SUBJECTIVE STRAIN ESTIMATION DEPENDING ON DRIVING MANOEUVRES AND TRAFFIC SITUATION

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ABSTRACT: An inadequate level of workload while driving is leading to increased errors and accidents. Therefore, there is a need for levelling the driver's workload through some assistance system. In addition to their specific functionalities (e.g. coordinate, prioritise information), these systems aim to optimize the driver's workload. Therefore, an assessment of the workload is required. As workload depends on external stress factors which can change dynamically, e.g. driving manoeuvres or environmental conditions, the workload estimation needs to be as dynamic and continuous rather then discrete. In this paper, the effects of traffic density and changes in the demands within a complex manoeuvre are estimated using a new developed method for a continuous subjective rating of the driver's workload. The results demonstrate that the variation of the stress factors moderate driver's strain. By integrating these findings with former results a qualitative and quantitative model of stress and strain is introduced.

1 Introduction

1.1 Workload measurement within the driver-vehicle-environment context

Workload is a very complex concept of interrelations between e.g. external task demands, internal resources, processing capacities and performance capabilities. These aspects are often indicated with the same term "workload" [1]. The approach presented here is based on a concept of stress and strain. According to DIN EN ISO 10075-1 [2] 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." While driving stress factors arise from different sources: First of all, the driving task poses differing demands on the driver. Follow 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 than under the condition of high visibility because the availability of relevant information is restricted. On the other hand, e.g. high temperature influences the driver directly by making him / her tired. A third category of stress sources are additional secondary tasks like operating a navigation system, using a mobile phone [3, 4] or communicating with passengers. The actual level of driver's strain evoked by the stress depends on driver characteristics such as abilities, skills and his state. Therefore, the same stress level does not necessarily result in the same strain for different drivers. Due to the vehicle motion within the driving environment and the interaction with other road users none of the three stress sources acts statically on the driver. They can be characterised by different distinctive changing dynamics which again demands a comparable high dynamic description of the possible resulting strain.

In general, strain cannot be measured directly but indirectly and is normally assessed multimodal [1, 5] by subjective, physiological and performance indicators. Behavioural indicators, e.g. steering wheel reversals or the standard deviation of the lateral position indicate individual coping strategies in terms of action control. Physiological measures such as the heart rate describe the driver's state by indicating his activation or arousal [1, 6]. Both indicators dynamically assess changes in strain but have problems in regard to are partly problematic with regard of sensitivity and specificity. This makes interpretation of these indicators sometimes very difficult. Indicators e.g. have to be differently interpreted according the test design (primary versus secondary task) but also with regard to different sources (changing of the driver state versus changing of the task demands) [7]. Besides, both types of indicators require special sensors in the vehicle which are not available in current series-production vehicles but would be mandatory for a wider application of strain adaptive systems not only in the field of research. The third group of subjective self report measurements like NASA-TLX or Instantaneous Self Assessment Method [8] don't need any specific sensors for assessment and in general have a higher sensitivity than the indicators mentioned above. However, these indicators are usually collected at discrete points in time like at the end of a test drive or at certain spatial- or time-triggered situations during the trip to analyse differences between systematically varied independent variables, system configurations, vehicles or drivers. This event-triggered and discrete assessment of the data is not suitable for measuring the effects of dynamically changing stress factors over time. In recent own real vehicle driving studies [9] it was shown that driver strain varies not only between different consecutive driving manoeuvres but even within one manoeuvre. Therefore strain should be analysed in regard to structural changes in place of level differences between certain time- or event-sections only by means of a likewise dynamic and continuous measurement. The second reason for a continuous measurement of both stress and strain is the final objective of this research: the definition and implementation of an online working model of driver stress and strain to manage the human machine interaction. These systems require continuous access to the workload level and its changes in order to provide an optimal support for the driver.

