WORKLOAD MANAGEMENT WHILE DRIVING: DO SUBJECTS' JUDGEMENTS REFLECT DRIVING SAFETY?

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ABSTRACT: N=24 subjects completed several runs in a high-fidelity driving simulator. While driving, the subjects had to perform a secondary task. In high-loaded situations, a so-called "Workload Manager" was active which guided driver's attention to sharp curves when approaching them and gave recommendations within which time interval (prior to and during the curve) not to perform the secondary task. Judgements and overriding behaviour of the driver indicate that the workload manager's attention-leading component is crucial for its evaluation. Extensive messages might not be necessary. Although the system does not influence velocity prior to sharp curves, it has a positive effect concerning possible critical situations in the curve (e.g. high lateral accelerations). Subjective methods show strong positive effects, objective measures only show a few effects. It is thus advisable to use different methods for the assessment of safety in human-factors studies.

1 INTRODUCTION

Several studies indicate that secondary tasks when driving (e.g. cell phoning, using navigation systems) might result in driver distraction (e.g. [1], [2], [3]). Up to 16% of the duration of driving driver's attention is directed to these subsidiary tasks [4]. According to [5], distraction is the reason of approx. 25% of all crashes.

According to [6], a "Workload Manager" (1) detects workload of the driver and (2) control external information which is addressed to the driver (e.g. incoming calls, information of the bord computer which is presented to the driver). However, this concept does not consider driver's self-paced actions (e.g. outgoing calls). In these cases, a workload manager should anticipate imminent workload and gives respective feedback to the driver. This requires information concerning upcoming driving situations (e.g. by means of digital maps; [7], [8]).

A systematic evaluation of a workload manager calls for various approaches of workload measurement which are discussed in literature (e.g. primary and secondary task measures, physiological measures as well as subjective measures). These methods go along with specific benefits and limitations [9]. Therefore, a simultaneous application of various methods is recommended [10]. However, problems can arise if these methods lead to contradictory implications (so-called "dissociations"). Hence, [11; p.105] suggests a simple rule: "If the person tells you that he is loaded and effortful, he is loaded and effortful whatever the behavioural and performance measures may show".

Aim of the present study was the evaluation of a workload manager which considers driver's self-paced actions and gives feedback regarding imminent workload. The system was meant to

(1) guide driver's attention to sharp curves prior to entering them and to

(2) give recommendations within which time interval (prior to and during the curve) not to perform the secondary task.

It was assumed that driving safety should be enhanced by guiding the driver's attention to particular attention-relevant aspects of the driving task. In order to answer this question, various approaches of workload measurement are realized.

2 METHODS

2.1 Driving task

This study was done in a PC-based driving simulator with motion system (Fig. 1 on the left). The visual system of the simulator provides a horizontal field of view of 180 degrees and a vertical view of 47 degrees generated by LCD projectors and presented on a spherical projection screen with a diameter of 6 m. The mock-up is taken from a BMW 520i that is cut off behind the B-pillar. Three mirrors (left, right and rear mirror) are realized via TFT displays. The simulator is run by a software called SILAB which was developed by the Wuerzburg Institute for Traffic Sciences (WIVW GmbH, for more information please visit www.wivw.de).

For the present study, a country road course was created (Fig. 1 on the right). The track led through a forest and consisted only of straight sections and curves with gradients between 88 m and 630 m. Oncoming traffic occurred with a mean frequency of 20 vehicles per min (sd = 5 vehicles per min). The subjects had to complete the course with a recommended speed of 80 km/h.

Fig. 1: High-fidelity driving simulator of the Wuerzburg Institute for Traffic Sciences

(on the left) and scene of the country road course (on the right).

In the following the results of two test runs are considered:

1. "Without system": In the first test run, the subjects had to perform the secondary task while driving without the workload manager.

2. “With system”: The second test run was realized with secondary task while driving and an active workload manager.

At the beginning of each run, the subjects had to perform a demonstration course with a length of approx. 3.3 km: In the first test run (“without system”), the subjects had to practice the secondary task while driving in this section. In the second test run (“with system”) the functionality of the workload manager was demonstrated. After completing the demonstration course, the subjects' task was to absolve the main course. This course had a length of approx. 14.6 km, resulting in a duration of approx. 15 min.

