WHAT IS STRENUOUS? DRIVING ITSELF OR THE DRIVING SITUATION?

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ABSTRACT

To avoid driver overload, assistance systems can be adapted regarding the driver's current strain. Physiological and performance workload measures require special sensors and are problematic concerning sensitivity and specificity. Within the presented study the driver's stress level was estimated in real-driving based on an analysis of different driving manoeuvres and environmental factors. The analyses show that different driving manoeuvres result in significantly different subjective strain levels. Furthermore, situational factors like the intention to overtake or road characteristics modify subjective strain systematically. This behaviour oriented approach to estimate strain seems to be an auspicious alternative to current measurements of strain.

KEYWORDS

Advanced driver assistance systems, stress, strain, driving manoeuvres

THE CONCEPT OF STRESS AND STRAIN AS BASIS FOR INFORMATION MANAGEMENT IN VEHICLES

Modern vehicle information systems (IVIS) and multimedia applications gain in importance. Additionally, advanced driver assistance systems (ADAS) provide extra information to the driver or warn him in dangerous situations. The example of telephoning while driving indicates that this additional information may be dangerous. Epidemiological [1-3] and experimental studies [4-6] point out that driver distraction may lead to dangerous situations resulting in a higher accident risk. To counteract this effect, information management systems are suggested which coordinate information for the driver on the one hand and adapt information presentation to the driver state, particularly the actual driver strain on the other hand. The major requirement for this approach is the access to the current driver's strain.

The theoretical background of the study conducted with Robert Bosch GmbH and presented here is the distinction between stress and strain [7]. 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.” Therefore psychological stress is equal for all human beings whereas resulting strain is individually different due to varying preconditions and coping strategies. Figure 1 gives an overview of the underlying theoretical background.

In traffic stress arises first of all from the requirements of the different driving manoeuvres (e.g. start and continue, overtaking etc.). These requirements in turn depend on vehicle characteristics (e.g. acceleration, driving with and without load) and other environmental conditions (e.g. darkness, wet roads, different visibility at intersections). These environmental conditions do not only modify the requirements of the driving manoeuvres but they may also act directly on the driver. For example, heat may lead to fatigue. Finally, additional stress may stem from secondary tasks with requirements of their own, like conversations with the passenger, operating information systems or telephoning while driving. The upper blocks in Figure 1 subsume these considerations.

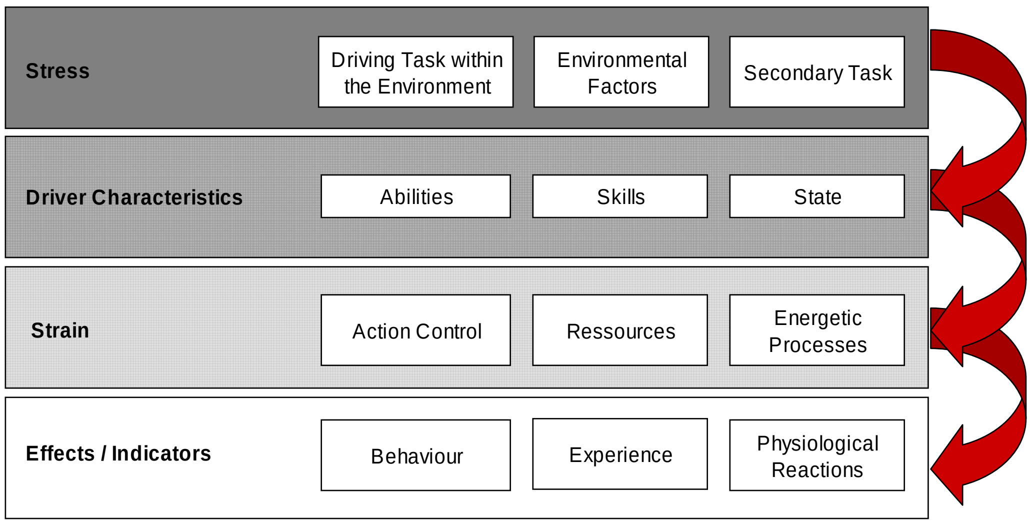

Figure 1: Underlying concept of stress and strain.

