Cognitive load estimation in the car: Practical experience from lab and on-road tests

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AutomotiveUI'15, September 1–3, 2015, Nottingham, UK
ACM 978-1-4503-3736-6

Abstract
An estimation of the actual cognitive load of the driver will be a necessity in the future, in particular when it comes to manually steered and automated vehicles sharing our roads simultaneously. The research project at hand proposes a noninvasive setting (pressure imaging in the seat) to infer the level of cognitive load at the driver in driving situations of varying complexity (difficulty level of the secondary task; PASAT). After a feasibility analysis (data collection in the lab), the experiment was repeated in the field. Quantitative and qualitative analysis reveal that variations in the sitting posture might be used as an indicator for an elevated level of stress, however, some of the results are statistically not significant. Nevertheless, the comparison between lab and field study showed some interesting findings, relevant for other researchers studying effects in either lab or on-road settings.

Author Keywords
On-road study, Simulator study, Subjective workload, Driving performance.

ACM Classification Keywords
Human-centered computing: [Human computer interaction (HCI)]: HCI design and evaluation methods, Field studies

Simulator study (Daimler LCT)

- Pressure sensor mat, type: XSENSOR X3 PX100:48.48.02
- Logitech G27 force-feedback racing wheel (+pedals)
- 1 x GoPro Hero cameras for ground truth recording
- IMU (Intersense Inertiacube) for steering wheel angle estimation
- Stereo speakers used to replay sound cues (PASAT test)
- Stereo sound system used to replay engine sound (LCT)
- Video beamer (3x4m) to show LCT simulator scene
- Audio recording device (driver feedback, PASAT+free speech)
- Room climatized (22°C)

Field study (car park 120x40m, track length 375m)

Toyota Rav4, 2001, Manual shift

- Pressure sensor mat, type: XSENSOR X3 PX100:48.48.02
- 2 x GoPro Hero cameras for ground truth recording
- GPS data logger (Conrad CR4)
- 3-axis accelerometer (ADXL320) to measure vehicle lateral acc.
- IMU (Intersense Inertiacube) for steering wheel angle estimation
- OBD/CAN-bus interface to gather vehicle-specific data (ELM327)
- Car stereo used to replay sound cues (PASAT test)
- Audio recording device (driver feedback, PASAT+free speech)
- Vehicle climatized (22°C)

Figure 1: General setting and sensors used in lab and field study. Red color indicates differences between the two settings.

Introduction

The number of traffic fatalities is declining (at least in the developed countries), most likely due to standard equipment in vehicles that accounts for enhanced crash worthiness (e. g., seat belts, airbags, anti lock braking system (ABS), electronic stability control (ESC), and other pre-crash safety systems). Other factors include update and enforcement of the road traffic law (e. g., allowing lower levels of alcohol) and improving education of road traffic safety (e. g., mandatory advanced driver training) [1]. On the other side, however, drivers today are more and more challenged by a sheer endless number of assistance systems either in the car and increasingly also app-based (Waze, etc.). For example, a BMW 3200CS car in 1962 had a total of only 17 control elements while one of the successors, a BMW X11 2011 model, had 82 controls (including the iDrive controller, which was counted as just 1 control). Last but not least, also the amount of traffic, number of road signs and other technical equipment brought into the car (Smarthpone, Tablet, etc.) supports driver distraction and cognitive overload.

It is known to all that a cognitively overloaded driver is a dangerous driver. It was identified, for example by [1], that traffic accidents relate closely to the driver's mental and physical states immediately before the accident. To pick up on that issue and inspired by previous work [4], we wanted to investigate the correlation between cognitive load, steering performance and driver's sitting postures under both, static lab and dynamic on-road conditions.

After a review of the research hypotheses and a description of the study settings, the rest of this paper is dedicated to a discussion of identified differences between the lab and the on-road settings, aiming at helping other researchers interested in setting-up similar studies to find their perfect setting.

