Analysis of Glance Movements in Critical Intersection Scenarios

Marina Plavši•, Klaus Bengler, Heiner Bubb
Lehrstuhl für Ergonomie
Technische Universität München
85747 Garching b. München, Germany

ABSTRACT

For designing effective and ergonomic assistance systems for road intersections it is highly beneficial to gain an understanding of the causes of driver’s errors. At intersections errors depend mainly on the applied visual strategies and perceived information. This paper reports on a study conducted in the fixed-base driving simulator, with an objective to compare driver’s visual strategies among three left-turn intersection scenarios, which can become critical with respect to safety.

The comparison of applied visual strategies showed that in the more complex situation drivers delegate more attention to the task and perform a less risky behavior. Nevertheless, in complex scenarios the driver’s visual behavior indicates a prioritization problem regarding the primary directions to scan. A system that in an appropriate moment visualizes the priority roads or even ideal eye-movement sequence could decrease both driver’s committed errors and mental workload.

Keywords: Road intersections, Eye movements, Erroneous behavior
INTRODUCTION

Intersection areas present one of the most difficult traffic situations where a lot of accidents happen. In Europe, depending on the country, intersections account for 30 to 60% of all injury-related accidents (Intersafe2, 2009).

In more than 95% of traffic accidents the causes lay in the driver’s erroneous behavior. The errorless performance is especially important at intersections, as at an intersection there is a short time span available for the error corrections. In order to safely perform the task, the driver should perceive all relevant information, process it in a correct way, decide on the driving action and then flawlessly execute it. The research results of Gruendl (2005) showed that the main causes for driver’s erroneous behavior are in the objectively or subjectively missing information. The wrong decisions and evaluations based on properly seen information are rarely the origin of accidents. This means that the safe performance depends mainly on the driver’s ability to perceive important information in optimal time.

The information at intersection is to more then 95% perceived by the visual channel. This means that the information perception depends highly on the driver’s eye movements and underlying visual strategies. In this case, the eye movements can be regarded as a result of preceding cognitive processes, which are hard to measure and evaluate. However, measuring and analyzing driver’s visual behavior can lead not just to understanding of information perception and prioritization strategies but also to a better understanding of underlying cognitive mechanisms.

Within this work, the applied visual strategies and eye movements at selected intersection scenarios are analyzed in experimental conditions. The aim is to analyze how the visual strategies with resulting erroneous performance of the driver differ from the visual strategies of the drivers who perform the maneuvers safely and whether and how the applied visual strategies depend upon the maneuver. In order to provoke erroneous behavior, the left-turn maneuver is chosen as the most difficult task. Each of scenarios contains a hazard object and it is designed in a way that if the driver does not pay attention to the road with hazardous object, an accident is likely to be caused. The normative driver’s behavior does not result in an accident. It is important hereby that hazardous objects have right of way and behave rule-compliant.

In the following, the advanced research with respect to the visual strategies at intersections is presented.

VISUAL STRATEGIES AT INTERSECTION

The basics of visual perception at intersection are similar to the basics of the perception of any arbitrary dynamic scene. The perception process can be divided
into several phases. The first phase is so called pre-attentive processing in which the first few fixations give an essential picture of the scene. Schweigert (2003) conducted a field experiment in which he found that the speed of the objects scanning at intersections is between 0.8 to 5 fixations per second. In the second phase, the fixations serve to fill in details and to identify the separate objects. In the same experiment Schweigert found that in the second phase the modal values of fixation durations are between 0.3-0.4s in the urban scenes. After being fixated, the objects are consciously identified and can be kept around 3 to 4s in the short-term memory. Still, the object can be lost even earlier if the new content suppresses the old, which is the case in visually loaded scenes such as intersections.

The eye movements while driving can be described by two mechanisms: bottom-up (data-driven) and top-down (knowledge-driven) mechanism. Bottom-up mechanism is controlled by occurrences of objects in the environment and the top-down mechanism indicates controlled strategies that are the result of information processing. For each traffic situation, driver chooses corresponding mental model and applies the visual strategies that correspond to the selected mental model. At intersections this can be considered as the consciously driven rule-based behavior.