Depending on different driver characteristics extraneous stress causes strain involving various aspects. The individual strain caused by the different stress factors can not be measured directly, but indirectly by various indicators of strain. By analysing performance measures, individual coping with stress factors is described. Physiological measures give an indication of the driver state in terms of activation or arousal. Subjective methods measure the perceived strain of the driver. Within the automotive sector, physiological (e.g. heart rate variability, eye movements) and performance measures (e.g. steering wheel reversals) are frequently used [8, 9]. However, these methods are problematic with regard to a lack of sensitivity and specificity as well as the requirements to introduce special sensors into the vehicle. But disposability in series-production vehicles would be mandatory for a wider application not only in the field of research.

For the study presented here, an alternative approach is described using information available in modern cars. By means of these vehicle information the external stress factors impinging upon the driver are detected, on the one hand caused by driving manoeuvres, on the other hand by situational or environmental conditions. It is analysed whether the objective measurement of these stress factors enables a prediction of the drivers' subjective strain. To this aim, drivers conducted a continuous rating of their strain level via a video observation of their driving after the trip and it was analysed to what extent strain relates systematically to the directly measured stress factors. The empirical study, measurement of stress factors (driving manoeuvres) and finally the rating method to measure strain is presented in detail in the next section.

METHOD

The approach presented here requires the measurement of drivers' stress in order to predict the resulting strain. In the first section, the study design is presented. Afterwards, the operationalisation of stress by differentiation of driving manoeuvres and additional environmental factors is described followed by the method to rate driver's strain by means of a post-hoc continuous video observation.

Study design and procedure

16 test drivers (11 male and 5 female) aged between 23 and 49 years (mean = 31 years) conducted a one hour trip on a motorway (Autobahn), federal road (Bundesstraße) and rural road (Landstraße). Using the DLR ViewCar [10, 11] driver behaviour (blinking, accelerating, steering, braking) and reactions of the vehicle (velocity, lateral acceleration, braking pressure) is recorded via CAN-Bus (see Figure 2). Digital video cameras placed on the dashboard and rear flap record the environment in front of and behind the vehicle. With a laser scanner objective dynamic environmental characteristics such as the distance and velocity of objects in front of the vehicle 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 a time stamp and stored in a database. For the study, a second vehicle was used in order to encourage car following and overtaking.

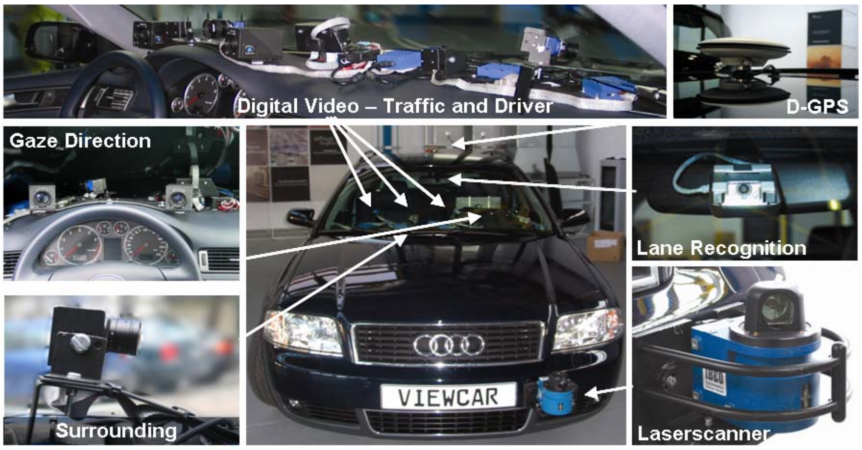

Figure 2: The DLR ViewCar designed to measure driving behaviour, car dynamics and the surrounding traffic.

In order to find different driving manoeuvres in a sufficient number and simultaneously take into account the most important environmental factors, the test track consisted of three different road sections: Two motorway sections, a federal road and a rural road. The federal and rural road included several small towns. On the motorway traffic density was considered as an additional environmental factor, which was higher on the first section and relatively low in the second one. On this second motorway section the drivers were instructed to perform lane change manoeuvres even if it was not necessary in order to observe different manoeuvres. On the federal road overtaking was not allowed and the second experimental vehicle drove ahead in order to achieve a comparable car following situation for all drivers. On the rural road there were several opportunities to overtake. The second experimental vehicle drove slowly in order to encourage overtaking. Thus, in concurrence with the study aims, the test trip was not a typical normal driving situation but one where different driving manoeuvres were systematically provoked to be able to analyse the interrelation between stress caused by different driving manoeuvres and strain.

