STRESS AND STRAIN WHILE DRIVING

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ABSTRACT

Driver assistance and information systems become more and more important in modern vehicles. One general aim of these systems is to optimize driver’s current workload, because overload as well as underload can increase errors, lead to critical situations and is furthermore experienced as unpleasant for the driver. To prevent these, driver information management systems can coordinate the distribution of information to the driver or driver assistance systems can take over parts of the driving task and thus facilitate driving. The major requirement for both of these systems is access to the current driver workload level. In a first study we developed an approach to estimate current driver workload by measuring stress factors (driving manoeuvres, environmental factors, driver intention) using sensor information available in modern cars. Because the approach was developed and tested in real driving, the estimation of strain is based on subjective ratings measured subsequent to the driving task (offline). The objective of the presented simulator study is on the one hand to validate the approach and on the other hand to show that the estimation is also possible with data measured online while driving. The analyses show that the dependencies between the stress factors and the workload level are reproduced. Furthermore, the comparison between online and offline measurement demonstrates that estimation of workload is possible both online and offline.

KEYWORDS

Advanced driver assistance systems, dynamic workload measurement, driving manoeuvres

STRESS AND STRAIN WITHIN THE DRIVER-VEHICLE-ENVIRONMENT CONTEXT

One aim of ADAS and information management systems is to assist the driver in managing his or her workload level. The major requirement for these systems is access to the current driver state. The approach presented in this paper is based on the concepts of stress and strain. According to DIN EN ISO 10075-1 [1] psychological stress is defined as “the total assessable influence impinging upon a human being from external sources and affecting it mentally”, whereas strain 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.” Stress factors while driving come from different sources. First of
all, the driving task poses different demands on the driver. Following a road requires primarily lateral control whereas following a preceding car additionally requires longitudinal control actions. The second source for increased stress is the environment modifying the requirements of the driving task as well as acting directly on the driver. For example follow a road during fog should likely be more difficult and strenuous because of the restricted availability of relevant information than under the condition of high visibility. On the other hand heat for example influences the driver directly making him/her tired. A third category of stress sources are additional secondary tasks like e.g. operating a navigation system, using a mobile phone while driving [2, 3] or communicating with passengers. The actual strain level of the driver when faced with stress factors depends on driver characteristics such as abilities, skills but also the driver state. Therefore, stress factors in a certain driving situation are equal for all drivers but the resulting strain is individually different.

Strain cannot be measured directly but indirectly by means of strain indicators [4, 5] like behavioural or performance measures, subjective measures and physiological reactions. Behavioural measures, e.g. steering wheel reversals or standard deviation of the lateral position indicate individual coping strategies of the driver in terms of action control, whereas physiological measures such as heart rate variability provide an indication of the driver state in terms of activation or arousal [5, 6]. Both kinds of indicators may be used in cars to estimate driver workload and use this for the design and functionalities for ADAS being adaptive to the current driver state. However, these methods are problematic with regard to sensitivity and specificity and therefore sometimes hard to interpret. For example, within a dual task paradigm the workload added by the secondary task leads to a decrease of the steering wheel reversal rate because driver attention is shifted to the secondary task. However, when the driver is concentrating only on the primary task of driving, the higher workload due to more difficult road conditions (e.g. narrower curves or smaller roads) leads to increased reversal rates because the driver has to invest more effort into steering [6, 7]. Thus higher workload may lead to either a decrease or an increase of the reversal rate depending on the reasons for the increased workload. Besides the lack of sensitivity and specificity, both types of indicators, physiological and performance measures are further on problematic as they require the existence of special sensors in the vehicle. Availability of these sensors in series-production vehicles would be mandatory for a wider application of workload adaptive systems not only in the field of research. The third group of subjective self report measurements e.g. NASA-TLX, Instantaneous Self Assessment Method [8] or Cooper Harper Scale do not need special sensors for assessment. However, they are usually collected at the end of experimental test drives or at certain time-points or location during a trip. The dynamic time-course of workload may thus not be analysed, which is important as driver workload itself changes in a highly dynamic way. In recent real driving studies [9] we could e.g. show that driver workload changes within different driving manoeuvres but there were also indices that workload varied even within one manoeuvre. Therefore workload should be analysed with regard of structural changes in place of level differences only. These dynamic changes can only be measured with a likewise dynamic workload measurement instead of a time- and event-triggered measurement respectively. The second reason for dynamic measured workload is the requirement of an also dynamic working adaptive assistance system that needs continuously access to workload changes in order to provide an optimal support for the driver.