1.2 Estimation of strain by continuous subjective rating measurement

To benefit from the higher sensitivity of subjective self-report measures and to avoid the disadvantages of the rather discrete time- or spatial-triggered methods, a continuous subjective rating method was developed and tested in different former experimental studies. Within a real car driving study subjective strain was measured subsequent to the test drive through a video analysis where 16 participants rated their experienced strain during the drive using a 15-point rating scale (see Figure 1). The rating scale consist of five verbal main categories (very little strenuous, little strenuous, moderate, strenuous, very strenuous) with 3 subcategories each. Participants were not informed about the underlying stress factors varied by different driving manoeuvres and environmental factors, to not influence their ratings. They were instructed to give a new rating whenever they perceived a change of their subjective strain and their actual rating was displayed within the video.

very little strenuous			little strenuous			moderate			strenuous			very strenuous		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Fig.1. 15-point rating scale of the rating method

After mapping the continuous ratings to the different driving manoeuvres and environmental factors the results of the study demonstrated that these stress factors were associated with significantly different Perception of strain [9]. Different driving manoeuvres with different requirements were identified as stress factors leading to different strain levels. As an example, approaching and following a preceding car was shown to cause more strain than just following a road as these manoeuvres pose, additional to lateral control, also longitudinal regulation demands on the driver. However, situational characteristics were shown to modify the effects. For example strain increases only during approaching and following a preceding car in situations where the driver had the possibility to overtake and prepared this manoeuvre. In addition the increase was larger with oncoming traffic (rural road) and difficult road characteristics, such as narrow lanes and curves, which posed extra demands on the lateral regulation and velocity adaptation. In road sections where overtaking was not allowed, these manoeuvres did not differ in strain. In these situations the existence of the preceding car seemed to rather support the driver in longitudinal regulation than posing additional demands on the driver. The relationship between the described stress factors and subjective strain was validated within the study by analysing the physiological indicator heart rate variability as well as the performance indicator steering wheel reversal rate which both resulted in comparable results.

As continuous subjective strain was measured post-hoc subsequent the test drives, it was not clear whether memory effects or the restricted availability of information within the video display influenced the results. With the intention to estimate these effects and to test if it is possible to rate subjective strain continuously while driving (online) a second study was conducted [10]. In order to vary different stress factors within the DLR Virtual Reality Laboratory (VR Lab), different road sections were constructed and surrounding traffic was implemented so that test drivers conducted different driving manoeuvres on different road sections for several times repeatedly. Resulting strain was measured multimodal and continuously by subjective (by the abovementioned rating method) as well as performance indicators. To analyse possible interferences between driving and rating participants were divided into different groups, two experimental groups that rated first simultaneously while driving and secondly after the test drive by means of a playback-function. A control group rated exclusively offline. Influences of the rating time (online vs. offline) on subjective strain were analysed by comparing the ratings of the experimental groups. To control the effect of different rating modes, a manual and a verbal rating input have been compared additionally. It could be shown that a continuous assessment of the subjective strain is not differing between the online and offline approach. The analyses of the driving performance indicators (e.g. average speed, standard deviation of lateral position) showed no statistical significant interferences between rating and driving although the online rating groups tended to decrease their driving speed with the additional rating task. Furthermore no significant main effect of rating time (online versus offline) and the rating mode (manual versus verbal input) on rating behaviour was found. However, there were significant interactions between these factors and very strenuous situations (e.g. the situation overtaking on the rural road). The control group which exclusively rated offline underestimated strain as well as the online rating group that rated by means of the manual input. Difficulties by only post-hoc rating may be due to difficulties in the perception of distances and velocities within the playback function of the VR Lab. The manual online rating seemed to be somewhat difficult in situations where participants had to focus on motor actions during the overtaking for example. On the other side these participants adjusted their underestimated ratings afterwards during offline rating, which led to a significant interaction in the comparison of online and offline rating behaviour of the experimental group. Therefore it can be subsumed that if the driving situation is not characterised by extremely high demands for the driver, online rating is applicable and preferred to exclusively offline rating. Whereas in very high demanding situations participants should have the possibility to adjust their online ratings by an additional offline rating. The influence of the varied stress factors on strain and its intercorrelations found in the first study were validated within the second study.

To summarize the results of both former studies it was demonstrated that the developed method to assess subjective strain continuously is an alternative to time- or event-triggered self report measures. By using this method, dynamic subjective strain information which is related to dynamically changing stress factors can be collected. Concerning the rating method (online or offline), it can be suggested to chose the method dependent on the experimental setup, i.e. whether it is a real driving tests or a simulator study, as both approaches result in comparable results.