A total of 3452 driving manoeuvres were realised by the 16 test drivers, 660 manoeuvres on the first motorway section, 470 on the second (motorway exit with 32 manoeuvres is counted as separate section), 701 driving manoeuvres on the federal road and 1589 on the rural road.

Estimation of the driver's stress through driving Manoeuvre and situation

Driver's stress emerges from the different requirements arising while driving from A to B depending on the route, the environment and the interaction with other road users and traffic participants. By analysing a trip more precisely it is shown that it consists of separable driving manoeuvres which pose different demands on the driver. The basic manoeuvres were compiled by Nagel [12] based on the question what kind of driving manoeuvre an automat must handle in order to securely move from A to B. He distinguishes 17 driving manoeuvres which were modified for the study presented here to consist of 14 manoeuvres with different requirements: "stop and standing", "start and continue", "follow a road", "approach obstacle ahead", "stop in front of obstacle", "pass obstacle to the left / right", "start after preceding car", "follow preceding car", "overtake", "cross intersection", "lane change", "turn left /

right”, “parking” and “approach to intersection”. The manoeuvre “stop and standing” was included as a starting point for every trip. Several manoeuvres with similar requirements to the driver were combined. The manoeuvres “enter parking slot”, “leave parking slot”, “slowdown to right road edge and stop”, “reverse direction” and “drive backwards” were combined as “parking”. “U-turn to the left / right” is included in “turn left / right”. Additionally, for the manoeuvres “turn left / right” and “cross intersection” a manoeuvre “approach to intersection” was added because an earlier study had shown that stress arises at different intersections particularly during the approach [13].

Table 1: Operationalisation of stress by distinction of 14 driving manoeuvres.

stop and standing	follow preceding car
start and continue	overtake
follow a road	cross intersection
approach obstacle ahead	lane change
stop in front of obstacle	turn left / right
pass obstacle to the left / right	parking
start after preceding car	approach to intersection

Each of these manoeuvres is characterised by different requirements which may be objectively described in terms of a resulting stress level. The manoeuvre “follow a road” for instance differs from the manoeuvre “follow a preceding car” in the existence of a leading vehicle. Both manoeuvres require lane keeping with regard to road characteristics and the choice of velocity taking into account traffic rules and safety. Additionally, “following a preceding car” requires keeping a safe distance. These different manoeuvres can be detected using different kinds of vehicle sensors [14]. In the presented study two observers independently rated the conducted driving manoeuvres of each test trip. Because interrelation between stress and strain is picked out as a central theme within the presented study, ratings of the observers were used in the following as measurement of stress. Using a self developed software tool the observers watched all test videos and indicated the actual driving manoeuvres. 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. Interrater reliability was at nearly 90%. An error analysis revealed three types of errors. 1.6% of the errors where due to definition problems (e.g. imprecise definition of the distance to preceding car where „follow a road“ changes to „approach obstacle ahead “), in 5.2% an observer missed a manoeuvre and in 4.9% he rated a manoeuvre which did not exist (“false alarms”). Additionally, the duration of the correctly classified manoeuvres could have been analysed. On the one hand there would have been discrepancies in the definition of the onset of each manoeuvre due to reaction times. On the other hand inter-rater reliability will increase because specific manoeuvres take relatively long time (e.g. “follow preceding car” on the federal road). Therefore the analysis was conducted with the number of driving manoeuvres.
Besides the driving manoeuvres environmental factors are important, because they change requirements of the driving tasks on the one hand, but they could also cause directly higher stress for the driver. Type of road (motorway, federal road and rural road), traffic density on the motorway and city vs. federal / rural road was considered as environmental factors.

