WHAT IS DIFFICULT AT INTERSECTIONS?
VIRTUAL AND REAL DRIVING

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ABSTRACT

One important source of drivers' errors is a high level of stress which may hinder the perception and processing of relevant information. In a real-driving study the visibility within the traffic situation was shown to be a major factor increasing stress. A driving simulator study with a systematic variation of visibility found that only an obstructed view of possibly dangerous vehicles increases stress. This knowledge can be used for future intersection ADAS specifically designed to reduce stress. The combination of real and virtual driving is ideally suited to systematically analyse factors influencing driving safety with a large validity.

KEYWORDS

Stress, intersection, driving behaviour, real-world driving, driving simulator

STRESS AND STRAIN WHILE DRIVING AND ADVANCED DRIVER ASSISTANCE SYSTEMS (ADAS)

According to DIN EN ISO 10075-1 psychological stress is defined as "the total of all assessable influences impinging upon a human being from external sources and affecting it mentally." Strain in contrast, is defined as "the immediate effect of mental stress on the individual (not the long-term effect) depending on his/her individual habitual and actual preconditions, including individual coping styles."

In traffic the driver is moving the vehicle in the environment (driver-vehicle-environment system). In this context, influences impinge upon the driver either from the vehicle and/or from the environment. Vehicle influences arise from the requirements of the different driving tasks. These requirements may be attributed to three hierarchical levels (e.g. [1,2]). The highest level, the navigation or strategic level, deals with the choice of the travel route. At the manoeuvring or tactical level the driver is concerned with transferring this planning into the current driving situation like, e.g. changing the lane. At the lowest level, the stabilisation or operational level, basic tasks such as steering and using the clutch are executed for lateral and longitudinal control. In order to cope with the different requirements of the tasks at these levels, different sorts of behavioural processes are used (e.g. [3]). In unknown, ambiguous or complex situations, knowledge-based behaviour is used to find solutions for action planning. This is particularly important for the navigation level of driving. In well-known situations rule-based behaviour based on “if-then” relations is applied (“if the traffic light turns yellow, then stop”). Accordingly, this rule-based behaviour is mainly used to deal with the demands of the manoeuvring level. Finally, skill-based behaviour may be described as reactions to stimuli without conscious attention or control, which is typical for the stabilisation level.

Thus, while driving the main source of stress is induced by driving tasks as these require certain actions to successfully complete these tasks. Subjective strain results from the individual coping with the tasks including different levels of action planning (knowledge-, rule- and skill-based behaviour). The actual strain level of a certain driver depends on traits and states of the driver. For example, experienced drivers will experience less strain than inexperienced drivers when they have to cope with driving through a complex intersection.

In addition to the driving task itself, every driving task is characterized by specific environmental conditions. For example, the stabilisation of a vehicle varies with different weather conditions. Stress is modified by environmental conditions that act on the vehicle, because they modify the requirements of the driving task. Traffic density and the complexity of the traffic situation are other important factors in this regard. However, relatively little is known about how these different factors contribute to stress and how drivers handle this. The study presented here contributes to this topic by examining certain aspects of the task of driving through intersections. Different stress factors were varied and the effect of these factors with regard to strain was measured using different indicators (driving behaviour and subjective ratings). The results give a picture of the most relevant stress factors and their relative importance for the subjective strain of the drivers. This study is presented in the next section.

However, in this study we found that certain factors like, e.g., traffic density and road width were confounded. This makes sense from the point of traffic management and road construction as, for example, larger roads are introduced to be able to handle larger amounts of traffic. On the other hand if one is interested in finding out how stress factors affects the driver a clear separation would be preferable. To that aim, a driving simulator study was conducted which is presented in a second section. Here it was possible to systematically vary one important factor, visibility of other vehicles, to better understand this effect on subjective strain and the way drivers handled this situation.

The aim of both studies is to derive requirements for advance driver assistance systems (ADAS) at intersections which reduce the strain of the driver and may thus prevent errors, dangerous situations or even accidents. The main idea is to identify stress factors and to develop an assistance strategy which helps the driver to cope with the stressful driving task. To achieve this it is necessary to understand what is stressful for the driver. Implications of the results with regard to this aim are discussed in the last section of this paper.

