28 [1905 ms], high traffic: 3.31 [2041 ms]), $F(1,35) = 8.94$, p =. 005. None of the other main effects or interactions were significant.

DISCUSSION

In this experiment, the significant age difference was found in the overall percentage of correct response on the DAT. This was interesting given the mixed findings of age differences on the performance of the hazard perception test. Using a video-based hazard perception test, Horswill et al. (2008) found large age differences in performance, while Borowsky et al. (2010) did not find any difference between mid-aged experience drivers and older (and experienced) drivers. Our finding supports the notion that age-related declines exist in driving hazard detection. We also found a trend for greater age differences at a higher traffic load. This implies that the traffic load in video-based hazard perception should be taken into consideration when interpreting age comparisons in such hazard perception performance.

One of the most important findings in this experiment was how younger and older participants' sensitivity and response criterion changed across the two traffic load conditions. There was no change in either sensitivity or criterion among younger participants, likely because both traffic conditions were relatively easy for them (as shown by their high accuracies). Among older participants, both traffic conditions were challenging, but particularly more so with high traffic load. In the high traffic load condition, older participants showed a lower sensitivity and also chose a more liberal response criterion. Note that a more liberal response criterion means that a participant was more likely to report seeing a target even when there was none, thus higher false alarms. In the context of driving, being more liberal could be beneficial as the consequence of missing a target (e.g., missing a stop sign or a pedestrian could lead to serious crashes) is much worse than making a false alarm (e.g., a driver thought there was a target and slowed down or stopped, which may reduce travel efficiency). Previous research has found that when drivers engaged in a phone conversation, they showed an increased number of false alarms in a hazard perception task, which helped them in missing fewer hazards (Burge and Chaparro 2012; Savage et al. 2013). Similarly, older participants in our study were likely compensating their reduced sensitivity to the task at the higher traffic load condition with a more liberal response criterion.

It was interesting to compare our results to those reported in Zahabi et al. (2017). In that study, younger and older drivers were asked to perform a panel logo sign detection task while driving. Older drivers showed a very low false alarm rate (3%) and a high rate of misses (45%) in detecting restaurant logo signs. In our study, when participants were asked to detect driving hazards, older drivers demonstrated much higher false alarm rates and the rate climbed with an increasing traffic load (low traffic: 7.2%, high traffic: 18.2%), while the rate of misses (32.4%) was lower than that in Zahabi et al. (2017). The general differences in the rates of false alarms and misses between the two studies may be because of the difference between the significance of a logo sign and a road hazard in driving. Missing a logo sign is mostly non-critical in terms of driving safety, while missing a road hazard could lead to severe safety consequences. Therefore, older drivers may be applying different strategies on modulating their response criterion based on the nature of the target detection task. However, given this comparison was made between two independent studies, a direct examination of the two situations is necessary for future research. In addition, the current study highlighted traffic load as a potential cue for changing response criterion. Future studies should examine other cues that could potentially elicit compensatory behaviors among older drivers. More specifically, it would be valuable to investigate whether and how various factors of a driving scene could change a driver's explicit risk perception and implicit preparation for a potentially needed response based on a brief processing of the road situation. Such knowledge could provide insights into the discrepancies in the findings of aging and driving hazard perception (e.g., Borowsky et al. 2010; Horswill et al. 2008).

As discussed in the introduction, behavioral compensation of older drivers has been observed in many high-level behaviors (Langford et al. 2008; Andrews and

Westerman 2012; Platten et al. 2013). Our study, for the first time, demonstrated that older drivers could also adopt flexible response criteria for driving hazard detection. While this flexibility could be a conscious and active strategy, like self-limiting driving exposure and avoiding left turns, it is also possible that the change in response criterion was more unconscious and passive, as an automatic response to increasing levels of processing noise (e.g., Allen, 1990; Allen et al. 2004). This compensation comes with the cost of increased false alarms that could potentially lead to more braking events and a slower speed. Indeed, evidence has shown that older drivers do drive more slowly (Platten et al. 2013; Reimer et al. 2013; Trick et al. 2010), and are more likely to be involved in rear-end crashes that could be a result of sudden braking (Yan et al. 2005).