1.3 Relation between stress and strain taking into account different levels of dynamics

Within the studies mentioned above the examined stress factors can be described as being of relatively low dynamics as within the real driving study e.g. participants passed within one hour of test drive only through seven different road sections. On the other hand, mapping subjective strain ratings on different driving manoeuvres also taking into account the manoeuvre sequence means estimating strain on a higher, more moderate dynamic level as the participants conducted several manoeuvres within the different road sections. For example within the abovementioned real driving study 16 participants conducted within a one hour test drive a total of 3452 driving manoeuvres, 1130 on the motorway, 32 on the motorway exit, 701 on the city road and 1589 on the rural road. Additionally there were indices that strain does not only differ among the manoeuvres but also even within a manoeuvre where the dynamic of changes is even higher and can be described as short-term changes. Within the following study higher dynamics of stress factors changes will be examined.

The other main issue of the research is validating the method for different dynamically stress factor changes, testing the sensitivity of the method and as a prospective objective establishing a qualitative and quantitative relationship between the measures of external stress factors and driver strain.

2 Method and test design

The main objective of the simulator study was to see whether even short time changes of external stress factors could be represented by means of the continuous rating method. As an environmental stress factor, traffic density was varied. By this the influence of different traffic densities on driver strain while driving on the motorway in general was measured. As former studies indicated that strain even differed within a complex manoeuvre the second aim was to assess the influence of different requirements within the complex manoeuvre "entering the motorway" on the driver's strain. To systematically distinguish between different demands "entering the motorway" was divided into four subtasks: First the orientation phase (at the beginning of the slip road), second the planning phase were participants begin to search for appropriate gaps, estimate velocities and plan their lane change during driving parallel to the other vehicles on the acceleration lane, third the active lane change phase characterised by the actual execution of the lane change and the last phase of driving on.

13 subjects (8 male and 5 female) between 24 and 35 years old (mean = 28) participated in the simulator study. The DLR simulator SimCar is characterised by a dynamic motion system and a high quality projection system that provides the image of the surrounding virtual environment and traffic. A wide field of view (240° × 40°) combined with a high resolution of approx. 9200 × 1280 pixels provides a detailed visual representation. For an overall realistic impression a complete vehicle has been integrated into the simulator. Driver behaviour (e.g. acceleration, steering) and the resulting vehicle dynamics (e.g. lateral acceleration, velocity) are recorded as well as information from the environmental model (e.g. preceding cars, road characteristics). The test track consists of two different parts: The first part is characterised by a set of two driving situations on the motorway with increasing and decreasing local traffic density in order to analyse the general influence of changing traffic on driver strain. The second part consisted of six consecutive manoeuvres "entering on the motorway" with fixed different local traffic densities. The order of increasing and decreasing traffic within the first part as well as the sequence of density levels within the second part was balanced between and within the subjects in order to control time- and cross-over effects. A total of about 1 hour of driving was realised within the simulator study.

Local traffic density was implemented by the traffic model introducing different numbers of vehicles. Local traffic density was defined by the coverage level of vehicles in front and besides the own vehicle and was then classified into 10 stages from 0 (no traffic) to 1 (traffic congestion) [11]. In order to allow analyses with repeated measures and to ensure equal traffic conditions for all participants during the second part of the test drive (the six consecutive manoeuvres “entering the motorway”) the coverage level was classified and applied by six conditions of different levels of traffic density. The six traffic densities were defined according the distinction of the different LOS-levels LOS1 (no traffic) to LOS6 (traffic congestion) [12].

Driver strain was measured continuously and multimodal by subjective (assessed by means of the online rating method with manual input), physiological (e.g. heart rate) and performance indicators (e.g. parameters of lateral control). Regarding the continuous rating method the participants were instructed to change their subjective strain ratings by pressing a steering wheel button whenever they experience a change in strain. Their actual rating was displayed in a head-up display on the 15-point rating scale and the verbal description of the main category (e.g. little strenuous, very strenuous). In order to ensure safe driving with simultaneous subjective rating and to counteract possible simulator sickness, the participants have been trained intensely to get used to the simulator and the rating task.