Before each run, the experimenter emphasized that the subject had to perform the secondary task only when the driving situation allowed it. To increase the drivers' motivation to drive safely as well as to perform the secondary task, a driver contest was conducted: On one hand the subjects were able to achieve points for working on the secondary tasks correctly. On the other hand the subjects could loose points for driving errors. The three subjects with the highest score gained a book voucher. The drivers were informed about this contest prior to the first test run.

Prior to the first test run, the subjects had to perform a “baseline run” with neither secondary task nor workload manager. This run was realized for the subjects to get to know the course and to get used to driving in the simulator. In the following, the baseline run is not considered.

2.2 Secondary task

The subjects had to perform a self-paced secondary task during the course: By means of a joystick, they had to navigate predefined items in a hierarchic menu system as fast and accurate as possible. The hierarchic menu system consisted of four items in the first menu level (“navigation”, “entertainment”, “telephone”, “in-vehicle computer”), two items each in the second and third menu level and four items in the fourth level (4*2*2*4 system). The menu system was presented in a display in the lower central console near the gear shift. The drivers had to avert their gaze from the road in order to look at the display.

2.3 Workload manager

In high-loading driving situations of the second test run, the workload manager gave recommendations in order to interrupt working on the secondary task and guide the driver's attention to the oncoming sharp curve. As the course consisted only of curves and straight sections, the high-loading situations were defined as sharp curves with a radius < 350 m. This definition was chosen due to preliminary studies. The system emitted messages in 18 of the 28 curves. These messages began 3s prior to entering the curve (a so-called “anticipatory phase”) and ended with leaving the curve.

Three conditions of the workload manager were realized as a “between-factor design” (see Fig. 2):

1. “Information”: A gong was emitted in regular intervals with a frequency of 1 Hz. The display of the secondary task remained active.

2. “Interruption”: The display of the secondary task was turned off. This occurred without any previous information for the subject.

3. “Combination – Information followed by interruption”: In the anticipatory phase, the workload manager emitted two gongs (equivalent to the condition “information”). Entering the curve, the display of the secondary task was turned off (equivalent to the condition “interruption”).

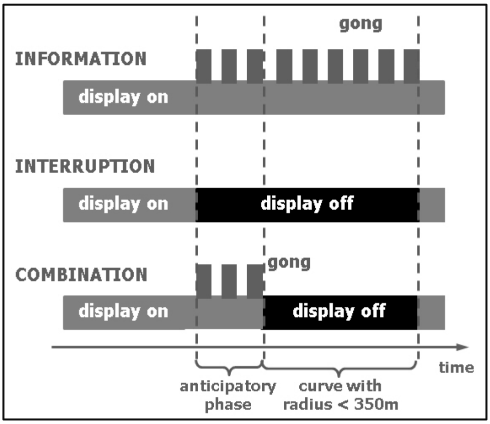


Fig. 2: Schematic description of the functionality of the conditions “information” (top), “interruption“ (middle) and “combination“ (bottom) during the anticipatory phase and the curve. The gongs are displayed as vertical bars, the activation of the system is labelled as colour (grey: display turned on; black: display turned off).

Via key press, the driver was able to override the messages of the workload manager to continue with the secondary task at any time. In the “information” condition, this caused the gongs to stop. In the “interruption“ condition, this turned the display on again. In the “combination“ condition, this stopped the gongs and turned the display back on, respectively.

2.4 Dependent variables

Various parameters of driver’s behaviour (e.g. steering activity, throttle activity, brake pedal activity) and vehicle’s behaviour (e.g. velocity, acceleration) were measured. Additionally, secondary task behaviour (e.g. using the joystick) and handling of the workload manager (e.g. overriding the system via key press) were recorded.

After each run, the subjects had to answer six questions of a questionnaire concerning the preceding run (e.g. “How attentive were you during driving?”) on a 16-point scale ranging from 0 = “not at all” to 15 = “very much”. After the run with the workload manager, the subjects answered an additional questionnaire concerning evaluation and acceptance of the system (26 questions) on 5-point scales and several questions in an open-question format about evaluation of the system and suggestions for improvement of the workload manager.

2.5 Sample

N=24 participants (11 female, 13 male) aged between 27 and 61 years (m=37.3; sd=8.7) took part in this study. The participants' mean driving experience was 18.2 years (sd=7.9 years). Prior to the study, all participants absolved a driving training in the high-fidelity driving simulator [12] in order to get familiar with the simulator and to reduce the probability of simulator sickness.