Our findings demonstrate that even at an old age our attentional functions are still adaptive according to the environmental conditions. This conclusion is consistent with findings in other domains such as older adults remaining strategic and adaptive in memory functions (for a review, see Castel 2007). Further research is warranted to examine individual differences in the capability to adapt attentional functions. Such research could provide useful information on the plasticity of attention and provide guidelines for the development of training methods to improve attentional function of older drivers.

In this paper, we introduced the Drive Aware Task (DAT) which adopts a well-controlled task procedure for presenting driving scenes. It is important to note that the DAT differs from driving or video-based hazard perception tasks, as it is a static rather than dynamic task. However, the combination of the driving context and the well-controlled laboratory task procedure allows us to precisely manipulate many factors in a driving scene, thus provides a unique opportunity to examine drivers' attentional processes in identifying a visual target among distractors in the context of driving. In the current DAT, participants are instructed to keep their eyes fixated at the center of the screen. During daily driving, drivers constantly scan across the wide visual field. Similarly, when performing a video-based hazard perception task, participants could also freely move their eyes. When eye movements are allowed, participants' hazard detection is a result of attentional allocation in a gist (Ball et al. 1993), covert attentional allocation (i.e., without eye movements; Mackenzie and Harris 2017), and visual scanning strategies (Romoser et al. 2013; Romoser and Fisher 2009). Using the fixated eye instruction, the current DAT allows the isolation of effects from attentional processing of static driving scenes without eye movements on hazard detection. Admittedly, when applying these findings about attentional processing without eye movements to understand hazard detection on road, it is critical to investigate how these attentional processes would translate to effective visual scanning in driving (e.g., Mackenzie and Harris 2017), and the interplay between these attentional processes and practice and learning of visual scanning. In addition, the current DAT used only three types of potential hazards on the road: vehicle, pedestrian, traffic light/sign (e.g., a pedestrian crossing in the right periphery could be a hazard for a driver turning right at an intersection). Future studies should attempt to cover more hazardous situations.

A practical implication of the present study is to use the DAT as a potential measure of driver attentional ability for research and rehabilitation purposes. In the

United States, the number of older drivers is expected to increase drastically in the next twenty years. By 2030, the older driver population is estimated to rise to 57 million (United States Government Accountability Office 2007), and they will represent about 25% of all licensed drivers in the United States (Lyman et al. 2002). As the older driver population experiences higher vehicle crash risks (Tefft 2012), linked to age-related declines in attentional functions (Ball et al. 1993), it is important to develop effective measures of attentional fitness-to-drive and cognitive training methods to improve older drivers' attentional functions. Future research should seek to validate the DAT with on-road driving and vehicle crash data, and further examine the effectiveness of the DAT as a measure of attentional functioning within the driving context.

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TABLE

Table 1. Unsafe driving scene characteristics using in the Drive Aware Task (DAT) in the experiment

Condition [1]	**Driving Direction**	**Scene Description**
1	Left	Green light, no left turn sign
2	Left	Green light, a pedestrian crossing in the left periphery
3	Right	Red light, no right turn on red sign
4	Right	Green light, a pedestrian crossing in the right periphery
5	Straight	Red light
6	Straight	Green light, opposing traffic turning left at intersection

[1] In the experiment, every scene condition was used for each of the light location (high/low) by traffic (little/much) combinations with two different intersection backgrounds, creating eight repetitions. The safe driving scenes were identical to the unsafe ones except the driving hazard was not eliminated.

FIGURE LEGENDS

Figure 1. A sample trial of the Drive Aware Task (DAT). The purpose and exposure of each displayed frame is noted above the image (e.g., “direction”, “500 ms”). The task is described in detail in the method section of the experiment.

Figure 2. Percentages of correct response on the DAT as a function of traffic load (low, high) and target presence (absent, present) among younger drivers (panel a) and older drivers (panel b). In the signal detection analysis, the percentage of correct response of the target-present trials correspondences to hit, and the percentage of correct response of the target-absent trials correspondence to correct rejection which is 100% minus the rate of false alarms. The error bars represent ±1 standard error.