To summarise: There are two main problems for measuring strain while driving. On the one hand, indicators should be measured by using sensors available in modern cars in order to provide a direct access to workload as well as a quick information exchange with future assistance system applications. On the other hand indicators are needed which enable to examine the time-course of strain because strain changes in a highly dynamic way and
therefore the dynamic information should be likewise available for future functionalities of workload adaptive systems. To solve these problems an alternative approach is presented here: (1) In order to get information about the current driver strain we use vehicle information available in modern cars to detect the external stress factors impinging upon the driver. At the moment, the detection of stress factors focuses on driving manoeuvres on the one hand and situational and environmental conditions on the other hand. In recent studies we could show that the manoeuvre detection by directly measuring vehicle sensor data is possible [10]. Based on this objective measurement of stress factors the associated individual strain level is to be estimated indirectly. To develop this estimation, (2) a method is introduced to measure besides physiological and performance workload also subjective workload continuously. Subjects rate their workload during task performance by entering a new workload judgement whenever they experience a change in their subjective workload. The method and some results of the main studies done to validate this new approach will be presented within the next sections.

ESTIMATION OF STRAIN BY DIRECTLY MEASURING STRESS FACTORS

The first study was conducted to answer the question whether it is possible to estimate driver strain from a measurement of stress factors. Driving manoeuvres and environmental conditions are identified using sensor information available in modern cars. The study design, procedure and some results are presented in following section. This study was conducted for the Robert Bosch GmbH. The results presented here are a summary of the results published at the ITS World Congress 2006 in London [9] approved by the Robert Bosch GmbH.

Methods

Subjects and data collection

Eleven male and five female test drivers aged between 23 and 49 years (mean = 31 years) participated in the real driving experiment and conducted a one hour trip on a motorway (Autobahn), a federal road (Bundesstraße) and a rural road (Landstraße). Using the DLR ViewCar [11, 12] vehicle dynamics (e.g. velocity, lateral acceleration, braking pressure) and driver behaviour (e.g. steering, braking, accelerating) is recorded via CAN-Bus (see Figure 1).

Figure 1: DLR ViewCar designed to measure driving and driver behaviour, car dynamics and the surrounding traffic.
Digital video cameras placed on the dashboard and rear flap record the environment surrounding the vehicle. With a laser scanner objective dynamic environmental characteristics such as the distance and velocity of preceding cars are measured with high precision. Position of the ViewCar is measured precisely by a DGPS system (including an inertia platform and odometer). The lane position of the ViewCar is identified by a lane tracking system. The recorded data is provided with time stamps and stored in a database. For this study a second vehicle was used with the intention to encourage car following and overtaking.

**Definition of stress factors: driving manoeuvres and environmental factors**

The test track consisted of three types of roads: (1) Two motorway sections with denser traffic at the first section and a lower density at the second section. In this second sections test drivers were instructed to spontaneously conduct lane change manoeuvres in order to observe different manoeuvres in an adequate number. The second part of the trip involved a federal (2) and rural (3) road section. On the federal road overtaking was not allowed while drivers were instructed to perform overtaking on the rural road. Additionally, the rural road was smaller and had narrower curves. On both sections the second experimental vehicle drove in front of the ViewCar in order to either provoke car following situations on the federal road or encourage overtaking on the rural road. By this approach, different manoeuvres could be observed under different environmental conditions.

Manoeuvres were defined in accordance to the approach of Nagel [13] who distinguishes seventeen separable driving manoeuvres based on the question what kind of manoeuvres an automat must handle in order to move securely from A to B. For the study presented here we modified the number of manoeuvres to fourteen manoeuvres with different requirements (see Table 1).

**Table 1: 14 driving manoeuvres (adapted from Nagel, 1994).**

<table>
<thead>
<tr>
<th>stop and standing</th>
<th>start and continue</th>
</tr>
</thead>
<tbody>
<tr>
<td>follow a road</td>
<td>approach obstacle ahead</td>
</tr>
<tr>
<td>stop in front of obstacle</td>
<td>pass obstacle to the left/right</td>
</tr>
<tr>
<td>start after preceding car</td>
<td>follow preceding car</td>
</tr>
<tr>
<td>overtake</td>
<td>approach to intersection</td>
</tr>
<tr>
<td>cross intersection</td>
<td>turn left/right</td>
</tr>
<tr>
<td>large change</td>
<td>parking</td>
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</table>

In this modification several manoeuvres with similar demands to the driver were combined, e.g. “entering / leaving parking slot”, “slow down to right road edge and stop” and “reverse direction” were combined as “parking”, as well as “U-turn to left/right” was included in “turn left/right”. Because of the result of an earlier study that strain at an intersection increases in particular during the approach the manoeuvre “approach to intersection” was added [14].