DRIVING THROUGH INTERSECTIONS - A STUDY WITH THE DLR VIEWCAR

To answer the question from which sources stress at intersections results, n = 31 drivers were observed while driving through different kinds of intersections by means of the DLR ViewCar [4,5]. After each intersection drivers were asked how strenuous driving through the intersection had been. A 15-point scale was used where drivers selected one out of 5 categories first (“very little” “little”, “medium”, “stressful” “very stressful”). In a second step drivers rated the finer position within the category chosen using a 3-point scale (lower, medium, upper part within this category; e.g. (1) “very little” and (2) “low”). Driver behavior (e.g. blinking, accelerating, steering, braking, changing gears) and reactions of the vehicle (e.g. velocity, lateral acceleration, brake pressure) were recorded via the CAN-Bus and, if necessary, using additional sensors with a higher precision. Digital video cameras placed on the dashboard and rear flap recorded the environment in front of and behind the vehicle. Characteristics of the traffic situation were measured by means of a video rating. With a laser scanner the distance and velocity of objects in front of the vehicle were measured with high precision. Additionally, gaze direction was measured using a video-based system. Finally, heart rate was measured. This study was conducted within the framework of the INVENT initiative. In this BmbF initiative the DLR was a sub-contractor of Robert Bosch GmbH, BMW Research and Technology GmbH, DaimlerChrysler AG and Volkswagen AG. Different characteristics of intersections were examined in order to find out which contribute most to increasing the difficulty of driving through an intersection (see [6,7]).

In order to evaluate the influence of different characteristics, pairs of intersections were selected which differed only with regard to one characteristic. For example, two intersections were selected where drivers went straight through at one point of the trip and turned right at another point. Thus, the intersections differed only in the driving manoeuvre. The main influence factors examined were “driving manoeuvre” (turn left, turn right, drive straight through), “signalization” (traffic lights, traffic sign, un-signalled intersection), “right of way” (having the right of way vs. having to yield). In order to describe the effect of each factor, the mean difference in the difficulty ratings of all pairs differing in just one factor was computed as an indicator of the effect size of each factor. Figure 1 shows an overview about these factors. Driving becomes more difficult when turning left or right as compared to going straight through the intersection. It is more difficult when yielding as compared to having the right of way. Drivers rated intersections with traffic lights as being more strenuous that intersections with no signalization and with traffic signs (the latter difference being smaller). Inspections of the videos recorded showed that this is probably due to the fact that traffic flow was also much larger at the intersections with traffic lights. It was unexpected that turning right was rated as being more difficult than turning left. However, a close inspection of the ratings for left turn intersections showed that some of these intersections which were comparable with regard to all factors examined were rated systematically different. This was not the case for right turn intersections. Thus, we assume that the effect of turning left is being underestimated and probably at least comparable to that of turning right. The cause of the different ratings turned out to be additional influence factors which had not been recognized in the route planning, like, e.g. different traffic densities at the intersections.

For two additional factors an estimation of their effects was possible in a post-hoc analysis where experts rated all intersections with regard to road width and visibility within the intersection. It was found that narrow roads presented more problems to the drivers than roads of medium width. Additionally, a poor visibility within the intersection increased the difficulty (see bottom of Figure 1).

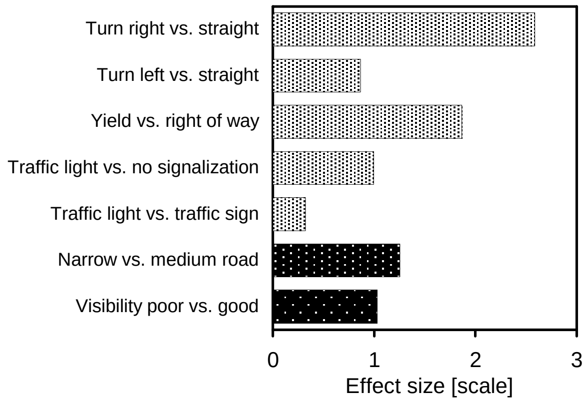

Figure 1: Strain related to different factors in the intersection crossing

To examine behaviour at these intersections the minimum speed when approaching was computed for each driver and then averaged for each intersection. Figure 2 gives the scatter-plot of these means plotted against the mean subjective strain rating in each intersection. A strong correlation ($R^2 = 0.82$) was found which shows that the minimum speed during the approach was slower the more strenuous the intersections were rated. Additionally, drivers began to slow down more early when approaching difficult intersections. Thus, drivers adapted their behaviour in a way which gave them more time to analyse the traffic situation at the intersection and enabled them to be ready to stop, if necessary.