3 RESULTS

3.1 How do drivers rate the system's effect?

It was assumed that the introduction of the workload manager while working on a secondary task leads to positive judgements on subjective safety compared to working on a secondary task without further assistance. The drivers' judgements confirm this hypothesis: Compared to the run without the workload manager, the subjects rate themselves as more attentive during driving (F (1;21) = 33.029; $p<.001$; eta²=.611; see Fig. 3 on the left) and the run itself as safer (F (1;21) = 25.225; $p<.001$; eta²=.546; see Fig. 3 on the right).

Furthermore, the combination of driving and performing the secondary task is rated as easier with workload manager than in the run without system ("information" without system: m=9.00 (sd=3.74); with system: m=7.25 (sd=2.25); "interruption" without system: m=10.88 (sd=2.23); with system: 7.63 (sd=3.20); "combination" without system: m=12.50 (sd=9.75); with system: m=9.75 (sd=1.67); F (1;21) = 32.187; $p<.001$; eta²=.605).

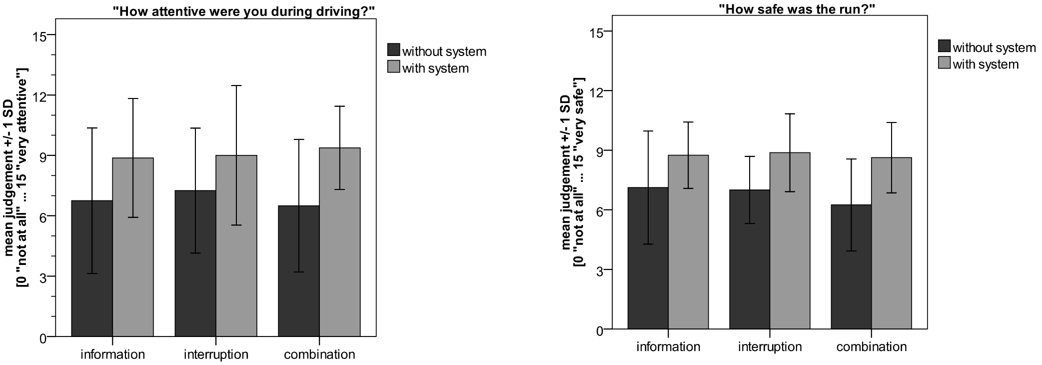


Fig. 3: Mean judgements concerning attention (on the left) and safety (on the right). Shown are mean values (with standard deviations) for the run without system and with system and each condition of the workload manager.

3.2 Does the system influence driving behaviour?

The introduction of the workload manager was meant to guide driver's attention prior to entering sharp curves. Accordingly, the drivers should reduce velocity during the anticipatory phase with workload manager more strongly compared to driving without the system. In Fig. 4 mean velocities (measured 3s, 2s, 1s and 0s prior to entering the curve, respectively) are compared with each other for each condition.

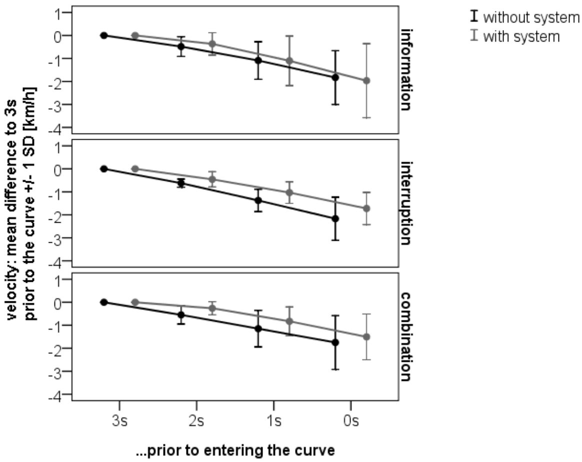


Fig. 4: Mean differences of velocity to the time point "3s prior to entering the curve" for different points in time during the anticipatory phase. Shown are mean values (and standard deviations) for the run without system and with system and each condition of the workload manager.

