Driving in fog: The effects of driving experience and visibility on speed compensation and hazard avoidance

Alexandra S. Mueller\textsuperscript{a,}\textsuperscript{*}, Lana M. Trick\textsuperscript{b}

\textsuperscript{a}Department of Psychology, University of Western Ontario, London, Ontario, N6A 3K7, Canada
\textsuperscript{b}Department of Psychology, University of Guelph, Guelph, Ontario, N1G 2W1, Canada

\textbf{ARTICLE INFO}

\textbf{Article history:}
Received 17 September 2011
Received in revised form 1 March 2012
Accepted 3 March 2012

\textbf{Keywords:}
Driving experience
Visibility
Fog
Speed
Collisions
Speed variability

\textbf{ABSTRACT}

Inexperienced drivers are more likely to have collisions than experienced drivers. Young novice drivers are overrepresented in collision statistics, and novice drivers are at greater risk for underestimating hazards. Experienced drivers, on the other hand, are more likely to overestimate hazards (e.g., overcompensation, inappropriate vehicle control, panic and freezing). Those cognition errors involve the inability to maintain attention, inappropriate visual search strategies, failure to recognize hazards, and poor decision-making (e.g., selecting inappropriate speeds for particular situations and poor maintenance of space around other vehicles). Novice drivers also tend to hold inaccurate expectations about hazards and where they are likely to be located, which explains in part their largely ineffective visual search strategies for hazards in the driving environment (Lerner and Westat, 2001; Pradhan et al., 2009; Vidotto et al., 2011). Moreover, they have the tendency to overestimate their ability to successfully manage hazardous events on the road (De Craen et al., 2011; Wallis and Horswill, 2007), which can be even further complicated by their propensity to underestimate braking distances to hazards (Deery, 1999).

When understanding the cognition errors made by young novice drivers, it is useful to consider Shiffrin and Schneider's (1977) distinction between automatic and controlled processing. Controlled processes are engaged whenever a person is performing a complex or unfamiliar task. These processes are carried out consciously and slowly, and they demand cognitive resources (attention), which means that they interfere with other controlled processes when performed in tandem. With adequate practice, some controlled processes become automatic, which is to say that these processes come to be carried out unconsciously and quickly and they do not require cognitive resources. Consequently, they do not interfere with other processes performed at the same time (automatic or controlled). Given that young drivers are less practiced, they may require controlled processing resources to carry out aspects of the task that more experienced drivers perform automatically. For example, novice drivers may require controlled processing to carry out aspects of speed control, steering, and visual search for hazards that experienced drivers carry out automatically, and this may contribute to cognition errors insofar as it is more difficult for novice drivers to carry out the basics of vehicle control while maintaining high levels of situational awareness and thinking ahead (Trick et al., 2004).

As the demands of the driving task increase, so too does the risk of collision; however, the risk appears to be greater for young novice drivers than for experienced drivers. Young novice drivers seem to be unable to cope as successfully as experienced drivers when the challenges of the driving task increase (Patten et al., 2006), and thus their risk of collision may increase under those circumstances. A common situation in which the demands of the driving task...
increase is when visibility is reduced, as occurs in adverse weather and at night.

Reduced visibility increases the risk of collision for everyone (Andrey et al., 2003; Cavallo et al., 2000; Clarke et al., 2006; Edwards, 1999; Sullivan and Flannagan, 2004); however, it appears that not all drivers are affected equally. Some are more likely to perform safety-related adaptations than others, and those adaptations chiefly involve reducing speed. Speed is an aspect of the driving task that can be altered in challenging situations to reduce the risk of collision. For example, in fog the distance from which a driver is able to perceive hazards is much shorter than in normal conditions. Consequently, speed reduction in fog gives drivers more time to react to hazards (Al-Ghamdi, 2007). Trick et al. (2009) found that older drivers (M = 71 years of age) reduced their speed substantially in fog whereas younger and less experienced drivers (M = 18 years of age) did not—they reduced speed by less than 1 kph—and had more collisions.

There are several possible causes for this differential speed reduction. Elderly drivers are generally more experienced. It is possible that their speed compensation reflects an accurate understanding of the risks involved in reduced visibility, to which novice drivers are relatively insensitive (Borowsky et al., 2009; Deery, 1999; Wallis and Horswill, 2007). Then again, age affects numerous aspects of driving performance, such as how often people drive and how cautious they are behind the wheel—older drivers are typically more cautious than younger drivers (Hakamies-Blomqvist and Wahlström, 1998). Moreover, impaired sensory and attentional functioning differentiates elderly drivers from younger drivers in many ways unrelated to driving expertise (Chao and Knight, 1997; Ivers et al., 1999).