Research hypotheses and method

The main aims of this research project were to investigate the influence of cognitive workload on 1) drivers' sitting behavior and 2) driving performance. According to [4], there is a relationship between road topology (steering behavior) and sitting postures. In detail, the authors study the impact of sitting on driving activities under real conditions, and conclude, for instance, that the dynamicity of a driver's sitting postures can be used to detect possible overlook of upcoming steering activities. To fully cover the problem field, we conducted first a lab study (simulated lane change test (LCT), according to the specification in ISO 26022:2010) to check the system setup in a closed environment and look at the relationship between workload and sitting postures without centrifugal forces effective on the driver. A previous study [4] already provided evidence that driving on a race track with high speed causes, at least for experienced drivers, some implicit, proactive behavior change with regard to the sitting position. After this first experiment, the experimental setting was transferred to a real car, and the study repeated in an on-road test (a parking lot with no other traffic). Both studies were accompanied with post-task qualitative data gathering to assess subjective conditions of the drivers (NASA TLX, questionnaire with experiment-related questions on a 5-level Likert scale).

Influenced by the works of [3, 2], the studies were designed as between-groups design with 5 series each (baseline (primary task only), secondary task (3 levels of workload, low to high; PASAT test with varying complexity), baseline – to allow identification of a potential learning effect). 19 volunteers participated in the lab study (9m/10f, 21-33 years, avg. 25.05$\pm$3.14 years) and 15 (different) subjects agreed to participate in the on-road study (8m/7f, 22-30 years, avg. 26.60$\pm$1.80 years). Both groups are comparable and all subjects were in possess of a driving license ($>$5 years) and drive at least 7,000km a year.

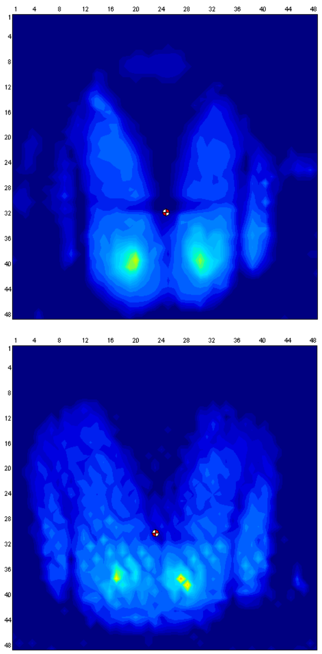

Figure 2: Top: Correct pressure image (lab setting; field study after correction with separate power supply). Bottom: Pressure image disturbed by electrical interference (caused by dynamo machine).

Hypotheses
The basic assumption in this research was, that the movement dynamics of a driver in the car seat (represented by the variance of the center of pressure (COP) in both lateral and longitudinal directions) depends on the level of cognitive load effective on the driver (expressed in this work by quantitative analysis of NASA-TLX forms filled out by the participants between each of the experimental series. Three research hypotheses were formulated, the most influential hypothesis H1 (which is this paper based on) reads as “The variance of the center of pressure (COP) on the seating increases with increasing cognitive level of a secondary task.” (In more details, and in order to make lab and on-road tests comparative, not the center of pressure alone, but the ratio longitudinal/lateral COP variance divided by vehicle longitudinal/lateral acceleration was finally used as measure and analyzed; see equation below.)

$$\frac{\sigma^2_{COP_{lateral}}}{\sigma^2_{a_{lateral}}}, \frac{\sigma^2_{COP_{longitudinal}}}{\sigma^2_{a_{longitudinal}}} \qquad (1)$$

Findings/Differences Lab vs. On-Road Studies

Highly relevant for the discussion in this workshop, we identify in the following the main differences between the simulator (lab, static) and the on-road (field, dynamic) study settings and try to explain the reasons. (Even more differences were identified; these will be discussed in the workshop). Some of them are obvious (e. g., difference in driver’s sitting postures due to the effect of the centrifugal force, as already investigated by [4] and others; see also [3] for a discussion on similarities between simulator and on-road settings), others are rather unexpected.

1) Road surface and electrical interference
To be able to compare measures from the pressure array mat between lab setting and on-road study, one has to pay attention to the road surface, as vibrations from the underground (e. g., gravel, potholes) would have a significant impact on the recordings (and data cleaning using data from accelerometers, etc. might be impossible). To account for this, we carefully selected our test site (flat surface, tarmac, no potholes). Another unexpected issue was electrical interference in the car as highlighted in Figure 2. Unwanted harmonics from the dynamo machine completely destroyed data received from the individual sensors of the pressure array mat. After some puzzling, we finally managed to solve the problem by installing an extra power supply (car battery) in the test vehicle.

2) Coherence between steering wheel angle and COP
Figure 3 shows that the correlation between the steering wheel angle and the deflection of the driver in lateral direction (expressed by the center of pressure; COP) is a direct one for the majority of subjects in the simulator study, while it is inverse in the field study (solid lines in the figure). The main reason for this behavior is the missing centrifugal force in the simulator study, and the fact that drivers automatically (and proactively) compensating centrifugal forces to some degree in real environments (as shown by [4]).