There is no difference concerning velocity between the run without and with system. This applies to all three conditions of the workload manager, respectively ("information": $F(3;21) = 0.130$; $p=.941$; $eta^2=.018$; "interruption": $F(3;21) = 1.471$; $p=.251$; $eta^2=.174$; "combination": $F(3; 21) = 0.705$; $p=.560$; $eta^2=.091$). Therefore, there is no systematic effect of the workload manager on velocity prior to entering sharp curves.

To determine the frequency of safety-critical events in sharp curves, a lateral acceleration higher than 4.5m/s² was chosen as indicator, a threshold which was judged as "just safe" in an earlier study [13]. With workload manager, the frequency of lateral accelerations higher than 4.5m/s² is reduced (see Fig. 5; $F(1;21) = 5.929$; $p=.024$; $eta^2=.220$). All conditions of the workload manager lead to a lower number of safety-critical events.

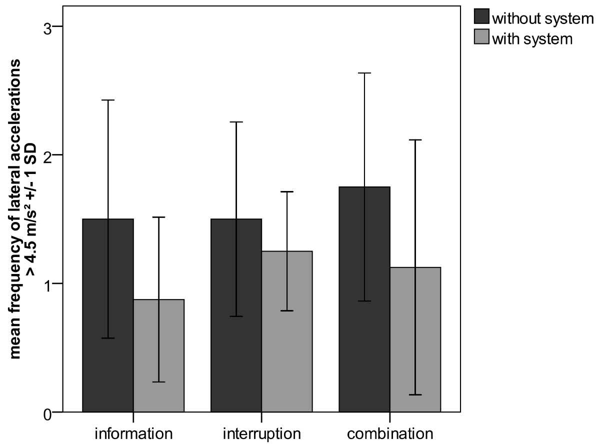


Fig. 5: Mean frequency of lateral accelerations > 4.5 m/s². Shown are mean values (with standard deviations) for the run without system and with system and each condition of the workload manager.

3.3 How do drivers interact with the system?

All conditions of the workload manager go along with positive effects on drivers' judgements, whereas effects on driving behaviour are quite smaller (i.e. velocity while approaching sharp curves, frequency of critical lateral accelerations within sharp curves). Therefore, it is analysed if the drivers really used the system while driving or if they overrode it as soon as the messages of the workload manager started.

The subjects of the "information" condition use the overriding function least (md=2.63% of all sharp curves; see Fig. 6 on the left). However, 2 of 8 subjects in this condition stopped 58% and 100% of the messages, respectively. In the "interruption" condition, the median of the subjects' overriding frequency is 15.79%. In this condition, the differences between the subjects concerning overriding frequency are smaller than in the other conditions. In the "combination" condition, the subjects override most often (md=57.89). In this condition, a large variation of overriding has to be considered: Whereas 2 of 8 subjects override each message, 1 subject uses overriding not at all.

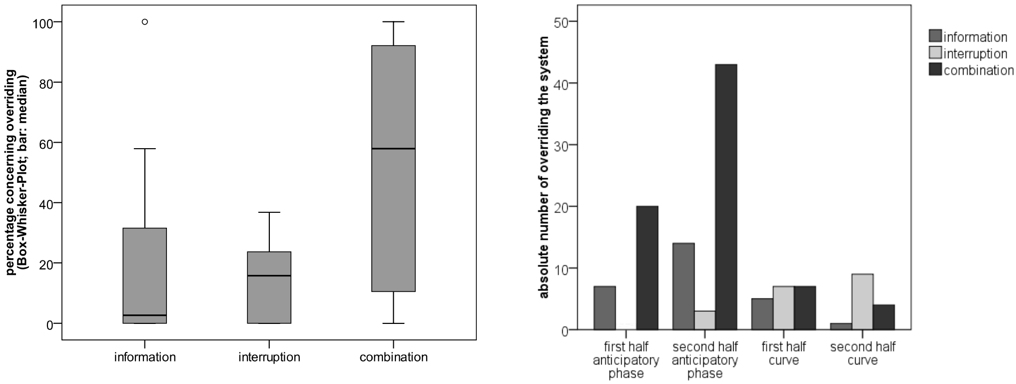


Fig. 6: Box-whisker-plots for mean percentages of overriding the workload manager for the different conditions (on the left); absolute numbers of overriding for the different conditions of the workload manager and sections prior to and within the curve (on the right).