In order to identify these manoeuvres in the study two different methods were used. First, a rule based algorithm was developed. By means of a finite state machine with the starting state “stop and standing” the available sensor information (e.g. CAN-Bus, laser scanner, lane tracking system) measured with the ViewCar was merged according to defined rules. This resulted in the detection of the fourteen manoeuvres (for a more detailed description of this procedure see [10]). In order to validate this algorithm, the manoeuvres were also identified by human observers. This gives an additional indication whether the definition of these manoeuvres is psychologically valid and where they can be distinguished by the drivers. Using a self-developed software tool two observers independently rated all conducted test trips. This event sampling results in a time log of the different manoeuvres during each test
trip. Interrater reliability was analysed by a third independent rater and was very satisfactory (over 90%). The following analyses use the manoeuvres identified by the second method. Overall, a total of 3452 driving manoeuvres were observed for the sixteen test drivers, 660 manoeuvres in the first motorway section (high traffic density), 470 on the second (low traffic density), 32 on the motorway exit, 701 on the federal road and 1589 on the rural road.

Measurement of subjective strain

Subjective strain was measured subsequent to the test trip by means of a video analysis. The measurement was not realised during driving because it might have been possible that this would distract the drivers. After the real driving test trip all subjects continuously rated their subjective strain watching their own trip. The video rating tool used was comparable to that of assessing the manoeuvres. A two step procedure was used where subjects first chose one of five main categories (“driving is very strenuous, strenuous, moderate, little strenuous and very little strenuous”). In a second step, one of three categories within the main categories was to be selected (“lower area”, “moderate”, “upper area”). An example of the resulting 15-point rating scale is shown in Figure 2.

<table>
<thead>
<tr>
<th>very little strenuous</th>
<th>little strenuous</th>
<th>moderate</th>
<th>strenuous</th>
<th>very strenuous</th>
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<tr>
<td>1</td>
<td>2</td>
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<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>15</td>
</tr>
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</table>

Figure 2: 15-point rating scale of the rating method.

The subjects were not told about the manoeuvres or environmental factors in order not to influence their rating. They were instructed to change their ratings whenever they perceived a change of their workload. One disadvantage of this post-hoc rating is the restricted availability of environmental information on the video display because subjects had only the front view out of the car. To delimit this error subjects were instructed to imagine being in the driving situation and subjective ratings were conducted very shortly after the real driving. The second disadvantage is the possibility of memory effects due to the rating subsequent the real driving task that should be kept in mind during the data analysis. However by comparing the results of both studies that will be presented in the following it can be suggested that the influence of memory effects is marginal.

Results – What is strenuous? Driving itself or the driving situation?

The first examination of the data revealed two different rater groups. Six out of the sixteen subjects showed a very small variance within their ratings i.e. they changed their judgements very seldom. The analyses of their ratings showed that these subjects mainly changed their ratings when the environment was different (e.g. switching the road type). The other ten subjects rated more dynamically and thus were used in the following analyses. Only twelve of the fourteen manoeuvres were conducted so frequent by all test drivers that they could be examined in the statistical analyses. For the following presentation three manoeuvres were selected (“follow a road”, “approach obstacle ahead” and “follow preceding car”) because they occurred in the three different conditions (highway, federal road, rural road) in a sufficient number which is important for the following statistical analyses (concerning the adequate number of cases). On the other hand the manoeuvres are characterised by occurring in sequence that offers the possibility to analyse cross-over effects regarding workload structural changes. In order to remove inter-individual differences
regarding the overall level and variability of ratings the average strain rating of each test driver depending on the stress factors were z-standardised.

A two-way 3×3 ANOVA with repeated measures (α = 5%) was used. The result of the analysis were two significant main effects (driving manoeuvre, F_{2,18} = 4.2, p = .032 and situation, F_{2,18} = 5.7, p = .012) as well as a significant interaction (manoeuvre*situation, F_{4,36} = 4.2, p = .007). The post-hoc pairwise comparisons of expected marginal means show that “approach obstacle ahead” tends to be more strenuous than “follow a road” (mean difference = .312, p = .107). “Follow preceding car” was rated as the most strenuous manoeuvre differing significantly from manoeuvre “follow a road” (mean difference = .408, p = .017). This shows that different manoeuvres are associated with different strain.

Regarding the other main effect “situation” the post-hoc pairwise comparisons show that driving on the rural road is associated with more strain than on the motorway, whereas driving on the motorway is more strenuous than driving on the federal road. The mean difference between rural road and federal road is significant (diff_mean = .919, p = .001), a trend can be seen between rural road and motorway (diff_mean = .556, p = .067). Both main effects as well as the interaction are shown in Figure 3.