The evidence concerning speed compensation in drivers is mixed. Some studies show that younger drivers do in fact reduce their speed in poor visibility (Horrey et al., 2003; Owens et al., 2010), though the specific effects of driving experience have not yet been examined. In this study we hypothesized an interaction between driving experience and visibility, as the speed reduction in fog compared to clear visibility should be greater for experienced drivers than for novice drivers. In fact, we expected experienced drivers to reduce their speed considerably in fog and also have faster hazard response times and fewer collisions. In contrast, novice drivers should not reduce their speed adequately to meet the demands of the driving environment in reduced visibility, and they should therefore have slower hazard response times and more collisions. Given that young novice drivers are less able to manage the driving task when the demands of the task increase, we also hypothesized that they would have more variability in their speed control compared to experienced drivers, particularly in fog when the driving task demands are greatest.

The goal of this study was to identify how drivers of different levels of experience adjust their driving behaviour to meet the demands of the environment. Simulated fog was presented as a potential hazard in order to increase the demands of the driving task. Experiment 1 examined how drivers adjust and maintain their speed based on their level of driving experience and the degree of visibility. Experiment 2 investigated whether the speed drivers selected in fog in Experiment 1 was adequate to safely avoid hazards in both clear (low demand) and foggy conditions (high demand).

2. Experiment 1 – method

2.1. Participants

Participants were recruited from public advertisements and the university undergraduate participant pool, and were paid $10.00 or one credit towards the research component of their course grade for their participation. They were divided into groups based on their license type1 and number of years of experience. In order to reduce the possibility of age-related impairment as a cause for speed compensation, only drivers under the age of 35 were tested. Comparisons were made between young drivers with a full G license (the young experienced group) and young drivers that had G1 and G2 licenses (the young novice group) based on the Ontario Graduated Licensing System (MTO, 2011).

The young experienced drivers (n = 19, 14 males) were on average 24 years old (SD = 3.07), had an average of 8 years of driving experience (SD = 3.08), and held a full valid driver’s license (G license). In contrast, young novice drivers (n = 19, 5 males) were on average 19 years old (SD = 2.19), had an average of half a year of driving experience (SD = 0.30), and held at minimum a valid entry-level driver’s license (G1 license). Table 1 contains descriptive statistics related to driving history for the two groups, as indicated by

| Table 1 |
| Participant driving history as percentages for items 1–7. Mean (SD) for item 8. |
| Young experienced drivers (n = 19) | Young novice drivers (n = 19) |
| 1. Road environments they drivea | 2.19 |
| Highway | 94.7% | 42.1% |
| Rural | 73.7% | 68.4% |
| Suburban | 73.7% | 57.9% |
| Urban | 94.7% | 73.7% |
| 2. Drive in adverse weatherb | 96.1% | 47.4% |
| Early morning | 26.3% | 15.8% |
| Morning | 78.9% | 42.1% |
| Afternoon | 84.2% | 84.2% |
| Evening | 89.5% | 73.7% |
| 3. Time of day they drivena | 84.2% | 68.4% |
| 4. Received a traffic ticket | 73.7% |
| 5. Been the driver in a traffic collision | 73.7% |
| 6. Taken a driver’s education course | 73.7% |
| 7. Level of driver’s license | 73.7% |
| G1 | 0.0% | 73.7% |
| G2 | 0.0% | 42.1% |
| G3 | 100.0% | 73.7% |
| 8. Average hours per week spent drivend | 69.1% |
| Spring | 6.2 (5.9) | 2.6 (2.8) |
| Summer | 11.7 (10.1) | 4.7 (6.7) |
| Fall | 6.4 (6.0) | 4.4 (6.2) |
| Winter | 6.9 (7.6) | 0.9 (2.6) |

---

1 In Ontario, individuals are eligible for an entry-level license at the age of 16. Upon passing a written exam about traffic rules and regulations, entry-level drivers hold a G1 license. The G1 license has restrictions concerning access to certain roads (e.g., they cannot drive on major highways), the time of day during which they may drive (i.e., they cannot drive between 24:00 and 5:00h), zero blood alcohol content, and passengers present in the vehicle (i.e., a fully licensed driver who has had their full license for at least four years must always be present in the front passenger seat). After at least 12 months of holding a valid G1 license and upon successfully passing a road test, novice drivers may acquire a G2 license, which has fewer restrictions (see MTO, 2011 for further information). Drivers must hold a G2 license for at least another 12 months and then, upon passing another road test, they can graduate to a full G license.