The ideal visual behavior at intersections is the successively scanning of all the directions from where the hazards can come from. With experience drivers develop strategies that serve to predict the position of the crucial information. In such a way the relatively rarely seen objects like bicycles and motorcycles can be overseen (Summala, 1996). Langham (2006) found that duration spent looking for hazards at intersection is not higher than 0.5s. This time corresponds to checking just one or two directions which driver considers as relevant before crossing.

When it is necessary to perform several tasks simultaneously, the drivers have to choose the right order of the tasks and sometimes to omit the ones of the less value to them. The information prioritization that drivers do is resembled in the fact that with the increasing difficulty of the driving task, the fixation durations are decreasing, especially with respect to the irrelevant traffic objects and scanning fixations. Schweigert (2003) found that when having to perform additional task, the drivers omit checking for irrelevant traffic objects. At intersections, even 68% of drivers retract from direct scanning for pedestrians. When having to perform these multiple tasks at once it may happen that the driver does not just fail to look in one of the relevant directions but also that the object that is fixated is not perceived.

How the tasks are prioritized is kept in the driver’s mental model of the situation. It is of interest to find out how the drivers do prioritize information and how it does depend on the performed task. This can be answered by analyzing the distribution of the driver’s attention. Additionally, the analyzed difference between erroneous and safe strategies may indicate the possible assistance support. Therefore, the presented approach focuses on the analysis of the distribution of attention and the difference between erroneous and safe visual strategies.
EXPERIMENTAL STUDY

APPARATUS

The study was conducted in the fixed-base driving simulator located at the Institute of Ergonomics, Technische Universität München. The driving simulator is shown in Figure 1(a). The applied software is the commercial software SILAB (SILAB, 2009). This software enables a very realistic simulation of the traffic situations as well as the full control over all road users. In this way it is possible to create the arbitrary intersection scenarios and to exchange a “look and feel” of the simulation.

The glance behavior was recorded by using eye-tracking system Dikablis (Ergoneers). The system consists of two cameras, one recording the user’s eye and the other recording the field of view (see Figure 1(b)).

![Image](image1.png)

**Figure 1.** Apparatus applied in the study (a) fixed-base driving simulator of Institute of Ergonomics, (b) Eye tracking system Dikablis (Ergoneers)

EXPERIMENTAL SITUATIONS

Four experimental scenarios are chosen for the investigation. In this paper, the analysis of three scenarios is presented. The fourth scenario was triggered just in some test runs and therefore cannot be appropriately evaluated.

In order to provoke the erroneous behavior of the drivers, the left turn as the most difficult maneuver is chosen for the analysis. Each of three scenarios involved a potentially dangerous vehicle. This vehicle becomes visible in the phase of turn execution and apart from being occluded it does not perform any dangerous or unusual action. All vehicles hereby comply to traffic rules. Also, in all scenarios, the hazardous vehicles have right of way.

The first scenario is one-carriageway intersection with one lane for each direction, regulated by traffic lights. The sketch of the scenario is presented in Figure 2. The green car depicts the own vehicle and it arrives at intersection during the red-light phase. Blue cars in Figure 2 present the vehicles that are not directly dangerous for the own vehicle. During the red phase, the vehicle on the opposite
lane that turns left is also visible to the driver. Behind this vehicle, there is an occluded potentially hazardous car (marked with H in Figure 2) that drives straight after the light changes to green.

FIGURE 2. Scenario 1 – Left turn at intersection regulated by traffic light. The potentially hazardous vehicle H is occluded for the own vehicle while waiting for the green lights: (a) approaching intersection, (b) turning at intersection

The second scenario is an unordered T-intersection, presented in Figure 3. The own vehicle reaches an intersection at approximately the same time as the vehicle from the left that stops to yield the own vehicle. In that moment the vehicle from the right (depicted by the red car in Figure 3) reaches the intersection and the own vehicle is supposed to yield right of way.