Strain does not differ between the three manoeuvres on the federal road (follow road – approach obstacle: T = .758, p = .468; follow road – follow car: T = .567, p = .585; approach obstacle – follow car: T = -.502, p = .628) However, on the other two road sections (motorway and rural road) where the driver can overtake strain increases during “approach obstacle ahead” and “follow preceding car” (motorway: follow road – approach obstacle: T = -2.525, p = .032; follow road – follow car: T = -2.355, p = .043; rural road: follow road – approach obstacle: T = -3.556, p = .006; follow road – follow car: T = -4.032, p = .003). Compared to the motorway strain increases even higher on the rural road (pairwise comparison shows a trend: diff_mean = .556, p = .067) which can be attributed to the additional environmental factors such as road width, narrow curves that make lateral control more difficult.
Overall after this first approach we could show that it is possible to estimate strain from different stress factors. Different test drivers continuously rated workload and therefore after mapping the dynamic ratings to the different driving manoeuvres it could be demonstrated that these driving manoeuvres were associated with significantly different strain. Moreover, the environment had to be taken into account for a better prediction because it additional modified strain. Furthermore the relation between the described stress factors and subjective strain could be validated within the study by analysing the physiological indicator heart rate variability as well as the performance indicator steering wheel reversal rate which resulted in comparable results. These results will be described in more detail within another paper.

As was mentioned above, it is not clear in which way the post-hoc rating influenced the results as not the whole information was available to the observers afterwards. In order to examine this question, a simulator study was conducted. In this way, even if subjects are distracted by the rating, this will pose no danger to the subjects. This study is presented in the next section.

CONTINUOUS SUBJECTIVE WORKLOAD MEASUREMENT

The main objectives for the simulator study are the following: (1) Is it possible to continuously measure strain while driving (online) or does the secondary rating task interfere with the primary rating task and therefore lead to additional stress? By means of a comparison between online and offline ratings within the simulator possible interferences among driving and rating task should be detected. (2) Can we validate our theoretical consideration concerning the interaction between indirectly estimated strain and directly measured stress factors? By means of the analysis of corresponding stress factors to the real driving study (e.g. driving manoeuvres and environmental factors) the workload model should be tested and verified.

Methods

Subjects and data collection

Twenty test drivers with a mean age of 26 years (twelve male, six female) participated in the study conducted in the DLR Virtual Reality Laboratory (VR-Lab). The VR-Lab consists of an immersive display (CAVE, Cave Automatic Virtual Environment) and suiting computer-hardware. By using stereo projection and a head tracking device it is possible to display a holographic simulation of a car cockpit and a virtual landscape. Everything of the car’s interior is simulated with the only real hardware being the driver’s seat, the steering wheel and the pedal box. Driver behaviour (e.g. accelerating, steering, braking) and reaction of the simulated vehicle (e.g. velocity and lateral position) is recorded via a simulated CAN-Bus. Subjective ratings are recorded and stored with the same timestamp as the driving behaviour. The VR-Lab as well as an example of the test track is demonstrated in Figure 4.
Stress factors and strain measurement

Comparable to the real driving study three different road situations were introduced in order to vary the influence of road and route characteristics as well as the influence of driver intention on strain as described above. Unfortunately it was not possible to implement a motorway in the simulator because of technical restrictions during that phase of development why the three road situations federal road without overtaking, rural road without overtaking and rural road with overtaking have been realised. By implementing a rural road section with as well as without overtaking the possible influence of driver intention and overtaking could be analysed anyway as well as differences between different road characteristics by comparing federal road (wider curves, 50 km/h speed-limit) with rural road without overtaking (narrower curves, 100 km/h speed-limit). By systematically varying the surrounding traffic the three manoeuvres “follow a road”, “approach obstacle ahead” and “follow preceding car” were found on all road sections in a sufficient number. Additionally, the subjects were instructed to “overtake” on the rural road section with overtaking whenever they had the possibility to do so.