self-reports (however, see Leaf et al., 2008 as it relates to the tendency of self-report measures to underestimate driving exposure). All participants had normal contrast sensitivity and normal or corrected-to-normal visual acuity. Acuity was assessed using the Ferris et al. (1982) Early Treatment of Diabetic Retinopathy Scale (ETDRS): young experienced drivers \( M = -0.09 \) log MAR, SD = 0.08 and young novice drivers \( M = -0.05 \) log MAR, SD = 0.08. Contrast sensitivity was measured using the Pelli–Robson contrast sensitivity test (Pelli et al., 1988): young experienced drivers \( M = 1.95 \) log MAR, SD = 0.00 and young novice drivers \( M = 1.97 \) log MAR, SD = 0.08. Thus, the two groups had similar acuity and contrast sensitivity. All participants were screened for predictors of simulator adaptation syndrome (SAS) using a questionnaire developed in our lab that we have found useful in the past. None of the participants experienced SAS during the study so there was no data loss.

2.2. Apparatus and stimuli

A DriveSafety DS-600c fixed-platform driving simulator was used for this experiment. It is a four-door sedan bordered by six 2.13 m tall viewing screens, providing a 300° wrap-around virtual environment. Three unique driving scenarios were created, and each involved two-lane roads through rural and industrial environments. The first was a 3 min practice scenario designed to allow participants to acclimate to the apparatus. The second and third were 5 min experimental scenarios that each encompassed 6.8 km of road with speed limits of 80 kph (one had clear visibility the other had fog). Fog density was set at 600 m for object-viewing distance (see Fig. 1), the same fog density used in Trick et al. (2009). Data were collected at 60 Hz.

Ambient traffic was present in every scenario and it was set to match the speed of the driver so that no rear-end collisions occurred when it became necessary to brake for hazards (participants were informed of this prior to testing). There were two hazards (passenger vehicles) present in each scenario, one on the left and right-hand side—the presentation order of which was counterbalanced between the two experimental scenarios. Each hazard was controlled by a time trigger and emerged from behind a large object on a driveway at the side of the road 4 s in advance of the driver and pursued a perpendicular trajectory into the path of the driver. It was difficult for participants to anticipate when the hazards would emerge because their location was unique to each scenario and there were a number of driveways that had large objects but no hazards.

There were 3 km of straight road allocated to measure speed and steering (across three distinct 1 km areas) per scenario. No hazards were presented in those areas in order to allow for an uncontaminated measurement of those variables.

2.3. Design and procedure

This experiment was a 2 (driving experience: young experienced and young novice drivers) × 2 (visibility: clear and fog) design. Condition order was counterbalanced across participants. The dependent variables were average speed and variability in speed. Average speed was measured in terms of average kph, and variability in speed was the standard deviation of average speed. The Standard Deviation of Lateral Position (SDLP), a standard measure of steering performance measured in meters, was also included.

Participants were presented with the practice scenario followed by the two experimental scenarios. Drivers were instructed to come to a complete stop if a hazard emerged on the road rather than swerving to avoid it. This instruction was given to minimize the risk of SAS, which can be prompted by rapid steering maneuvers. To reduce the likelihood of distraction from non-driving related activities, drivers were instructed not to use the radio. They were also advised that the fog light controls were automatic in the vehicle. After the three scenarios were finished participants completed a follow-up Simulator Sickness Questionnaire (Kennedy et al., 1993) assessing any symptoms of SAS. Then they completed a questionnaire asking about their past and present driving experience.