Measurement of subjective strain

In order to analyse subjective strain during different driving manoeuvres subjective ratings were used. This was not done during the test trip as this would have interfered with the primary driving task. A video observation was conducted after the trip where test drivers continually rated their subjective strain. A two step procedure was used where subjects first chose one of five main categories ("Driving is very strenuous, strenuous, moderate, little, very little strenuous"). In a second step subjects chose one of three categories within this first category ("lower area", "middle" and "upper area"). This post-hoc rating may be difficult because some of the environmental information is not visible in the video (e.g. vehicles behind). To avoid this, subjects were instructed to imagine being in the driving situation seen in the video. Subjects reported that this procedure was not difficult for them. To what extent ratings during and after the test trip differ has to be analysed more precisely in future studies.

RESULTS – STRAIN DEPENDING ON DRIVING MANOEUVRES AND SITUATION

A first screening of the strain rating showed that a group of six test drivers did not use much of the scale (small variance) and changed their ratings relatively slowly, e.g. when the car went from the motorway to the federal road. These drivers clearly did not differentiate between different driving situations or manoeuvres and are thus excluded from the further analysis. A detailed study of these test drivers is necessary to find out what they use as a basis of their strain rating. The following analyses are based on the 10 remaining drivers having a high temporal dynamic which was determined with the distribution of the average duration of ratings across the subjects.

Twelve of the fourteen manoeuvres were realised by the test drivers several times and can therefore be analysed. The manoeuvres "start after preceding car" and "stop in front of an obstacle" were found only in a few cases. This is due to the fact that these manoeuvres were conducted mainly before and at intersections and therefore were assigned to the manoeuvres "approach to intersection", "cross intersection" and "turn left / right". These manoeuvres could also occur during congestions but these were not found during the test drives. Thus, a complete analysis is feasible for the remaining 12 manoeuvres.

The results are presented with regard to two aspects: (1) Different driving manoeuvres result in significantly different strain levels. (2) Different environmental conditions modify the strain level additionally. In order to demonstrate both effects three manoeuvres ("follow a road", "approach obstacle ahead", "follow preceding car") were selected that were observed in different environmental conditions (during the motorway with high / low traffic density and on federal and rural roads).

For each test driver the average strain rating for each driving manoeuvre was computed. In order to remove inter-individual differences in the overall level and variability of the ratings these mean values were z -standardised over all manoeuvres of one driver. In a second step an average strain value for each of the three manoeuvres analysed in the specific road sections was computed from these z-values per driver (e.g. mean z-value for "follow a road" on motorway with low traffic density). The first analysis tested whether these three driving manoeuvres differed and whether traffic density (low and high density at the motorway) had an additional influence (two-way 3x2 analysis of variance with repeated measures). A significant main effect for the factor driving manoeuvre ($F_{2,16} = 3.8$, $p = .043$) was found but no difference between the different traffic densities and no interaction (main effect of the factor section $F_{1,8} = 0.001$, $p = .978$, interaction $F_{2,16} = 0.48$, $p = .628$). Thus, in this comparison the driving situation (more precisely traffic density) did not modify the effect of the different driving manoeuvres on subjective strain (see Fig. 3).

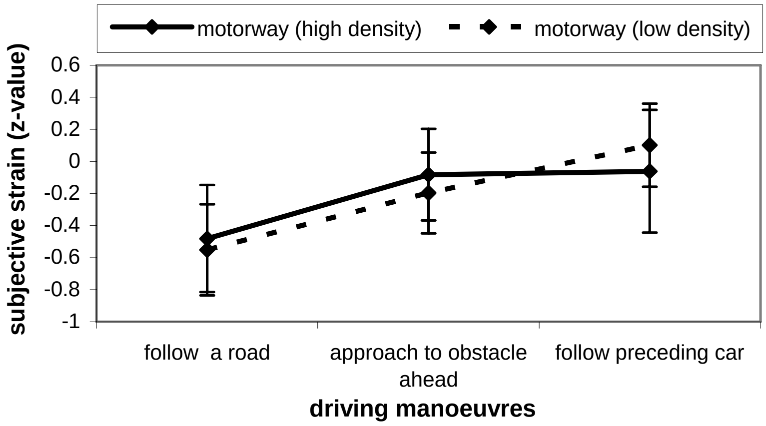

Figure 3: Strain (z-standardised mean values) depending on traffic density and driving manoeuvres on the motorway.