In order to examine the effect of rating strain during the trip subjects were divided into an experimental and a control group. The experimental group (n = 14) rated workload dynamically over the whole test course (online) as well as offline after the driving by means of a playback function within the simulator. Because the interferences may vary depending on the rating mode seven of the fourteen subjects made their rating by manual response (entry by means of a steering wheel button), seven subjects by voice. The control group (n = 6) did not rate online while driving but only offline after the test drive. In the offline rating, all groups did two consecutive runs using once the manual and once the verbal mode. The order was balanced between the subjects. The 15-point rating scale was exactly the same as in the real driving study (see Figure 2). The current workload rating was shown in a head-up display as a number (1 - 15) within a bar which lengths represented the rating. Additionally, the five verbal main categories were displayed (e.g. very strenuous, moderate). In order to ensure safe driving with simultaneous subjective rating, subjects have been trained intensely to handle this dual task before the test drive. This may be the reason why subjects did not show high inter-individual differences regarding the overall level and variability. Therefore in contrast to the first study subjective ratings have not been z-standardised.
Results - Dynamic workload measurement

The average speed, the standard deviation of lateral position and the steering wheel reversal rate were examined in order to find out whether the rating influences driving. The analysis showed no significant difference between the three groups in the three parameters examined. However there is a trend ($F_{2,17} = 3.539, p = .052$) that subjects tend to drive slower with the rating task (see Figure 5). This is true for manual as well as verbal rating.

![Figure 5: Trend in average speed for the three groups which differed in the rating mode (manual, verbal, no online rating).](image)

When examining the post-hoc ratings there is also no significant difference between the three groups ($F_{2,16} = .371, p = .696$). However, a significant interaction between group and situation is found ($F_{4,32} = 3.093, p = .029$). As Figure 6 shows, strain of the control group does not differ between the three environmental situations. Both experimental groups rate higher strain on the rural road without and with overtaking. The interaction between the factors situation and rating group is displayed across all manoeuvres.

![Figure 6: Significant interaction between group and situation (n = 20).](image)

Comparing online and the two offline ratings of the experimental groups (factor rating time) shows no significant overall difference between the three ratings ($F_{2,22} = .938, p = .407$). However, a significant interaction between rating time and situation ($F_{4,44} = 2.712, p = .042$) as well as a trend between rating time and manoeuvres ($F_{4,44} = 2.363, p = .068$) is found. On the rural road with overtaking as well as during "approach obstacle ahead" (the situation and accordingly manoeuvre with the largest strain) workload was rated lower online compared to offline. The significant three-way interaction between rating time, situation and rating mode ($F_{4,44} = 2.712, p = .027$) shows that this is mainly due to the group with manual online rating which rated their workload online as being lower than post-hoc. However the overall effects of driving manoeuvres ($F_{2,22} = 20.895, p = .000$) and situation ($F_{2,22} = 17.340, p = .000$) are still found in this group with a somewhat reduced level (see figure 7). Comparing these main
effects with the analogous effects of the real driving study equal dependencies between stress factors and resulting strain can be described.

Figure 7: Significant main effects “driving manoeuvre” and “situation” (n = 20).

To summarise: (1) Dynamic measurement of workload while driving is likewise possible as afterwards. We did not find significant effects of the rating on driving behaviour. On the other hand, during very strenuous driving manoeuvres and situations a manual rating seems to be somewhat more difficult for the subjects. Subjects underestimated their workload in these situations. However, the main differences due to driving manoeuvres and situations were still found (compare figure 7 and figure 3) even if the modifying influence of the environment was nearly the same for all three manoeuvres that could be caused by the driving task itself being more difficult in the simulator because e.g. of difficulties in the perception of distances and velocities. Finally, a post-hoc rating without having rated online (control group) leads to more difficulties in estimating strain depending on manoeuvres and situations (Figure 6). This may be due to comparable difficulties as mentioned above. It is hard to estimate speed in the driving simulator when just looking at a scenario and driving in it. Thus, at least for a simulator study, online rating seems preferable to post-hoc ratings. (2) The relation between stress factors (driving manoeuvres and situation) and the subjective strain is quite comparable to the real driving study.

DISCUSSION

Information about the current driver state or workload is basic with regard to safety and comfort system in order not to overload the driver and to avoid underload. This information has to be dynamically available because the advanced driver assistance and especially the information management systems work dynamically, too. The aims of the studies were therefore first to assess driver workload by means of currently available sensor information in modern cars (because classical workload indicators are only feasible by means of special sensors, e.g. ECG) and second to do the measurement in a dynamic, continuous way. To deal
with these issues we developed the alternative approach of workload estimation by directly measuring stress factors, such as driving manoeuvres and environmental condition. Within both studies, the real driving study and the simulator study, we could show that a measurement of stress factors allows a good estimation of strain. Different manoeuvres lead to different workload and this relation is modified by situational aspects. These coherences will be examined in further studies to validate the results. At the same time a method was developed to continuously measure subjective strain without any spatial or temporal trigger. Subjects changed their rating whenever they perceive any change in strain. We could show that the method is applicable both online while driving and post-hoc by means of a video observation and playback function in the simulator.

REFERENCES