2.4. Results and discussion

Average speed, speed variability and SDLP were analysed by means of 2 (driving experience) × 2 (visibility) factorial split-plot analyses of variance, and Greenhouse–Geisser corrections for violations of the sphericity assumption were used. Given that there was an age and gender imbalance between the two groups of drivers, an additional analysis of covariance (with age and gender as covariates) was performed for average speed, speed variability and SDLP. Although the main effect of driving experience on average speed was not significant (F(1, 36) = 2.15, ns) all drivers reduced their speed in fog compared to clear visibility (F(1, 36) = 37.93, p < .001, \( \eta_p^2 = 0.51 \)). Furthermore, the interaction between driving experience and visibility was also significant, F(1, 36) = 4.26, p < .05, \( \eta_p^2 = 0.11 \) (see Fig. 2). In clear visibility young experienced drivers drove significantly faster than young novice drivers, F(1, 36) = 7.34, p < .05, \( \eta_p^2 = 0.17 \), yet in fog there was no difference between the two groups, F(1, 36) = 0.12, ns. In general, compared to older and more experienced drivers, young drivers are more likely to speed (Jonah, 1986, 1990) and have more speed-related collisions (Curry et al., 2011; Liu et al., 2005). It is possible that the higher driving

![Fig. 1. Example of the clear (left) and foggy (right) driving environments.](image-url)
speeds in clear visibility chosen by young experienced drivers in this experiment were due to youthfulness rather than driving experience. Nevertheless, as anticipated, young experienced drivers reduced their speed more than young novice drivers to fog (M reduction = 8.49 kph, SD = 7.40, as compared to 4.23 kph, SD = 5.13 for the young novice group). Both age, F(1, 36) = 0.75, ns, and gender, F(1, 34) = 3.50, ns, were non-significant main effects and neither interacted significantly with the experimental variables.

It is interesting that this experiment found a significant speed reduction in young novice drivers, given that the young drivers in Trick et al. (2009) did not reduce their speed appreciably. Both groups were similar in age and therefore the difference between the two studies might reflect a disparity in the amount of experience that each group had. The young novice drivers in Experiment 1 had on average half a year of experience, whereas the young drivers in Trick et al. had on average 2 years of experience. It is possible that the speed reduction in Experiment 1 reflects a lack of confidence in driving skill, whereas the absence of speed adjustment in Trick et al. might be indicative of the unwarranted self-confidence that typically leads to risky behaviour in young drivers who have comparatively more experience (De Cræn et al., 2011; Wallis and Horrey, 2007).

As anticipated, young novice drivers were significantly more variable than young experienced drivers in their speed (F(1, 36) = 8.09, p < .01, $\eta^2_p = 0.18$) and SDLP, (F(1, 36) = 24.30, p < .001, $\eta^2_p = 0.40$). The greater variability in young novice drivers on both speed variability and SDLP would be expected given the findings by Curry et al. (2011) and McKnight and McKnight (2003), which suggest that most of the collisions involving young novice drivers have to do with cognition errors. Based on their findings and Trick et al. (2004), it seems plausible that the young novice drivers in this experiment had more difficulty managing the driving task because they had fewer cognitive resources available. In other words, young novice drivers had more variability in their speed control and SDLP because of the interference that arose from controlled driving behaviours being performed simultaneously (e.g., searching for hazards while controlling vehicle speed and steering). In contrast, young experienced drivers had rendered several aspects of the driving task more automatic (e.g., speed and steering control), and thus coped with task-related demands without a cost to either behaviour. To provide further clarification on the matter though, future studies should consider using a dual-task paradigm to assess cognitive load under similar experimental situations involving novice and experienced drivers as well as different conditions of visibility.

Even though there was no effect of visibility on speed variability, F(1, 36) = 1.74, ns, there was a significant main effect of visibility on SDLP, F(1, 36) = 4.56, p < .05, $\eta^2_p = 0.11$, as all drivers were more variable in clear visibility than fog. However, the difference between SDLP in clear visibility (M = 0.20) and fog (M = 0.19) was minimal. Unexpectedly, there was no significant interaction between driving experience and visibility on speed variability (F(1, 36) = 3.56, ns) or on SDLP (F(1, 36) = 0.75, ns). Horrey et al. (2003) used a greater fog density and found effects of visibility on speed variability and therefore it is likely that more demanding driving conditions (e.g., greater fog density or cognitive load) are necessary to elicit an interaction between driving experience and visibility on speed variability and SDLP.

In terms of speed variability in the present experiment, both age, F(1, 34) = 2.94, ns, and gender, F(1, 34) = 0.35, ns, were non-significant main effects and neither variable interacted significantly with any of the experimental variables. Regarding SDLP, neither age, F(1, 34) = 0.44, ns, nor gender, F(1, 34) = 1.76, ns, were significant main effects and they did not interact with any of the other experimental variables.

Because there were so few hazards in Experiment 1 hazard response time data were not gathered. Consequently it is unclear whether the speed reductions drivers made were adequate to help them avoid collision.