3 Results

In order to analyse the overall influence of dynamically changing traffic densities on subjective and physiological strain, these indicators were mapped to the different coverage levels while driving on the motorway and the 6 LOS levels on the slip road by computing mean values for each level of the factors. Concerning the different demands of the manoeuvre “entering the motorway”, the indicators were mapped likewise and mean values dependant from both factors, the manoeuvre phase and the LOS-level were computed for each participant (e.g. mean subjective strain during the orientation phase with high traffic density LOS6).

Although systematic control of the environment is an advantage of simulator studies, sufficient high coverage levels (> 0.7) of local traffic density on the whole motorway were not realised for all test drivers. This is probably due to the fact that the local traffic density strongly depends on the interaction between vehicles and therefore on the individual driving behaviour of the test drivers and the individual interaction with surrounding traffic respectively. As a consequence the number of analysed coverage levels is only 7 (0 to 0.6) and only 6 out of the 13 subjects can be included in the analyses concerning the influence of traffic in strain during the whole drive on the motorway. Therefore the results have to be interpreted as trends. The heart rate values have been intra-individually z-standardised across the whole data to control different inter-individual physiological initial levels. Subjective ratings have not been standardised as the inter-individual variability was marginal by reason of the extensive training phase.

In order to describe the overall influence of dynamically changing traffic density on strain two separate two-way 2×7 Design ANOVAS with repeated measures (sequence of increasing / decreasing traffic density, 7 levels of traffic density coverage, α = 5%) were performed for the subjective ratings and the heart rate. Concerning the subjective rating the effect of "traffic density" was significant ($F_{6,30}$ = 8.720, $p < .001$) whereas the second main effect "sequence" ($F_{1,6}$ =.335, p = .588) and the interaction between "traffic*sequence" ($F_{6,30}$ =.891, p = .514) were both not significant. The pairwise comparisons demonstrated that subjective strain increased with raising traffic density up to a medium coverage level of 0.3 but then remained on this level without increasing any higher. The equivalent analysis was computed for the intra-individual z-standardised heart rate (mean). The results tend to demonstrate comparable effects (traffic density: $F_{6,30}$ = 2.304, p = .060, sequence: $F_{1,5}$ =.424, p = .544, traffic*sequence: $F_{6,30}$ =1.048, p = .415). Mean heart rate also increased significantly with raising traffic density up to a medium level but in contrast to the subjective rating decreased again with even higher traffic, whereas the decrease was not statistical significant. In Figure 2 both strain indicators are displayed.[1]

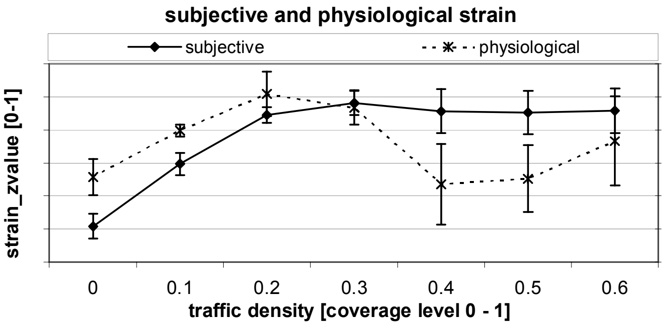

Fig.2. Strain dependent from traffic density (n = 6)

Besides this overall effect, the influence of different traffic densities on strain during the complex manoeuvre "entering the motorway" is described within the following analyses. The 6 different traffic densities on the slip road and the different demands of the manoeuvre can be characterised as of higher dynamics as the increasing and decreasing traffic density during the drive on the motorway. The analysed factors are therefore traffic density by means of the LOS levels and the 4 different phases of the manoeuvre "entering the motorway". For both strain indicators two separate two-way 6×4 Design ANOVAS with repeated measures (6 LOS levels, 4 phases, α = 5%) were performed. Due to technical problems not all traffic densities have been realised completely in the simulation and therefore only 11 out of the 13 subjects can be included in the analyses. Regarding the influence of the different LOS levels the main effects are significant in both analyses (mean subjective rating: $F_{5,50}$ =3.484, p = .009, mean heart rate: $F_{5,50}$ =4.947, p = .001). Subjective strain increases with increasing traffic, whereas only the lower stages differ significantly from the higher ones with subjective strain reaching a plateau. Physiological strain as well increases up to a medium traffic density but then

