An Eye-tracking Evaluation of Driver Distraction and Unfamiliar Road Signs

Stephanie Hurtado
Carleton University
Ottawa, Canada
stephanie.hurtado@carleton.ca

Sonia Chiasson
Carleton University
Ottawa, Canada
chiasson@scs.carleton.ca

ABSTRACT

It is difficult enough for drivers to handle distractions when they are in a familiar environment, but what happens when drivers are placed in a new environment? We explore drivers' behaviour when they encounter road signs from three countries. We conducted two eye-tracking studies with 50 participants. Participants spent increased time looking at unfamiliar road signs. Misinterpretation occurred due to the influence of previous experience and many drivers drove at reduced speeds throughout to compensate for the anticipated cognitive load.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

Author Keywords

Driver behaviour; Driver distraction; Driver safety;
Eye-tracking study; Road signs.

INTRODUCTION

The United Nations World Tourism Organization recorded 1.2 billion international tourist arrivals worldwide in 2015 [26]; a large number will rent vehicles during their stay. Aty and Radwin [2] found foreign drivers have higher accident rates at intersections with turning manoeuvres. Likewise, a study showed tourists visiting the Greek Island of Crete were 2.5 times more vulnerable to accidents [27].

Road signs are designed to provide critical cues for drivers, regardless of where drivers are from. Consequences of ignoring or misunderstanding these cues can cause drivers to make errors in judgement and increase their risk of accidents. Surprisingly, there is no universally accepted standard for road signs; rather there exists a variety of guidelines set at provincial or state levels. As such, one does not even need to travel internationally to encounter unfamiliar road signs. A recent article published by the Boston Globe [8] showed how confusing some Canadian road signs can be for an American driving along the New Brunswick coast. There is little research looking at drivers in unfamiliar environments. Therefore, we have minimal data to understand drivers' behaviour when they encounter an unfamiliar situation, and how this may contribute to driving distraction. If we understood this issue, then we could design tools to reduce hazards while driving, and minimize distractions such as those external to the vehicle. Therefore, in this paper, we address this gap by exploring drivers' behaviour when they encounter road signs from different countries.

We conducted two user studies simulating highway and city driving using an open source driving simulator and eye tracking software. In each study, we compared Canadian, German, and Chinese road signs. We provide empirical results from 50 participants' driving performance to evaluate their reaction when encountering unfamiliar road signs. We propose two recommendations we believe will improve driver safety, and minimize distraction.

BACKGROUND

Road signs communicate upcoming changes to drivers' immediate environment. When understood correctly, they allow for effective decision making. A sub-field of Ergonomics extensively studies sign design features such as colour, size, and placement [6, 12]. Examination of cross cultural understanding of road signs revealed low comprehension scores for non-local signs and misinterpretation of road signs rules [29]. Understanding of traffic rules and consequently driving behaviour, is influenced by local driving practices, immediate surroundings, and general rules. These factors can conflict with each other [31], and result in "selective looking" behaviour [5]. A well designed road sign should trigger recollection from previous driving experiences such that a driver will carry out conditioned actions [3]. An excellent representation of this is the design of a red octagon to denote a stop sign since the shape and colour remain the same among most countries. This allows foreign drivers' conditioned action of stopping their vehicle even though the textual representation of 'stop' might differ.

In the same manner, this design method can be extended to vehicle user interfaces, or advanced driver assistance systems (ADAS). Interfaces and ADAS can be designed to provide support through information, or warnings, to help mitigate driving risk [7, 16, 28]. Münter *et al.* [25] suggest that context-aware navigation systems be implemented using a rule-based approach. For example, in familiar environments, support should be minimized and present drivers only with main road

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Figure 1: Highway track view with a German road sign

sections. Drivers who identify as having a poor sense of direction will require additional support on unfamiliar routes. This flexibility can improve usability, driver acceptability, and reliance [20, 10]. A failure in design, whether it be in the form of a complex road sign or an overcrowded interface, can draw drivers' attention away from the main driving task [30]. This can decrease drivers' situational awareness, which hinders their abilities to react and make efficient decisions while driving [15, 13].

Although most studies focus primarily on internal distractions [32, 30], drivers may also become distracted by events external to their vehicle [24]. Zhang *et al.*'s [35] concern was that signs with more information might increase visual distraction therefore they tested highway road signs with varying number of logo panels. Results revealed that while the nine-panel signs captured participants' attention longer and resulted in a slower average speed, the changes were small and statistically insignificant. Their findings align with those of Metz and Krüger [24] and Dukic et al. [11].