3. Experiment 2 – method

In Experiment 1 all drivers reduced their speed to the same overall speed, whereas elderly drivers in Trick et al. (2009) reduced their speed so that it was lower than that observed in younger drivers. However, it is important to note that the elderly drivers in Trick et al. also drove slower than the younger drivers in clear visibility, and Trick et al. (2010) found that the degree to which elderly drivers reduce their speed is related to selective attention impairment. Moreover, the elderly drivers in Trick et al. (2009, 2010) had worse acuity and contrast sensitivity than the younger drivers. Consequently, there are two possibilities that might explain the difference between the two studies: (1) the young experienced drivers in Experiment 1 were relatively inexperienced compared to those in the 2009 study, or (2) perhaps elderly drivers reduce their speed more than younger drivers because of age-related factors (such as sensory and attentional impairment, or cautiousness). Therefore, Experiment 2 included an additional group of older participants who had considerably more experience (all were under the age of 55 though). Drivers were instructed to strictly adhere to the speed limit (80 kph), which was approximately the same speed drivers reduced to in Experiment 1, and collisions and hazard response times were measured over longer drives.

3.1. Participants

Methods of participant recruitment and payment were the same as in Experiment 1. Participants were divided into three groups, primarily based on their driving experience (there was some overlap between groups as it relates to license type). The older experienced drivers (n = 16, 10 males) were on average 42 years old (SD = 11.70), had an average of 25 years of driving experience (SD = 11.35), and held a full valid driver’s license (G license in the Province of Ontario). The second group involved young drivers with moderate experience (n = 16, 5 males), who were on average 18 years old (SD = 1.01), had an average of 3 years of driving experience (SD = 0.95), and held at minimum a valid intermediate-level driver’s license (G2 license in the Province of Ontario) though approximately 31% of the sample had a full G license. Finally, the young novice drivers (n = 16, 7 males) were on average 18 years
Table 2
Participant driving history as percentages for items 1–7. Mean (SD) for item 8.

<table>
<thead>
<tr>
<th>1. Road environments they drive&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Older experienced drivers (n = 16)</th>
<th>Young moderately experienced drivers (n = 16)</th>
<th>Young novice drivers (n = 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highway</td>
<td>100.0%</td>
<td>93.8%</td>
<td>25.0%</td>
</tr>
<tr>
<td>Rural</td>
<td>93.8%</td>
<td>75.0%</td>
<td>62.5%</td>
</tr>
<tr>
<td>Suburban</td>
<td>81.3%</td>
<td>75.0%</td>
<td>68.8%</td>
</tr>
<tr>
<td>Urban</td>
<td>93.8%</td>
<td>81.3%</td>
<td>81.3%</td>
</tr>
<tr>
<td>2. Drive in adverse weather&lt;sup&gt;b&lt;/sup&gt;</td>
<td>100.0%</td>
<td>81.3%</td>
<td>40.6%</td>
</tr>
<tr>
<td>3. Time of day they drive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early morning</td>
<td>43.8%</td>
<td>18.8%</td>
<td>18.8%</td>
</tr>
<tr>
<td>Morning</td>
<td>87.5%</td>
<td>81.3%</td>
<td>56.3%</td>
</tr>
<tr>
<td>Afternoon</td>
<td>87.5%</td>
<td>87.5%</td>
<td>87.5%</td>
</tr>
<tr>
<td>Evening</td>
<td>100.0%</td>
<td>100.0%</td>
<td>62.5%</td>
</tr>
<tr>
<td>4. Received a ticket</td>
<td>75.0%</td>
<td>18.8%</td>
<td>12.5%</td>
</tr>
<tr>
<td>5. Been the driver in a traffic collision</td>
<td>68.8%</td>
<td>31.3%</td>
<td>12.5%</td>
</tr>
<tr>
<td>6. Taken a driver’s education course</td>
<td>81.3%</td>
<td>100.0%</td>
<td>56.3%</td>
</tr>
<tr>
<td>7. Level of driver’s license</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G1</td>
<td>0.0%</td>
<td>0.0%</td>
<td>81.3%</td>
</tr>
<tr>
<td>G2</td>
<td>0.0%</td>
<td>68.8%</td>
<td>18.8%</td>
</tr>
<tr>
<td>C</td>
<td>100.0%</td>
<td>31.3%</td>
<td>0.0%</td>
</tr>
<tr>
<td>8. Average hours per week spent driving&lt;sup&gt;d&lt;/sup&gt;</td>
<td>14.9 (19.9)</td>
<td>7.6 (6.3)</td>
<td>5.3 (8.9)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Participants were asked to select the following road environments they typically drive in at present: highway, rural, suburban and urban. The numbers reflect the percentage of sample that said that they had traveled in each environment.