Figure 3. Scenario 2 – an unordered T-intersection with a potentially hazardous vehicle coming from right (a) approaching intersection, (b) turning at intersection

The third intersection consists of two broad lanes in each direction. This intersection is regulated by traffic lights that are in a continuous yellow phase. This is a complex scenario with six groups of independently moving objects, which is on the limit of the driver’s processing capacity (Baddeley, 2009). The subject vehicle approaches from the minor street and has to give the right of way the crossing vehicles both from left and right as well as the oncoming vehicle. All three
potentially hazardous vehicles reach the conflict area of intersection at the same time with the own vehicle (see Figure 4).

Figure 4. Scenario 3 – Two lanes intersection with three potentially hazardous vehicles, and one vulnerable road user (a) approaching intersection, (b) turning at intersection

TEST SAMPLE AND EXPERIMENTAL PROCEDURE

Thirty drivers took part in the experiment but one third did not finish the test because of the occurring simulator sickness. The presented analysis refers to twenty test subjects that completed the test. The participants possessed the driver’s license of the European B category for 8.6 years on average. The group is age-homogeneous with the mean age of 25.8 years (SD = 7.27). The test sample consisted mainly from the students of the Mechanical Engineering department. The gender distribution of 19 males and 1 female reflects the distribution of the student population.

The aim of the study was not revealed to the participants before they finished the trial. The participants got a short introduction about the driving simulator and the eye tracking system and were told that the goal of the study is the evaluation of the simulator. First, the participants drove the practice course to get used to the simulation environment and only afterwards the full course equipped with the eye tracking system. Before starting the test, participants filled in the demographic questionnaires. After the trial, the participants were confronted with their own drive and eye movements and for each of the three intersections, they were administered a situation-specific questionnaire. The trial lasted about one hour.

RESULTS

The performed analysis includes subjective and objective data. Subjective data consists of the subjective evaluations of the performance, perceived risk and mental workload. The objective analysis is the task and error analysis as well as the analysis of the attention distribution and various glance parameters. The results of
the latter two are presented in this paper. The focus hereby is the comparison between the test persons performing an erroneous behavior and causing an accident and test persons who safely performed the maneuver.

The number of participants who performed errors and caused an accident is relatively high: 14, 8 and 10 for the first, second and third scenario, respectively (see Table 1). The reason for erroneous behavior in the first two scenarios is mainly in not searching for and not expecting the hazards. Participants were simply performing the turn without reassuring that no other vehicles come from the oncoming lane and the right street. These directions have been checked but the glances happened too early to see the hazards, already during the segment of approaching intersection. The necessary glance of checking again for the possible hazardous vehicle just before executing the turn was not performed by around 50% of test persons. The reason that such accidents do not happen so often in reality is that alike scenarios are relatively rare and the other road users usually compensate for the driver’s errors. Still, this study shows that the drivers’ usual visual strategies have deficiencies and offer a high potential for the support.

Table 1. Number of participants causing an accident and performing safely in each scenario

<table>
<thead>
<tr>
<th>Erroneous behavior</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe performance</td>
<td>6</td>
<td>12</td>
<td>10</td>
</tr>
</tbody>
</table>

Closer comparison between subjects causing an accident and subjects who safely performed the maneuver, shows the difference in the distribution fixations. The Figure 5 presents the difference between these two groups for Scenario 1 and Scenario 3. It can be seen that subjects performing safely have on average higher number of shorter fixations, whereby subjects causing an accident had less fixations that lasted longer. Such subjects were scanning the scene relatively slow. The slower scanning may indicate higher processing time or inattentive cognitive state. In that way the mental model of the scenario is not refreshed often enough. This can be an explanation of why elderly drivers have problems at intersections.