Our larger term goal is to use in-vehicle systems and feedback to improve driver safety. We look to improve on context-aware systems by understanding how drivers behave in unfamiliar situations. Specifically, we examine road signs which can be used by Advanced Driver Assistance Systems to provide informational support for drivers.

EXPERIMENTAL SETUP

To investigate driver distraction and road sign identification, we designed both highway and city driving simulated tracks. Portions of each track were used to test road signs from three different countries (Canada, Germany, China). Figure 1 shows the highway track with German road signs.

We designed the driving tracks using OpenDS [21] a Java-based open source driving simulator. For our highway simulation, we used a pre-configured map which modelled roads on an open hilly terrain. The closed circuit track with vehicle traffic allowed participants to drive at higher speeds for longer durations, similar to highway driving. Furthermore, we used a pre-configured map with cross-walk markers, roundabouts and vehicle traffic to simulate city driving. Each simulation model was used three times, once to test each country's road signs. We used two separate tracks as driving practice for participants before they were introduced to either the Highway or City simulation. Participants were allowed to drive freely around the practice tracks. Participants used a Logitech G27 steering wheel and foot pedals to control their vehicle. The two right-most pedals controlled the brake and gas. The driver interface was connected to a laptop running OpenDS software. Control of the steering wheel and the pedal sensitivity were adjusted during pilot testing to provide more realistic feedback to drivers. A 55-inch monitor was used to display the simulation, as shown in Figure 2. Participants sat approximately 70 cm from the monitor. The vehicle controls were set to simulate an automatic car.

Figure 2: Driving simulator lab set-up

To capture eye gaze movements, we used SMI's iViewETG system, a glasses-type eye tracker with integrated audio recording. To get an accurate eye gaze reading, the SMI device required a 3-point calibration per participant.

In both studies, the starting position on the track for each country was changed to minimize user habituation. Driving for each country took approximately 5 minutes. The majority of the road signs were used in both studies in order to see differences in sign recognition accuracy between highway and city conditions. Some variation was necessary based on their pertinence to each track. For example, participants encountered a pedestrian cross-walk sign on the city track but not on the highway track. Text-only signs were avoided to ensure participants who were familiar with the language of the sign did not have a significant advantage over other participants; however two text signs on the Chinese track (the stop and slow down signs) were used because there was no symbol based alternative. These Chinese signs followed the same shape and colour conventions as its equivalent Canadian and German sign. The road signs used for both studies can be found in Hurtado [17]. Each city track had 19 signs from the prescribed country and each highway track had 25 signs.

METHODOLOGY

Each participant completed either the Highway or City study. For each study, we used a within-subjects design where each participant drove three tracks. Presentation order of the tracks was determined using a Latin square[1]. Each track contained road signs from one of three countries (Independent Variable): Canada, China, and Germany. According to the United

[1] The order of the tracks were assigned using a 3x3 table. Participants were sequentially assigned a presentation order from one table row.

Nations World Tourism Organization, these countries are included in the top three tourist regions [26]. Participants were recruited from within Canada. Participants were told the aim of the study was to recognize road signs present while driving. This study was cleared by the University's research and ethics board. A session lasted 45 minutes on average.

With participant consent and pre-test questionnaire[2] completed, the experimenter demonstrated the functionality of the wheel and pedal set and allowed participants to drive a practice track to familiarize themselves with the sensitivity of the vehicle controls and demonstrate that they could successfully control their on-screen vehicle. For the actual tracks, the experimenter instructed participants to obey speed limits, avoid collisions, and maintain vehicle in the proper lane while driving. Additionally, the experimenter instructed participants to verbally identify the road signs as they appeared along the tracks. Participants were fitted with the SMI eye tracker and gaze calibration was adjusted for each participant. While driving, participants received navigational directions from the experimenter when necessary and were given a few minutes break between tracks. The session concluded with a post-test questionnaire measuring participants' recognition and interpretation of the signs, as well as their opinions and perceptions of each track.

Our hypotheses are as follows:

- **H1:** If participants face unfamiliar road signs, their driving performance will decrease, as measured by a decrease in driving speed and in lane keeping ability.

- **H2:** Drivers will experience a higher cognitive workload with unfamiliar road signs, as measured by an increase in the visual time needed to identify a sign and a decrease in sign recognition accuracy.