[1] By reason of a better demonstration z-values of both indicators are displayed within the figure. The analyses of subjective z-values result in comparable findings as the absolute ratings.

decreases again. The difference between the lowest level and the others is the only significant result. The factor “phase” has a significant influence on strain for the subjective indicator ($F_{3,30}$ =13.406, $p < .001$) whereas only a tendency is found for the z-standardised heart rate ($F_{3,30}$ =2.786, $p = .058$). Both indicators increase up to phase 3 follow by a decrease so that the highest strain is related to the active lane change in both indicators (see Figure 3).

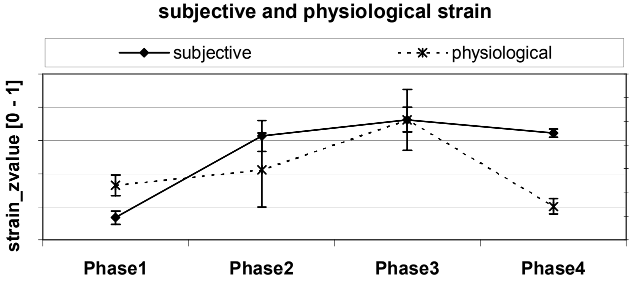

Fig.3. Strain dependent from the manoeuvre phases (n = 11)

Furthermore, a significant interaction between LOS level and manoeuvre phase for both indicators (mean subjective rating: $F_{15,150}$ =4.338, $p = .000$, mean heart rate: $F_{15,150}$ =2.665, $p = .001$) can be found.

Figure 4 demonstrates the interaction between the both factors. Regarding the subjective indicator strain increases during low traffic densities (LOS2 and LOS3) in phase 2 (planning phase) and decreases during the actual lane change and the continuation of the manoeuvre. From LOS3 strain remains on a high level and increases even more with increasing traffic respectively. In phase 4 strain is comparable to during the actual lane change except during the highest density level. Within the highest level (LOS6) strain decreases within phase 4 which is probably due to the very low velocities within the congestion. The interaction concerning the physiological indicator demonstrates a somewhat different relation. At high density levels a comparable increase in strain up to the lane change manoeuvre can be described, whereas at low levels strain first decreases in phase 2 and then got its maximum in phase 3.

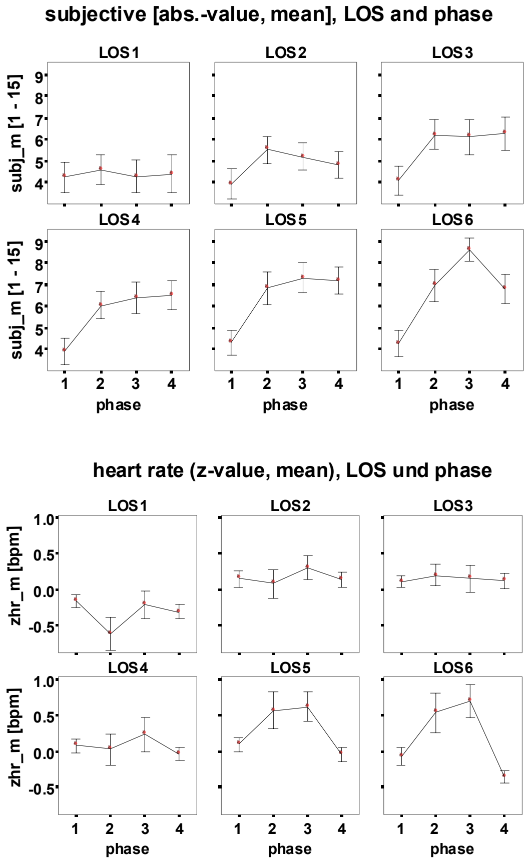

Fig.4. Interaction between LOS level and manoeuvre phase (n = 11)