For the second analysis both sections of the motorway were averaged and compared to the federal and rural road. A two-way 3x3 analysis of variance with repeated measures was used to examine the effect of manoeuvre and road type. Both, main effects and the interaction were significant (manoeuvre: $F_{2,18} = 4.2$, $p = .032$; road section $F_{2,18} = 5.7$, $p = .012$, interaction $F_{4,36} = 4.2$, $p = .007$). Figure 4 gives the results. On the federal road the three manoeuvres do not differ with regard to strain. On the rural road and the motorway “approach obstacle ahead” and “follow a vehicle” result in more strain than “follow a road”. This effect is larger on the rural road than on the motorway. This increase in strain is due to the fact that drivers prepared to take over when approaching and following a car on the motorway and the rural road while overtaking was prohibited on the federal road. The larger effect on the rural road as compared to the motorway results from the possibility of oncoming traffic. Finally, the manoeuvre “follow a road” is more strenuous on the rural road probably because more curves and smaller lanes require more attention of the driver with regard to lateral control.

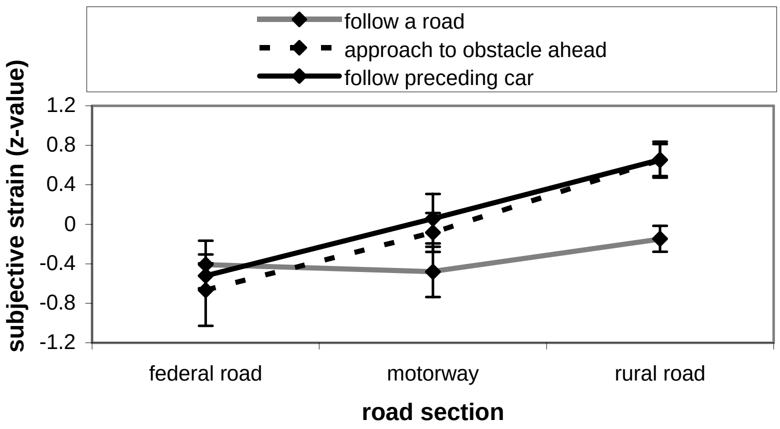

Figure 4: Strain (z-standardised mean values) depending on road sections and driving manoeuvres.

DISCUSSION

The results show that an estimation of drivers strain by objectively measuring stress factors is possible. Different driving manoeuvres with different requirements were identified as stress factors leading to different strain levels. As an example, approaching and following a car was shown to cause more strain than just following a road. However, situational characteristics were shown to modify the effects. On the federal road overtaking was not allowed whereas subjects were instructed to overtake on the motorway and rural road. On the federal road the three manoeuvres did not differ in strain, i.e. the additional requirements on the longitudinal regulation arising from the preceding car do not cause higher strain. Regarding the direction of the effect it is even a little less stressful to follow a car than to drive on the road which could be explained by the fact that a preceding car supports the driver of in regulating and adapting velocity to environmental factors (road characteristics, speed limits).

Approaching and following a car only increases strain if the driver prepares to overtake (motorway and rural road). The increase is larger if other vehicle may approach from the opposite direction (rural road). Additionally, characteristics of the road (lane width and number of curves) contributed to increase subjective strain.
Results of this study may be used for the estimation of the actual driver's strain by means of an objective detection of driving manoeuvres, the identification of driver's intent and of situational conditions. Driver assistance systems could thus help drivers to "optimise" their current strain by adapting e.g. the functionality to actual strain. The approach presented is a good alternative to the physiological measurements because the necessary information is available in modern cars. The approach could be extended in different directions: Some of the driving manoeuvres such as "crossing intersection" and "enter / leave parking slot" should be analysed in more detail to find different phases with different strain. Additional situational conditions which further modify strain have to be identified (e.g. having right of way or not at intersections, number of other road users etc.). Finally, other environmental factors which probably also increase the overall difficulty of driving, e.g. road condition, visibility and weather should be analysed in terms of their influence on strain. Detection and identification of these environmental factors can be improved by the development of additional sensors for driver assistance systems resulting in a better description and estimation of driver strain.

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