Driving performance and cognitive workload can encompass a variety of measures and we focus on a subset. For the first hypothesis, we specifically look at driving performance in terms of speed and lane keeping to identify if unfamiliar road signs contribute to drivers' distraction. We are particularly interested in these measures because both unsafe driving speed and lane drifting can increase driving risk.

For the second hypothesis, we measure specific aspects of cognitive workload. The cognitive workload is affected by every environmental element a driver needs to be aware of when driving. This can include elements such as traffic, pedestrians, and road signs which each attract some of the driver's attention. A higher overall workload therefore may affect drivers' ability to keep track of these elements by splitting their attention, and unfamiliar elements may require more attention to process [34]. In our work, we focus on the ability to handle familiar versus unfamiliar road signs.

Data Collection

Data was collected using OpenDS driving logs which stores vehicle and driving information. Furthermore we defined an

[2]Pre-test questionnaire collected participants' previous driving experience, foreign driving experience (outside of Canada), driving license level, and general demographics.

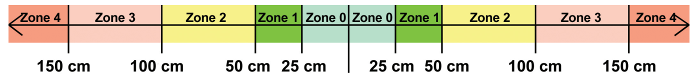


Figure 3: Distance (cm) from ideal path on either side of the center of the lane

ideal driving path within each track's property files. This path reflects a vehicle that stays centred in their lane throughout the track. Using our modified version of OpenDS Analyzer tool, we categorized driving deviation from ideal path into four zones. Figure 3 shows the boundaries of each zone. Cases where a participant decided to pass a leading vehicle were marked as a controlled pass and were not counted against the final Zone scores. If participants went too far off the track, they were reset to the start of the track. This was counted as a reset in the analysis; data on distance, zones, and road sign identification were not counted until the participant returned to the original position where they went off the track. We use the sum of the distance (m) travelled in each zone, the total number of cars passed, the total number of resets that occurred, and the percentage of time spent in each zone over the total distance (m) travelled, to determine if there is a relationship between lane deviation and sign recognition.

Using eye-tracking, we captured video of participants' gaze fixation points and the duration of their gaze fixation in milliseconds (ms). During the session, the experimenter scored participants' verbal identification of road signs using a modified version of Shinar *et. al*'s road sign guessability score[29].

Verbal responses from participants identifying road signs were also audio recorded and used to verify scores assigned. The pre-test questionnaires gave us an understanding of participants' previous driving experience while the post-test questionnaires measured three main areas: the perceived difficulty of each track using a 3-point Likert scale, participants' perceived ability to keep in their proper lane, and obey posted speed limits, on a 3-point scale from Poor to Excellent, and participants' ability to recognize and interpret road signs that appeared on each track. They were shown road sign images and asked to indicate whether each had appeared on the track and to interpret the rule conveyed by each sign.

Participants

Both driving studies required participants to have a valid driver's license from any country. This ensured they minimally had an understanding of the basic road regulations.

Highway Study: We recruited 25 participants, 12 female and 13 male with an average age of 31.7 years (S.D.=12.94). Five reported having had a driving license issued by a country other than Canada. The average driving experience was 13.8 years (S.D.=12.59), with the highest being 46 years and the lowest being 1 year. Fifteen participants reported having experience driving in a foreign country.

City Study: Twenty-five participants, 11 female and 14 male with an average age of 32.52 years (S.D.=14.65) were recruited for this study. Of these participants, 8 reported having had a driver's license issued by another country. The average driving

	Max	Min	Median	Mean	Standard Deviation
Highway Study					
Germany	13.76	0	3.11	3.44	2.50
Canada	14.01	0	3.38	3.70	2.57
China	14.13	0	3.64	4.12	2.96
City Study					
Germany	13.73	0	2.06	2.50	2.03
Canada	11.46	0	2.41	2.85	2.25
China	10.43	0	2.88	3.35	2.23

Table 1: Total gaze fixation time (seconds) per sign. A time of 0 occurred if a participant never glanced at a given sign.

experience was 13.08 years (S.D.=13.32), with the highest being 47 years and the lowest being 1 year. Ten participants reported having experience driving in a foreign country.