<sup>b</sup> Adverse weather was a composite variable created from participant responses to whether they drive in rain, fog, snowfalls, and storms (rain, snow and hail). The numbers represent the percentage of the sample that said they drive in those weather conditions.

<sup>c</sup> Participants were asked to select the following times of day that they typically drive: early morning (12:00–6:00 a.m.), morning (7:00–11:00 a.m.), afternoon (12:00–5:00 p.m.), and evening (6:00–11:00 p.m.). The numbers represent the percentage of the sample that said that they drove at each time of day.

<sup>d</sup> Participants gave an estimate of the average number of hours they spend behind the wheel per season within the past two years.

old (SD = 2.00), had an average of half a year of driving experience (SD = 0.36), and held at minimum a valid entry-level driver’s license (G1 license in the Province of Ontario). These young novice drivers were the same average age as the young moderately experienced drivers (and both groups were younger than the young experienced drivers in Experiment 1). See Table 2 for descriptive statistics concerning driving history for the three groups.

All participants had normal or corrected-to-normal acuity and contrast sensitivity. The acuity measures for the three groups were as follows: older experienced drivers \((M = –0.06 \text{ log MAR}, SD = 0.09)\), young moderately experienced drivers \((M = –0.04 \text{ log MAR}, SD = 0.19)\), and young novice drivers \((M = –0.11 \text{ log MAR}, SD = 0.08)\). Contrast sensitivities were as follows: older experienced drivers \((M = 1.99 \text{ log MAR}, SD = 0.09)\), young moderately experienced drivers \((M = 1.99 \text{ log MAR}, SD = 0.10)\), and young novice drivers \((M = 1.96 \text{ log MAR}, SD = 0.04)\). All three groups had similar visual acuity and contrast sensitivity. Each participant was screened for predictors of SAS (none were removed due to adverse symptoms of SAS post-test).

3.2. Apparatus and stimuli

Participants were tested in the same driving simulator described in Experiment 1. There were 5 driving scenarios, the first being a 3 min practice scenario in which there were 3 hazards presented. Each of the four 6 min experimental scenarios encompassed 7.1 km of road with speed limits of 80 kph (two had clear visibility and two had fog). Every scenario included the same types of driving environments and ambient traffic as in Experiment 1. Visibility conditions were also manipulated as in the first experiment.

Each scenario had 3 km of straight road allocated to measure speed (divided across distinct areas of 1200 m, 1000 m, and 800 m), as in Experiment 1. However, there were more hazards in this experiment: 24 hazards in total, 12 hazards in each visibility condition (6 in each of the two scenarios for each condition). The method of hazard presentation was the same as in Experiment 1. In each scenario five hazards approached from the right and there was an additional trial in which a sixth hazard approached from the left. Because hazards emerging from the left would take longer to come into the path of the driver, hazard response times were based on right-hand hazards only (10 hazards in total per visibility condition). A variety of hazards were used: bobtail truck, sport utility vehicle (SUV), wheel loader, tow truck, pickup truck, public transportation bus, tractor trailer cab, dump truck, sedan, and school bus. Hazards varied from drive to drive, but every hazard type appeared in both clear and foggy conditions.

3.3. Design and procedure

This experiment was a 3 (driving experience: older experienced, young moderately experienced and young novice drivers) \(\times\) 2 (visibility: clear and fog) design. Average speed was measured to assess whether participants adhered to the speed limit as instructed. The number of collisions and hazard response time were also measured.

Participants were presented with the practice scenario, followed by the four experimental scenarios (presentation order was counterbalanced across participants). The instructions were to travel at the speed limit (80 kph). Otherwise the procedure was the same as in Experiment 1.

3.4. Results and discussion

Average speed and hazard response time were analysed separately by means of 3 (driving experience) \(\times\) 2 (visibility) factorial split-plot analyses of variance, and Greenhouse–Geisser corrections for violations of the sphericity assumption were used. Holm’s sequential Bonferroni corrected pairwise comparisons were used for post hoc analyses. In addition, because there was an age and gender imbalance between the three groups of drivers, average speed and hazard response time were further analysed separately
Fig. 3. Hazard response time (by pressing the brake pedal) as a function of driving experience and visibility. Error bars are ±1 SE.

by means of an additional analysis of covariance (with age and gender as covariates). A critical value of p < 0.05 was used for all tests.