3) Mental demand and dual-task performance
When comparing the subjective mental demand (NASA-TLX) and the performance achieved with the secondary task (PASAT) (see Figure 4), it can be seen that the average mental demand in the simulator study (blue, bold-faced line) is significantly higher as compared to the on-road experiment (red, bold-faced line). Looking at an objective measure – the performance achieved in the auditory secondary task (PASAT; same configuration for both series) – it can be indicated that the avg. performance is higher for the on-road part of the study compared to the simulator part, suggesting that lower mental demand results in higher dual-task performance. The reasons is, that the driving simulator study introduced a new, relatively unknown setting/environment for most of the subjects, and this might have finally caused higher mental demand and lower performance for the secondary task. On the other hand, the

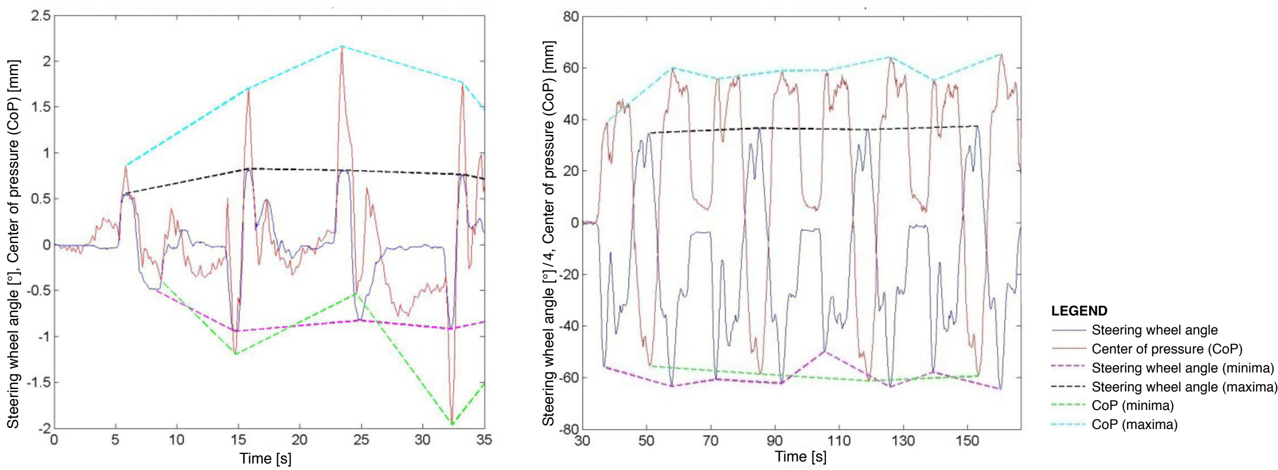

Figure 3: Course of steering wheel angle and center of pressure (COP; driver seat). Left: simulator study, right: on-road test.

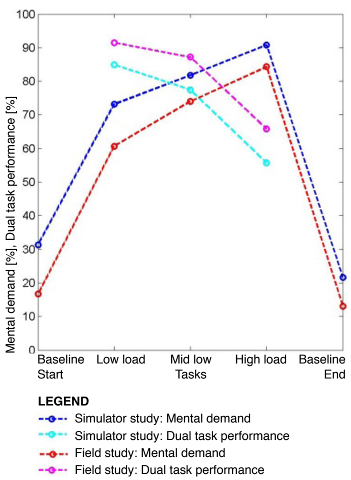

Figure 4: Mental demand (NASA-TLX) versus dual-task performance (PASAT).

on-road study was perceived as familiar and largely automated activity for the drivers (all of them are in possess of a driving license and have several years of driving experience). Due to this fact, the mental demand is lower in the field study, i. e., more resources available for ancillary tasks.

Conclusion

When designing on-road experiments, a good deal of factors need to be considered and unexpected problems solved at the last moment. But finally, researchers get rewarded with more realistic results as compared to lab settings. On the other hand, in lot of cases on-road studies cannot be conducted for monetary, safety, etc. reasons. In this case, carefully designed lab studies need to be executed instead (see also [3]). This paper has discussed, based on practical experience in both settings, potential issues one has to deal with, aiming at raising the awareness of researchers for unexpected problems and the importance of test runs when setting-up their own studies.

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