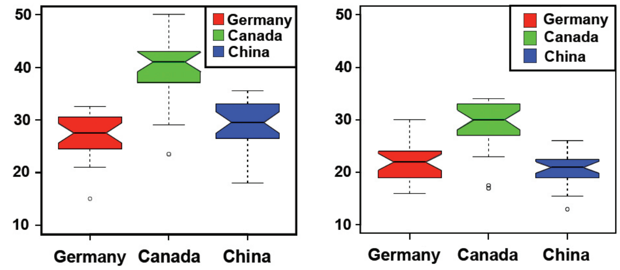
RESULTS

We conducted statistical analysis to compare performance between countries. Prior to testing, Shapiro-Wilk tests were used to check normality. Non-parametric tests were then used in cases where data did not follow a normal distribution. In all cases where overall differences are highlighted between countries, these are statistically significant to the $p < 0.05$ level, while Bonferroni-corrected pairwise comparisons are significant to the $p < 0.0167$ level. Table 2 summarizes the inferential statistics for the Results sub-sections.

Gaze Fixation

We examine the *longest consecutive gaze fixation time* (in seconds) per participant on each individual road sign per track. Fixation points are considered consecutive when the subject stared at a road sign without looking away. We also examine the *total gaze fixation time* (in seconds) participants spent looking at a sign. Due to limitations of the eye tracking software, gaze data could not be reliably collected from participants wearing eyeglasses. Therefore, the gaze fixation data is composed of 17 participants from the Highway study and 15 from the City study. For the statistical analysis, we calculated the mean value across all road signs for each participant, giving us one data point per participant per track.

From Table 1, we see that participants generally spent 2-3 seconds looking at a road sign to develop an understanding of its message. A Friedman test comparing the mean *total gaze fixation times* for each Highway track was significant (see Table 2). Bonferroni-adjusted pairwise comparisons using Wilcoxon rank sum tests showed a significant difference between Germany-Canada, and between German-China, with longest gazes for China. The City tracks similarly resulted in significant differences between Germany-China, with China also having the longest gazes. To further understand the differences, we looked at participants' *longest consecutive gaze fixation* and found that in both studies, road signs with the highest gaze fixation times contained two or more images. Observations during both sessions revealed some participants coming to a complete stop to identify a road sign. Additionally, we noticed participants bringing their face closer to the display if they did not comprehend a sign. On the other hand, participants who were focused on the leading vehicle, on passing a vehicle, or on other track elements would miss looking at a road sign completely. These observations help to explain outlier data encountered in our analysis as seen in the min and max values from Table 1.



(a) Highway Study (b) City Study

Figure 4: Scores from the verbal road sign identification by study

Road Sign Identification

Figure 4 shows the *scores of participants' verbal identification of signs encountered* in each study. The Canadian track outperformed the other two countries in both studies. Friedman tests comparing scores between countries show significant differences for both the Highway and City studies (see Table 2). Likewise, post-hoc Bonferroni-adjusted pairwise Wilcoxon tests revealed significant differences between Canada-China and between Canada-Germany for both studies.

Participants were able to accurately identify significantly more signs on the Canadian tracks, likely due to familiarity. Twenty participants on the German Highway track and 24 participants on the German City track had at least one negative score, indicating they interpreted a road sign as the opposite of its intended meaning. Participants had particular difficulty identifying German road signs No Overtaking, and End Of No Overtaking Zone. This may have occurred because typically Canadian road signs with a diagonal line through an image mean the action is prohibited. On the contrary, German road signs with an open red circle indicate a prohibited action, and a diagonal line negates the original meaning. This highlights a significant consequence of not having standardization: road signs interpreted as opposite to their intended meaning.

Lane Deviation

Participants had good lane keeping abilities in both studies with the most time spent in Zones 0 and 1, particularly on the Canadian track where participants spent 96.6% and 89.3% (Highway study and City Study, respectively) of their total driving time in their proper lane. A Friedman test comparing *distance travelled in the proper lane* per country on the Highway track yielded significant results (see Table 2). Post-hoc Wilcoxon tests with Bonferroni adjusted alpha levels showed participants kept within their lane for a longer distance on the Canadian Highway track compared to both Germany and China, but no statistically significant differences were found on the City track. We also compared the amount of deviation