APPENDICIES

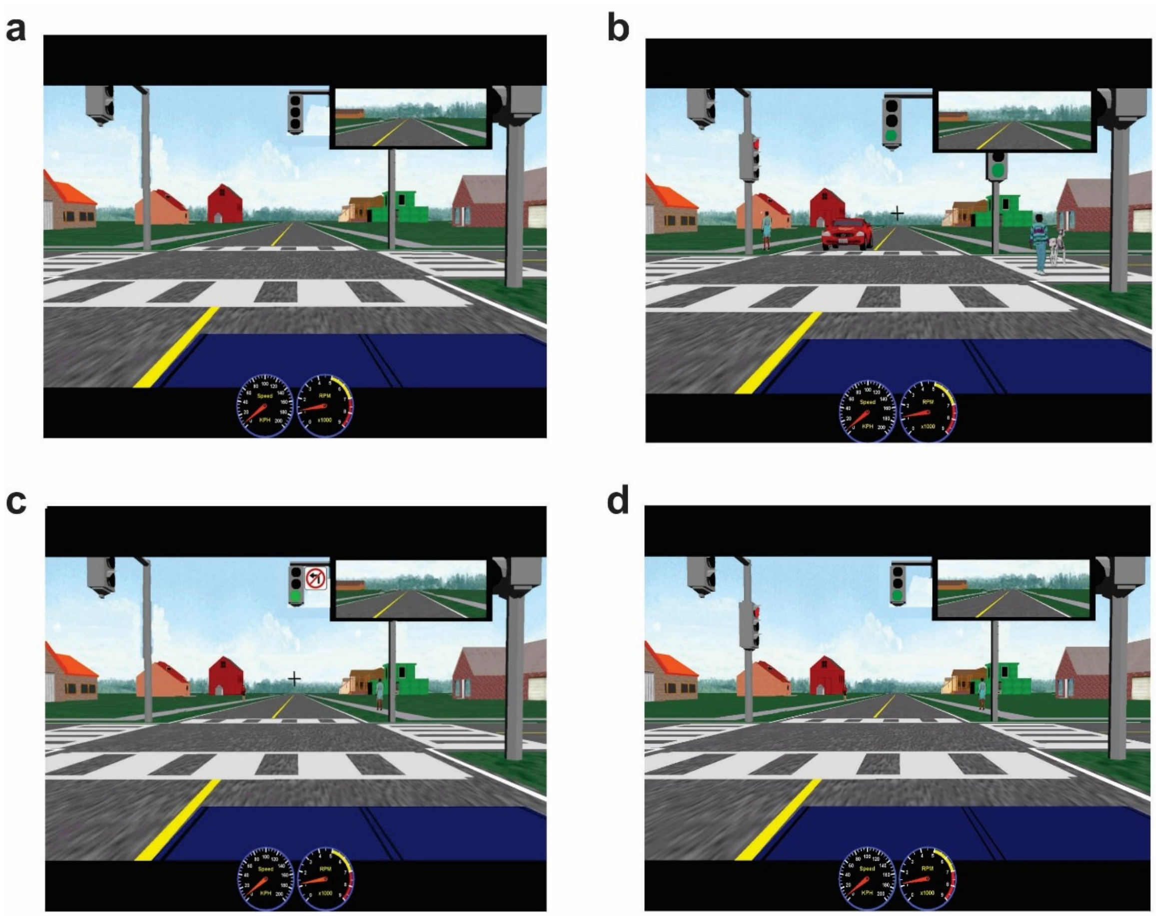
Supplementary text

Description of the Drive Aware Task (DAT). The DAT employed a well-controlled task procedure that is similar to typical laboratory measures using abstract stimuli (e.g., the Attentional Visual Field task, see Feng, Craik, Levine, Moreno, Naglie, & Choi, 2016; the Useful Field Of View task, see Ball et al., 1993).This controlled procedure allowed manipulation of many task parameters such as travel direction, level of visual clutter, and location of the hazard, with repeated measures of each condition. The driving context was provided by presenting simulated driving scenes (static images) with instructions on a travel direction (similar to the method used in Caird et al., 2005). Only intersection scenes were used in the DAT as intersections are known to be particularly challenging for older drivers (Federal Highway Administration, 1995; Romoser et al., 2013). The static intersection images were edited screen captures from driving simulations. Half of the presented scenes included a driving hazard (hazard-present scenes) while the other half were identical but did not include any hazard (hazard-absent scenes). Each hazard-present scene included one driving hazard, such as a red light, a vehicle turning onto the driver's path, and a jaywalking pedestrian that would prevent the driver from travelling the instructed direction (conditions in the current studies listed in Table 1). It is important to note how we defined hazards in our scenes: an object was regarded as a hazard only when it prevented safe travel on the instructed direction. For example, if "no left turn" sign occurred at the intersection but the travel direction is "turning right", this sign was not regarded as a hazard. This context of travelling direction is critical in driving as whether an object on road poses a threat to safe travel does not just depend on the identity of the object but also its location and the driver's intended travel direction. With a brief presentation of the travel direction and the intersection images, drivers were required to make a decision about whether it is safe to travel in the instructed direction.

The DAT used in this study was particularly developed for the current purpose of research. An earlier variation of the DAT with fewer manipulated factors has been used in a previous study (Feng et al., 2015). The DAT was developed using Microsoft Visual Studio C++. Each trial started with a fixation square (see the "fixation" display in Figure 1) presented at the center of the display for 500 ms, followed by an arrow (i.e., "←", "↑", or "→") indicating the corresponding travel direction (left, straight, or right) for 500 ms. Participants were told to speak out the direction of the arrow to facilitate their memory of it for a later response. After the travel direction display, a road scene of an intersection was displayed for 5000 ms. The intersection scene did not include any traffic-related information such as traffic lights, signs, pedestrians, or