Drivers were instructed to maintain a speed of 80 kph regardless of condition in this experiment, but analyses of average speed were carried out to ensure drivers followed the instructions. As it turns out, there were slight differences in speed across conditions despite the instructions. Although the main effect of driving experience on average speed was not significant, F(2, 45) = 0.65, ns, all drivers drove significantly faster in clear visibility than fog, F(1, 45) = 4.69, p < .05, \( \eta^2_g = 0.09 \). Nevertheless, the average speed difference between clear (79.99 kph) and foggy (78.89 kph) visibility was very small. The interaction between driving experience and visibility was also not significant, F(2, 45) = 0.11, ns. Neither age nor gender had an effect (F(1, 43) = 0.97, ns; F(1, 43) = 1.89, ns, respectively) and these factors did not interact with any other variable.

Normally collisions are rare events and there are typically too few to analyse. However, in this study there were collisions even though the total drive duration was less than 30 min. All of the collisions occurred with young novice drivers. Four out of 16 young novice drivers had one or more collisions (25% of the novice sample). Three of these eight collisions occurred in clear visibility and the remaining five occurred in fog. None of the other drivers had collisions (neither young moderately experienced nor older experienced). The data suggest that young novice drivers have the greatest risk of collision overall, even under conditions of low task demand.

As expected, there was a significant main effect of driving experience on hazard response time, F(2, 45) = 12.41, p < .001, \( \eta^2_g = 0.36 \) (see Fig. 3). Tukey’s HSD comparisons revealed that older experienced drivers braked faster than young novice drivers (p < .01, d = 1.73), however they did not significantly differ from young moderately experienced drivers. Furthermore, young moderately experienced drivers did not significantly differ from young novice drivers in their hazard response times. Combined with the collision data, these results suggest that the speeds drivers reduced to in fog in Experiment 1 were sufficient only for the young experienced drivers. Contrary to prediction, both the main effect of visibility, F(1, 45) = 0.08, ns, and the interaction between driving experience and visibility were not significant, F(2, 45) = 0.14, ns².

Although the older experienced drivers in this experiment were substantially older than the other two groups, age was not significant as a main effect on hazard response time, F(1, 43) = 0.18, ns, and it did not significantly interact with any of the experimental variables. Furthermore, there was no main effect of gender (F(1, 43) = 0.68, ns), and gender did not significantly interact with any of the experimental variables.

Finally, post hoc analyses of speed variability and SDLP were performed to investigate the suggestion posed in Experiment 1 that more challenging drives (longer durations and more hazards in this case) might allow an interaction between driving experience and visibility to manifest. There were no significant effects or interactions on speed variability, as would be expected given that part of the experimental task was to adhere to the speed limit. Both age and gender had no significant effect on speed variability (F(1, 43) = 2.02, ns, and F(1, 43) = 2.03, ns, respectively) and there were also no interactions between these variables and any other variable.

Interestingly, there was a significant main effect of driving experience on SDLP, F(2, 45) = 4.88, p < .05, \( \eta^2_g = 0.12 \), as drivers were overall more variable in their SDLP in fog than in clear visibility. Moreover, there was a significant interaction between driving experience and visibility, F(2, 45) = 3.42, p < .05, \( \eta^2_g = 0.13 \), which provided clarification for the main effect of driving experience. Tukey’s HSD comparisons revealed that in both clear (p < .05, d = 0.95) and foggy conditions (p < .05, d = 1.42) young novice drivers were significantly more variable in SDLP than older experienced drivers. However, in both visibility conditions young novice drivers did not significantly differ from young moderately experienced drivers, and young moderately experienced drivers did not significantly differ from older experienced drivers. These findings would be expected given the disparity of available cognitive resources between novice and experienced drivers as discussed in Experiment 1. Neither age, F(1, 43) = 0.09, ns, nor gender, F(1, 43) = 0.01, ns, were significant main effects and neither significantly interacted with the experimental variables.