Furthermore, the points in time of overriding were analysed. For this purpose, the time of system activity was split into four sections (which differ in their duration):

1. First half of the anticipatory phase (3s to 1.5s before entering the curve)

2. Second half of the anticipatory phase (1.5s before entering the curve until entering the curve)

3. First half of the curve

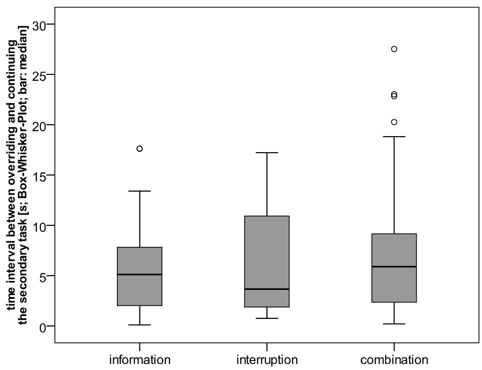
4. Second half of the curve

Concerning the points in time of overriding, further differences between the conditions become obvious (see Fig. 4 on the right): Whereas the subjects in the “interruption” condition override the manager while passing through the curve, the subjects in the conditions “information” and “combination” override the manager prior to entering the curve.

3.4 Why do drivers override the messages?

Primarily, drivers might wish to continue working on the secondary task in order to get a high score in the drivers’ contest. In this case, the interval between overriding and continuing to work on the secondary task has to be rather short. However, as Fig. 7 on the left shows, the median for the interval between overriding the messages of the workload manager and continuing the secondary task is 5.56s (“information”: 5.11s; ”interruption”: 3.67s; ”combination”: 5.89s). Especially in the condition ”combination”, a lot of intervals are rather long.

These results indicate that drivers particularly accept the information component of a workload manager prior to entering a curve. Drivers’ judgements confirm this impression (see Fig. 7 on the right): They rate the end of the messages as too late (t(23) = 2.298; p=.031). This implies that drivers regard the guiding of their attention back to a high-loading driving situation as the most important benefit of the workload manager.



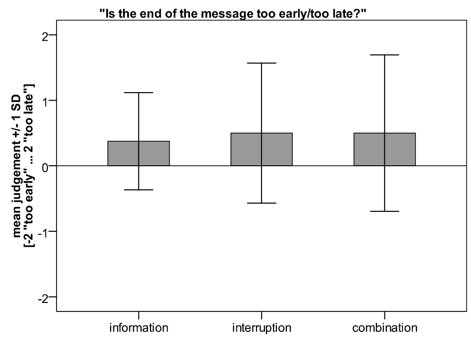


Fig. 7: Box-whisker-plots for mean time intervals between overriding and continuing the secondary task (on the left); mean judgements concerning end of the messages. Shown are mean values (with standard deviations) for the different conditions.

4 DISCUSSION

In the present paper, a new design of workload manager was introduced which enlarged previously known variations of such systems: Whereas workload managers typically detect workload of the driver and control external information which is addressed to the driver [6], the manager in the study guided driver's attention to sharp curves prior to entering them and gave recommendations when not to perform a self-paced distraction task.

The workload manager is rated as positive: According to the subjects, assisted driving is safer and the drivers are more attentive compared to a run without the system. Furthermore, with the workload manager the combination of driving and performing the secondary task is judged as easier. However, the subjects override a substantial part of the messages of the system. Most overrides occur prior to the curve. The relative long interval between overriding and continuing with the secondary task indicates that the drivers do not override the workload manager in order to continue with the secondary task but to stop the message.

These results indicate that the workload manager's attention-leading component is crucial for the evaluation of the system. An indication prior to high-loaded situations seems to be sufficient for driving. Extensive messages of a management system might neither be necessary nor desired.

Concerning speed, the workload manager has no systematic effect while entering the curves: Compared with driving without system, the subjects do not alter velocity. However, the system has a positive effect concerning rare and extreme events in sharp curves: The frequency of high lateral accelerations is reduced.

The comparison of subjective and objective methods for the assessment of safety shows, that the introduction of the workload manager leads to strong overall-effects concerning drivers judgements. On the other hand, only few or rather small effects can be found regarding objective data. As a consequence, an exclusive application of subjective methods may lead to an overestimation of the effects. Therefore, it is advised to use different methods for the assessment of safety in human-factors studies.

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