vehicles. After a blank interval of 200 ms, participants viewed the intersection scene that included all traffic-related information. The intersection scene was repeated five times, with each presentation lasting 200 ms followed by a 200 ms blank interval. This setting was implemented to prevent participants' eye movements during the presentation of the intersection scene. With participants' eye fixations at the center, the DAT can examine spatial allocation of attention in a glance (similar to the Attentional Field of View task and the Useful Field of View task). A duration of 200 ms was chosen because the programming and execution of an eye movement would take longer than this amount of time (Liversedges, Gilchrist, &

Everling, 2011). Participants were instructed to maintain a fixation of their eyes at the center. In addition, participants were instructed to verbally report the digit presented at the center of one of the third to fifth presentations. In other presentations, a fixation cross ("+") appeared at the center. Because the digit only appeared in one of the presentations (location of the digit occurrence among the third, fourth, or fifth presentation was randomly chosen for each trial thus participants could not predict), it would be very difficult for a participant to catch the digit unless maintaining the fixation at the center. This component of the task was designed to further encourage participants' fixation at the center. After five repeats of an intersection scene, participants reported whether it was safe to travel in the instructed direction by clicking the "safe" or "unsafe" button. If participants chose "safe", the trial ended. If participants chose "unsafe", then they were further probed to report if the hazard was a traffic light/sign, a pedestrian, or a vehicle by clicking one of the three corresponding buttons on the screen. There were 96 trials (half safe [i.e., target absent], half unsafe [i.e., target present]), with a brief break after each block of 24 trials. Several factors were systematically varied among the intersections scenes, including target presence (present, absent), travel direction (left, straight, right), traffic light position (low, high), and traffic load (low, high). While it is possible to examine the effect of every factor in the task (e.g., Feng et al., 2015), the current study was primarily interested in signal detection criteria, thus our analyses were focused on target presence and traffic load factors.

Supplementary figure



Supplementary Figure. (a) An example intersection scene without traffic related information (environment display) for a trial. (b) An example intersection scene (stimulus display) for the condition of unsafe right turn due to a pedestrian crossing the street in the right periphery. (c) An example intersection scene (stimulus display) in the DAT for the condition of unsafe left turn due to “no left turn” sign. (d) An example intersection scene (stimulus display) for the condition of safe right turn as a match to the example shown in (c).