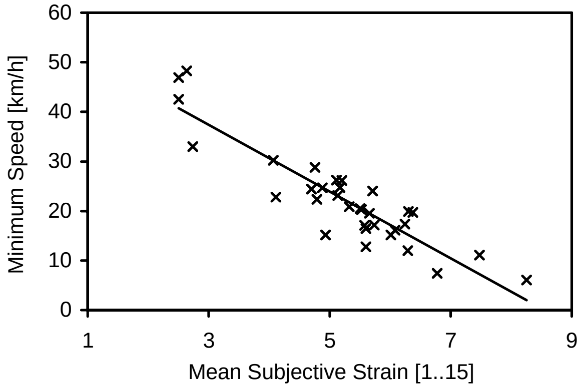

Figure 2: Correlation between subjective strain and minimum speed when approaching

Overall, this real-driving study pointed out which characteristics of an intersection contribute to increasing the difficulty for the drivers to deal with the appropriate situation. However, although more than 4000 intersections crossing were observed in the time-course of this study, no real critical situation occurred. The ratings of the drivers showed that all intersections were at most of medium difficulty which was due to the fact that endangering the test drivers was to be prevented. Finally, it was not possible to independently vary different influence factors. For example, the intersection with traffic lights was also the largest road with the strongest traffic which may explain why these intersections crossings were rated as being more difficult. A systematic variation and analyses of characteristics is, however, easily accomplished in a driving simulation, where a second study was conducted concentrating on visibility. This was one of the important influence factors in the first study which had not been varied systematically.

VISIBILITY AT INTERSECTIONS - A STUDY IN THE VIRTUAL-REALITY-LAB

The Virtual-Reality Laboratory (VR Lab) of the DLR is used to enable the development and testing of assistance functions at a reasonable cost and to test their effect in stressful or dangerous situations. It consists of a three-sided cave in which a vehicle can be controlled in a simulated driving environment. The test subject sees a three-dimensional representation of the entire environment using shutter glasses which give a slightly different picture for each eye of the driver thus creating a 3-dimensional impression. Only standard PCs are used in the VR lab as this greatly reduces the costs and the innovation cycles for computer hardware are very fast. One PC each is responsible for the display on a CAVE wall. Another computer takes care of the sound output to a Dolby 5.1 sound system and the traffic and environment simulation. The vehicle dynamics and the displays are calculated on a fifth computer. Feedback on the driving behavior of the vehicle is created via a steering force actuator and pedals. Head-tracking is performed via ultrasound sensors so that the depicted scenario can be adapted to the head movements of the test subject.

In this VR Lab a study was conducted (see [8]) with n = 20 test subjects (6 female, 14 male, 26.4 years of age with a standard deviation of 3.3). They drove in a simulated town environment where visibility at intersections was systematically varied by placing a different number of buildings (0 to 4) at the different edges of the intersections. This resulted in 16 different intersections (2 with either 0 or 4 buildings, 8 with either 3 or 1 buildings and 6 with 2 buildings). At each of these intersections drivers were instructed to turn right and had to yield to oncoming traffic. Figure 3 gives an example of an intersection with three buildings including one to the left which interferes with watching cars coming from the left.

Figure 3: Example for an intersection with 3 buildings

Due to the short time available between two intersections, subjective ratings were not obtained. However, driver behaviour was recorded in order to analyse how drivers handled the different situations. As shown in the first study presented above, there is a strong correlation between subjective strain and driving behaviour. Thus, the analysis of driving behaviour allows some conclusions with regard to strain. As nearly all drivers stopped at the intersection, the minimum speed while approaching was not a good measure. Instead, the time needed to pass the intersection was taken as an indicator of the difficulty of the situation. For half of the drivers, other traffic was present at the intersections. For the other 10 drivers, no traffic was coming.

For the analyses, intersections were classified first into ones where there was no house blocking the view to the left (where cars to which drivers' had to yield were coming) and others were the view was blocked (free vs. blocked view; within-subjects factor). The second factor was the number of houses. Of course, on the one hand the intersection without houses had always a free view. On the other hand, the intersection with 4 houses had always a blocked view. Thus, examining the interaction of both factors was only possible for 1 to 3 houses (within-subjects factor). The third between subjects factor was the presence or absence of other traffic.

A three-way analysis of variance was conducted for the time it took to pass the intersection. In this analyses, a significant main effect of free vs. blocked view ($F_{1,18} = 7.0$, $p = 0.016$) and of traffic ($F_{1,18} = 7.9$, $p = 0.011$) was found but no effect of the number of houses and no interaction (all $p > 0.10$). Figure 4 presents the results for the two significant factors (mean and standard errors). When other traffic is present, it takes about 2.4 seconds longer to pass the intersection. When the view is blocked, it takes about 0.8 seconds longer than when the view is free even when no other traffic is coming (1.1 seconds with other traffic, 0.4 seconds without).