4. Conclusions

Young novice drivers are at disproportionate risk of collision. Research suggests that these collisions may be primarily due to errors in decision-making, faulty selective attention and visual search strategies, as well as inappropriate expectations about hazards (Curry et al., 2011; Lerner and Westat, 2001; McKnight and McKnight, 2003; Pradhan et al., 2009; Vidotto et al., 2011). The results from the present experiments support those from previous research insofar as they show that young novice drivers did not manage the driving task as well as experienced drivers. This may be because the young novice drivers did not have adequate cognitive resources available to successfully manage all the aspects of the driving task (Trick et al., 2004). Young novice drivers had the longest hazard response times, the smallest speed compensation to fog, and the greatest variability in speed control and SDLP. Moreover, though collisions are typically rare in driving simulated studies, 25% of the young novice drivers had collisions in this study whereas none of the other drivers did.

---

² Given the effect of visibility on average speed, it was possible that speed compensation may have obscured any effect of visibility on hazard response time; therefore, we calculated a speed compensation index (using the same technique as Trick et al., 2010) to factor in the effects of speed reductions to fog. This index was calculated by dividing the average speed in the clear visibility condition by the average speed in the fog condition for each participant. The index was multiplied by the hazard response time in the fog condition to create a corrected hazard response time that factored in changes in speed. When the corrected response times were re-analysed the same pattern of results emerged as in the original uncorrected hazard response time analysis.
Experiment 1 shows that driving experience can influence the degree to which drivers modulate certain behaviours when potential hazards are present. Speed reduction is an adaptation that may reduce the likelihood of collision when the demand of the driving task increases; in the case of this study, the demand of the driving task was increased through the presentation of simulated fog. Evidence from Experiment 2 indicates that the speed drivers reduced to in fog in Experiment 1 allows for adequate hazard response times both in young moderately experienced and older experienced drivers. However, that speed reduction was insufficient for young novice drivers as several were unable to safely respond to hazards in either condition of visibility. It is possible that further speed reduction would allow young novice drivers to manage the driving task as effectively as experienced drivers.

A limitation of this study and many others that use driving simulators is that there is always the risk that participants might not interpret the experimental task as they would in real life. In other words, their behaviour may not completely reflect that simulated driving conditions. Although simulated fog is similar to real fog, it is not exactly the same. The limitations of current simulator technology restrict the ability to perfectly simulate fog, and while driving simulators allow researchers to assess driving behaviour in risk-free environments, the absence of any potential physical harm in itself might encourage drivers to not take the task seriously.

The level of fog used in this study was relatively low (at 600 m object-viewing distance) and there were only a few effects of visibility. A stronger visibility manipulation (with denser fog) may have produced larger effects. Even so, the visibility manipulation used in the present study was adequate to produce some effects insofar as it caused drivers to reduce their driving speed. Nevertheless, in future it would be useful to test performance in a variety of types of fog because compensations may vary, particularly as they relate to free or restricted speed tasks.

Another direction for future research should include dual tasks to examine the influence of cognitive load on driving behaviour. This would clarify whether the observed effects in this study reflect differences in available cognitive resources between drivers of different levels of experience. Experienced drivers should have aspects of the driving task rendered more automatic than novice drivers and therefore, unlike novice drivers, they should be able to adjust their speed appropriately and avoid collision when performing multiple tasks at once. The findings of this study reiterate the general consensus in the driving literature that young novice drivers require practice to lower their risk of collision. Although there are issues with simulated environments, simulated training methods may provide young novice drivers with the opportunity to obtain some of the necessary experience off of the actual road (Allen et al., 2011; Pradhan et al., 2009; Taylor et al., 2011; Vidotto et al., 2011). Driving simulators are ideal environments to train new drivers in simulated high-risk situations (such as fog) without the risk of physical harm to them or others on the road. Nevertheless, given the limitations of driving simulator technology, there is no substitute for real world experience. Although driving in fog may not always be possible, it is imperative that novice drivers be taught about hazardous situations early on in their training so that when the time comes to face more challenging situations they will be better prepared.

Acknowledgements

This research was funded by grants to the second author from the Canadian Foundation for Innovation, the Ontario Innovation Trust, Auto21 Network Centres of Excellence, and the Natural Sciences and Engineering Research Council of Canada.

References


Chao, L.L., Knight, R.T., 1997. Prefrontal deficits in attention and inhibitory control with aging. Cerebral Cortex 7 (1), 63–69.


Pradhan, A.K., Pollatsak, A., Knodler, M., Fisher, D.L., 2009. Can younger drivers be trained to scan for information that will reduce their risk in roadway traffic scenarios that are hard to identify as hazardous? Ergonomics 52 (6), 657–673.