The Figure 5(b) shows that in the third scenario both groups showed a more narrow distribution of fixation durations, which is the consequence of the high number of objects in the scene. Accordingly, the number of fixations per second increased from 1.9 in the first to 2.3 in the third scenario, showing higher degree of attention. Still, this attention was often improperly distributed. Even though not visible from the Figure 5 (b), in a contrast to the first and second scenario, in the third scenario two groups of behavior that precedes the collision are distinguished: subjects scanning the scene relatively slow and the ones that scan the scene ineffectively fast. The latter group shows about 50% higher saccade amplitudes and changes of direction of glances than the group not being involved in accident. Such behavior reflects inefficient search strategy where all directions are scanned very fast, probably expecting that in that way more of relevant objects can be perceived. In three of such cases the accident cause was in a “look-but-not-see” error.
Hazardous vehicles were fixated for longer than 80ms but the drivers did not perceive them.

Figure 5. Distribution of fixation durations of test subjects causing an accident and those not causing an accident in (a) Scenario 1 and (b) Scenario 3.

Figure 6 presents the distribution of attention in Scenario 1. As it can be seen the ratio of irrelevant glances is very high. The reason is that glances during the red light phase are also included in the analysis and they mainly contribute to the irrelevant glances. In other two scenarios, the ratio of irrelevant glances is, even though lower, still relatively high: 25% on average. From Figure 6 can also be seen that high number of glances belongs to the planned trajectory. These glances belong mainly to the currently driven segment (up to 1s in front of the vehicle). It can also be seen that drivers involved in an accident had slightly higher attention to the relevant objects than the other group. The similar behavior is observed in other two scenarios as well (see Figure 7 and 8). In general, the highest percentage of irrelevant glances and by that the least attention is present in the phase of leaving the intersection. Hereby, the drivers expect to peripherally capture the vulnerable traffic participants and irregular behavior of other road users. Several drivers endangered the crossing pedestrian in the last segment in the third scenario because of not paying attention to this segment. Conclusively, the main difference between the group of drivers causing an accident in the first scenario and those not causing one is in the number of glances in the direction of the hazardous vehicle. The first group performed one additional glance in all directions just before committing the turn whereby the other group left this glance out. Such visual behavior is observed in other scenarios as well and presents a very dangerous strategy that can be counteracted by an assistance system.

The distribution of attention of both groups of participants, those who committed an erroneous behavior and those who performed the maneuver safely, in Scenario 2 is given in Figure 7. Again, it can be seen that the group of drivers committed an accident had relatively higher ratio of irrelevant glances and glances to the driving path. Also, fewer glances have been given to the crossing lanes both left and right. It can be seen that in both scenarios very low ratio of glances is in the direction of vehicles not having right of way. In the first scenario just 7% (SD=2) and in the second just 15% (SD=3) of glances is in the direction of traffic.
participants not having right of way. Subjects rely to the high extent on the rule-compliant behavior of others. Increment in the second scenario may indicate uncertainty of regulation rules at an unordered intersection.

The distribution of attention in Scenario 3 is presented in Figure 8. The number of glances to the further driving path decreased to 18% (SD=3) and the attention is equally shared among roads in all directions. As already mentioned, the main reason for accidents was either the very fast scanning characterized by short glances or the very slow scanning of the situation with just one glance in each direction. In such a strategy the glances just before the turn were missing. Even though participants in general gave more attention to the road and irrelevant glances decreased for 10%, the drivers had a problem to prioritize the information and very often the sequence of glances was inappropriate.
CONCLUSIONS

The reported study analyzed driver’s visual behavior in three left-turn intersection scenarios. The visual behavior showed a specific pattern for each intersection and the applied visual strategies offer a high potential for the support. In the ‘simple’ scenarios the most problematic are ineffective or insufficient searching strategies. In the third scenario drivers have additional problem to prioritize the directions to scan. To keep in mind the regulations rules continuously and to search simultaneously for numerous potential hazards seem to occupy driver’s cognitive capacities to a very high extent. This fact is also confirmed by analysis of subjective data. A solution could be an intersection assistance that is visually informing the driver in critical moment in which direction there are vehicles with right of way.

REFERENCES


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