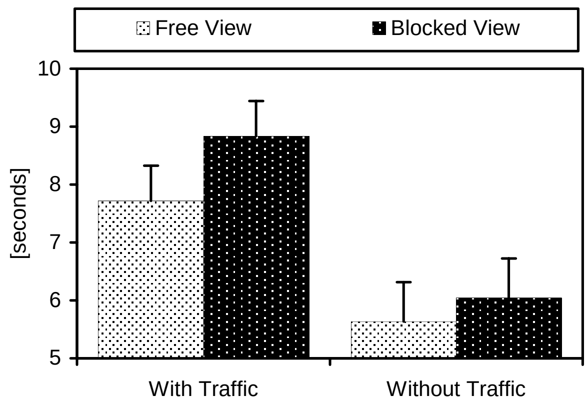

Figure 4: Duration of crossing the intersection

To summarize: In the VR Lab similar effects were found as in real traffic. Drivers take longer to cross the intersection when intersections become more difficult. Difficulty was here induced by bad visibility to the left when drivers wanted to turn right and had to yield to oncoming traffic from the left. Expectations play an important role as drivers take longer when they expect other vehicles (condition 'with traffic'). Finally, the sheer number of buildings is not relevant but only the buildings which obstruct the view to the 'important' vehicles. Thus, at least in this situation, the number of possible distractions had no clear effect.

From a methodological point of view the experiment in the VR Lab gives additional insight into the important influencing factors covered by the term ‘visibility’ while the real-driving study with the DLR ViewCar shows that visibility is really an important factor influencing the difficulty of crossing an intersection.

COMBINING REAL AND VIRTUAL DRIVING – THE VALUE FOR ADAS

ADAS are more and more being developed with the aim to increase safety. As human factors are involved in the majority of accidents it is assumed that ADAS may reach this aim by counteracting errors and providing support when it is required by the driver. The idea is that the probability of an error increases when the stress for the driver becomes too large. Thus, in order to develop ADAS which increase safety knowledge is needed about the traffic situations where large stress occurs for the drivers. In the introduction it was pointed out that one has to distinguish between stress from the outside and subjective strain within the driver. The latter is crucial for safety because it depends on driver characteristics and the way the driver handles the stress. The second aspect was illustrated in this paper in both studies presented: In the more difficult situations drivers adapted their driving behaviour to be able to cope with the demands of these situations.

From the first field study the relative importance of different stress factors can be analyzed to give indications where ADAS which support the driver would be most useful to reduce subjective strain. The question remains how to support the driver in these situations. To answer this question, driving simulator studies like the second study presented here are helpful to find out where the stress results from by manipulating possible sources of difficulties. In this study not the limited visibility of the intersection per se (number of houses) was found to be strenuous but the obstruction of the view of vehicles to which the driver had to yield. This supports the idea that in order to assist the driver by an ADAS one would have to provide information not about the whole traffic situation at the intersection but only about those vehicles with right of way.

From a methodological point of view, the combination of field and simulator studies is very well suited to examine these questions. From the field studies ecological valid information is gained about which stress factors are really important for the driver and how drivers cope with these situations. However, a deep understanding of how these factors work is difficult because different aspect of these factors are sometimes hard to manipulate in real traffic independently from other important factors. Additionally, researchers have to be careful to not overtax the drivers because of the possible risks of an accident. Simulator studies are ideally suited to cover these areas. The traffic scenario can easily be manipulated and even very stressful situations may be introduced without danger to the driver. By including driving scenarios in the simulator which are similar to those in field studies and by comparing the results one obtains an indication about the validity of the simulator study.

The infrastructure provided by the German Aerospace Center (DLR) enables to examine the effects of different influencing factors in a comparable manner in real traffic using the ViewCar and in a driving simulation in the VR Lab. Additionally, a motion-based driving simulation enables driving in a simulation with a larger degree of reality [9-11]. The next step of these studies is to introduce prototypes for new advanced driver assistance systems. Beginning with the hypothesis obtained from the studies on stress and strain concepts for ADAS are developed which reduce the strain of the driver. The success of this approach is tested in the simulators, first, to prove that these systems work as intended. In a final step, these prototypes are then introduced and tested in a real car (DLR FASCar; “FAS” meaning “Fahrerassistenzsysteme” = ADAS). Thus, combining virtual and real driving in the way presented in this paper contributes to developing ADAS which really support the driver.

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