	Omnibus	CA-GR	CA-CH	GR-CH	Omnibus	CA-GR	CA-CH	GR-CH
	Highway				City			
Total gaze fixation	$\chi^2(2) = 12.12$	$Z = -2.63$	n.s.	$Z = 3.34$	$\chi^2(2) = 14.8$	n.s.	n.s.	$Z = 3.29$
Road sign ID	$\chi^2(2) = 33.36$	$Z = 4.35$	$Z = 4.35$	n.s.	$\chi^2(2) = 28.60$	$Z = 4.17$	$Z = 4.27$	n.s.
Distance in correct lane	$\chi^2(2) = 35.52$	$Z = 3.91$	$Z = 4.37$	$Z = -3.11$	n.s.	–	–	–
Speed	$\chi^2(2) = 10.64$	n.s.	n.s.	$Z = -3.30$	$F(2,48) = 28.79$	$p < 0.001$	n.s	$p < 0.001$
Perceived difficulty	$\chi^2(2) = 28.41$	$Z = -3.62$	$Z = -4.12$	n.s.	$\chi^2(2) = 21.79$	$Z = -3.35$	$Z = -3.73$	n.s.
Perceived distraction	$\chi^2(2) = 37.06$	$Z = -4.20$	$Z = -4.39$	$Z = -3.08$	$\chi^2(2) = 34.13$	n.s	$Z = -4.21$	n.s
Perceived ability to stay in lane	n.s.	–	–	–	n.s.	–	–	–
Perceived ability to obey	$\chi^2(2) = 8.58$	n.s	n.s	n.s	$\chi^2(2) = 21.85$	$Z = 2.99$	$Z = 3.79$	n.s

Table 2: Statistical omnibus and pairwise comparisons between countries. CA = Canada, CH = China, and GR = Germany, n.s. = not significant, – indicates that the test was not performed. Omnibus tests are significant at $p < 0.05$ and pairwise comparisons are significant at $p < 0.0167$ due to Bonferroni correction.

	Difficulty	Distraction	Ability to Obey	Lane Keeping
Highway Study				
Germany	2.04	3.16	2.04	2.04
Canada	2.72	4.28	2.32	2.28
China	1.68	2.52	1.96	2.12
City Study				
Germany	2.04	3.56	2.64	2.00
Canada	2.60	4.88	3.04	2.12
China	1.72	2.88	2.20	2.12

Table 3: Mean Likert scale responses to perception questionnaire; 1 = most negative, 5 = most positive.

that occurred before and after an unfamiliar road sign was encountered; however, results were inconclusive.

Speed
Participants were generally cautious in both studies, maintaining *driving speeds* well below the posted speed limit. We conducted ANOVAs and found overall statistical differences between countries for the Highway study (see Table 2), and pairwise t-test comparisons identified differences between China-Germany, with China having the lowest average driving speed and Germany the highest. The German track also had the highest average driving speed in the City study. Drivers were especially cautious driving on the City tracks, with mean speeds of approximately 20 km/h. The reduced speeds in both studies at least partially explained why drivers were mostly able to stay within their lanes.

Perception Questionnaire
Participants completed an online questionnaire at the end of both studies. Their responses are summarized in Table 3 and covered four categories: perceived track difficulty, perceived level of road sign distraction, perceived ability to obey road signs, perceived lane keeping. Both studies show the Canadian track was rated least difficult. Post-hoc Wilcoxon tests with Bonferroni correction confirm these findings with significant differences found between Canada-China and Canada-Germany. The Canadian track was also rated least distracting, while the Chinese tracks were rated most distracting. These results suggest that participants are more inclined to perceive a familiar environment as easier in terms of cognitive workload.

Participants had mixed perceptions about their abilities to stay in the correct lane on both studies and a Friedman test found no significant differences between participants' perceived lane keeping abilities per track. Additionally, participants perceived that obeying road signs was easier on the Canadian Highway track, but we found no statistical differences between the countries in the City study.

Recognition and Interpretation Questionnaire
On the post-test, participants *recognized* whether a given sign had been present on the tracks and *interpreted* their meaning. Both studies saw *recognition scores* higher than 70% for the 15 road signs on the questionnaire, but many participants failed to correctly interpret their meaning. The Canadian tracks had the best overall scores: 80% for recognition and 66% for interpretation. In comparison, the Chinese track had the worst interpretation score (46%) in the Highway study and the German track had the worst score in the City study (22%). It was evident in many cases (e.g., Bus Stop, Avoid Collisions, No Hazardous Goods) that participants related the road signs to ones they had previously seen. Whether this exposure was from road signs encountered during the simulation, or from real-life driving is unclear. For example, the Chinese sign Stop for Inspection had 56% and 40% (Highway and City study, respectively) of participants believing that it meant Do Not Enter, likely due to the similarities with the North American Do Not Enter road sign. Participants who correctly identified the Bus Stop road sign on the German track said they initially thought that it meant "hospital", but its placement near bus shelters altered their interpretation. Participants frequently looked to their environment for interpretation clues.