4 Discussion and perspective

The results of previous studies demonstrated that the developed approach of continuous subjective strain measurement is applicable to assess the effect of different stress factors (manoeuvre and situation) on driver strain in different experimental setups such as real driving and simulation as well online as offline. Furthermore it was demonstrated that the relation between the measurement of varying external factors and the resulting driver strain, taking into consideration different levels of dynamics can also be represented by the method. The influence of short-term change of local traffic density is describable as well as the influence of various demands within the complex manoeuvre "entering the motorway". Concerning the general influence of traffic density on driver strain the analyses of the subjective and the physiological indicators show only partly comparable results: During high traffic densities subjective strain remains on a plateau whereas physiological strain decreases. This may be due to different sensitivities of the mean heart rate regarding physical and mental load. Mean heart rate is seen as sensitive to physical load but less sensitive to mental load.

It can be argued that mental load is higher than physical load in high traffic density situations due to a restricted scope of action or behaviour within the congestion. As a result the indicator of mean heart rate might be less sensitive in high traffic density situations than in low traffic density situations. In order to validate this interpretation other physiological indicators being more sensitive to mental load as e.g. the heart rate variability, should be analysed in further studies. Besides it can be stated that during high traffic densities strain increases until the actual lane change, whereas strain reached its maximum already during the planning phase in low densities, where the driver has to estimate velocities and distances to other vehicles and decide the lane change. The significant interaction demonstrates the importance to describe relations among different dynamically changing stress factors and resulting subjective driver strain more precisely. By means of the continuous subjective rating method more detailed information about the influence of factors on strain can be gathered than by a subjective questionnaire after the whole test drive which in turn results in a better understanding of the analysed aspect. However the dynamics should be analysed in more detail in further studies by examining the changing sequences. To reach the general aim of the research to model stress and strain within the driver-vehicle-environment context the relative influence of different stress factors with different changing dynamics on strain can be described and modelled by integrating the results of the studies. The final and prospective aim of the research is then the indirect estimation of the related strain via the underlying model of stress and strain by directly measuring the involved stress factors via CAN-Bus (e.g. manoeuvre recognition) or laser scanner (e.g. traffic density) in order to provide this information to possible adaptive assistance or information systems.

5 References

[1] De Waard, D.: The Measurement of Drivers' Mental Workload (Traffic Research Center VSC, 1996)

[2] DIN EN ISO 10075-1: Ergonomische Grundlagen bezüglich psychischer Arbeitsbelastung, 2000

[3] Alm, H., Nilsson, L.: The effects of a mobile telephone task on driver behaviour in a car following situation, Accident Analysis & Prevention, 1995, 27, (5), pp. 707-15

[4] Becker, S., Brockmann, M., Bruckmayr, E., Hofmann, O., Krause, R., Mertens, A., Nin, R., Sonntag, J.: Telefonieren am Steuer (Wirtschaftsverlag NW, 1995)

[5] Wickens, C.D., Hollands, J.: Engineering psychology and human performance (Longman, 1999)

[6] Hicks, T. G., Wierwille, W. W.: Comparison of Five Mental Workload Assessment Procedures in a Moving-Base Driving Simulator, Human Factors, 1979, 21, pp. 129-143

[7] MacDonald, W.A., Hoffman, E.R.: Review of relationships between steering wheel reversal rate and driving task demand, Human Factors, 1980, 22, pp. 733-739

[8] Girard, J.M., Wilczyk, M., Barloy, Y., Simon, P., Popieul, J.C.: Towards an On-line Assessment of Subjective Driver Workload. Driving Simulator Conference, Orlando, USA, 2005, pp. 382-391

[9] Schießl, C., Vollrath, M., Altmüller, T., Dambier, M., Kornblum, C.: What is strenuous? Driving itself or the driving situation? 13th World Congress on Intelligent Transportation and Systems and Services, London, Great Britain, October 2006

[10] Schießl, C.: Dynamic access to the actual driver state. 6 th European Congress on Intelligent Transportation Systems and Services, Aalborg, Denmark, Juni 2007

[11] Knake-Langhorst, S., Schießl, C.: Local traffic condition - improvement of a vehicle based measurement approach. 6th European Congress of Intelligent Transportation Systems and Services, Aalborg, Denmark, June 2007

[12] Special report 209: Highway capacity manual. Washington, D.C.: Transportation Research Board, 1985