DISCUSSION
In general, participants required about 2-3 seconds to look at a road sign and verbally identify its meaning while driving. In both studies, we noticed that the road signs that required the most visual time were those that contained two or more images. In driving, response time is critical, which means reducing the complexity of a road sign design should be made a priority in interface design [22]. One participant on our highway track commented that she was so focused on trying to identify the Chinese character on the road sign that it was not until she noticed the shape and colour of the road sign that she was able to identify it as a stop sign. Our session observations noted that some participants would come to a complete stop to identify a road sign. Although behaviour on a simulator is less precise than actual driving [23, 4], it does suggest that some participants will reduce their speed substantially to

spend more time looking at a sign. This behaviour can lead to collisions due to fast approaching vehicles on highways, or closely following vehicles in cities. Thus, complex road signs may increase the probability of car accidents because they hold drivers' visual attention for longer.

Some participants' gaze fixation times were short but their verbal identification of road signs were incorrect. Duration of gaze alone is not indicative of road sign comprehension, which is why we also considered verbal identification of road signs. Our findings show that participants were unsurprisingly better at identifying Canadian road signs. This aligns with findings from previous studies which demonstrate that drivers are better able to comprehend local road signs over foreign ones [9]. Additionally, the explanations for some of the road signs demonstrated that participants tried to relate an unfamiliar road sign with a visually similar local road sign. This supports previous studies [3, 5] which state that drivers have a tendency to use previous experiences and local practices in unfamiliar situations (e.g., a different country). This can cause a misinterpretation of traffic rules, increasing drivers' susceptibility to risk [31]. We observed this in our studies, where some road signs were mistaken for the opposite of their actual meaning. This can result in drivers making dangerous decisions (e.g., passing a vehicle, entering a prohibited street).

To better assess driver distraction, we measured participants' lane deviation. Our findings show that, for the most part, participants did not deviate from their proper lane. Deviations within Zone 1 and 2 were not considered hazardous. To our knowledge, our study was the first to measure lane deviation with unfamiliar road signs using a driving simulator. The majority of papers that examine driver distraction do so with static images or videos [33, 19]. From our results, we cannot claim that unfamiliar road signs result in distraction based on lane keeping. Participants did, however, drive much more slowly than expected, which likely helped them minimize lane deviation. In real-life, driving at half the posted speed limit could also be very dangerous.

Data collected from the post-test questionnaire gave us participants' opinions of each track. For both studies, Canada scored best overall in terms of difficulty and perceived road sign distraction which aligns with our statistical findings on performance. However, some perceptions did not align with performance. For example, while participants had good lane keeping abilities, their perceptions were mixed. Participants also indicated that Chinese road signs were the most distracting, yet our lane deviation data and the number of reported unfamiliar signs did not support this perception. Rather, perceived distraction relates to a higher cognitive workload as seen by duration of gaze fixation on unfamiliar road signs. A comment made by Participant 22 during our Highway study summarizes this relationship well: "*I was more familiar with Canadian signs therefore I was able to be more attentive to my speed, I could remember what prior road signs said, and knew what my driving restrictions were. On the other countries, I was unfamiliar with the signs therefore, I did not pay attention to my speed limit, or to traffic in front of me*". Participants were able to correctly recognize whether a sign appeared on one of the tracks with more than 70% accuracy had difficulty describing the meaning of road signs. In particular, the most confusing signs also had the longest gaze fixations. This further supports our initial comments about the necessity of simple road sign designs.

From the findings discussed, we direct our focus to how we can apply this understanding to enhancing in-vehicle systems. Our findings can be a starting point to designing in-vehicle systems that help reduce external driving distraction. In our case, we focus on unfamiliar road signs. Studies describe implementing systems that alert drivers to dangers on the road [28, 20] (e.g., following too closely), in the attempt to reduce hazardous and distracted driving. We propose that it may be possible to further reduce these risks by designing an in-vehicle system which presents drivers with road sign information when drivers are in an unfamiliar location. This information could be retrieved using context-aware systems [1]. Additionally, context-aware systems would have knowledge about drivers' behaviour [18, 25] and could theoretically know about drivers' movements and geo-location. Therefore, systems could warn drivers when they attempt to do something against traffic regulations.

Studies show that current image processing systems still require extensive work before they can provide an accurate and reliable method for dynamically identifying objects in real-time [14]. We suggest an alternative is to use web-based services such as Google Maps[3] Street View feature to asynchronously identify road signs present along routes. Translation or interpretation details could be retrieved in real-time by the car using geo-location. These road signs could be processed and stored by in-vehicle systems such that when a driver encounters an unfamiliar sign or attempts to contradict local traffic signs, the system could present the driver with information about the road sign. Different modalities could be used for in-vehicle interfaces such that drivers could communicate via speech or touch if they want more information about the sign. Such a system would be particularly helpful for new or temporary drivers in foreign environments, or even as a driving aid to new drivers in their local environment.

We recognize that re-evaluating road sign designs will take a long time and significant cost efforts, which is why we believe designing in-vehicle systems may be the key to helping drivers with road signs. The methods discussed for in-vehicle systems require further exploration; our findings merely reveal that a problem exists and we suggest a potential solution.

Limitations

The eye tracking glasses were not able to register the eye movements of participants who wore eyeglasses. Additionally, in the City study, the eye tracker was not properly positioned on two participants which resulted in gaze fixation not being captured. We were unable to include these participants in our eye tracking analysis. This may have had an impact on our gaze fixation results and our comparison between unfamiliar signs and gaze duration, however, we were still able to analyze

[3] http://maps.google.ca/maps

gaze data from over 60% of the participants. Data from all 50 participants was used in the analysis not requiring gaze data.

Some participants had more trouble controlling the steering wheel than others which may have made it more difficult for them to stay in their lane. This may be due to the sensitivity of the steering wheel, or participants' unfamiliarity with gaming "wheels". In an attempt to balance this, we gave all participants a practice run on a test track so they can familiarize themselves with the controls and sensitivity.

RECOMMENDATIONS

Based on our observations and findings, we propose two recommendations. We believe these will improve driver safety, and minimize distraction.

R1: In-vehicle systems should be used as context-aware interpreters

In-vehicle systems should be context-aware in order to convey the meaning of road signs to drivers. From our studies, we specifically believe that geographical context would be beneficial to inform in-vehicle systems that are capable of assisting drivers in an unfamiliar place. They can act as interpreters to help drivers understand foreign traffic signs and policies. The systems could relate current signs with ones equivalent to the driver's local traffic signs or policies.

Context-aware systems might also use other contextual information to customize their output. For example, sensors might determine a driver's level of stress or fatigue, and external input such as weather or traffic conditions could also influence the in-vehicle system. Further research would be needed to determine the best combinations.

R2: In-vehicle systems should leverage mapping services

In-vehicle systems should leverage web mapping services like Google Maps to present drivers with road sign information such as upcoming signs and/or road sign rules. This would differ from traditional turn-by-turn directions found on navigational systems. Instead, it would present drivers with information about warnings, prohibited/permitted actions, and cautions encountered along their route in a familiar language.

This recommendation is made as an alternative to using dynamic image processing methods. Additionally, this design should selectively alert drivers about traffic sign policies if they drive in an illegal manner (e.g., passing vehicles), to prevent overwhelming drivers with notifications and causing further distraction. As discussed in the literature [10, 20], overwhelming users can affect user acceptance and usability.

CONCLUSION

This paper is concerned with how unfamiliar road signs affect drivers' behaviour. Our findings show that participants fixate longer on road signs with a complex design and those that are unfamiliar. This may increase their risk of collisions. Likewise, misinterpretation of signs occurred due to the influence of previous driving experience and local driving practices. This may lead drivers to make errors in judgement, putting them further at risk for accidents. Results also demonstrated that participants had the tendency to stay in their lane even when they encountered unfamiliar road signs, although many drivers drove at reduced speeds throughout the track to compensate for the anticipated cognitive load.

To aid drivers in understanding unfamiliar road signs, we suggest using this data as a starting point for developing in-vehicle systems that are context-aware, and can use web mapping services to present drivers with road sign information. This information should be presented in an unobtrusive way to promote user acceptance and reduce the chances of further distraction. More research is necessary in this area to determine the optimal approach for reducing driving risk.

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