# DO SLOW COMPUTERSYSTEMS IMPAIR DRIVING SAFETY?

Fabian Utesch, Mark Vollrath
Department of Engineering and Traffic Psychology
Technische Universität Braunschweig
Gaußstraße 23, D-38106 Braunschweig, Germany
f.utesch@tu-braunschweig.de

**ABSTRACT**: Although many modern in-vehicle information systems (IVIS) possess delays, up to now, there has been little research about safety-related issues. Therefore the effects of delays in menu interaction on driving performance were investigated. Delay length (0,500,1000 ms), delay type (constant, variable) and the application of an acoustic feedback (with, without) were varied in an artificial menu system. Driver performance was measured with the Lane Change Task (LCT) simulation. Drivers performed significantly better under constant delays. Longer delays did not have an effect on driving performance, though they were perceived as more annoying. To minimize driver distraction, modern IVIS should have constant delays. To improve driver satisfaction, manufacturers of IVIS should avoid long delays in menu interaction.

## 1 OBJECTIVE

Nowadays, drivers often conduct secondary tasks while driving. These interactions have the potential of distracting them from the road [1]. In 78% of accidents and 65% of near accidents in the USA, glances away from the road are a cause or contributing factor [2]. A form of inattention is involved in 25% of the accidents in the USA [3] and every glance away from the road decreases the probability of recognizing and reacting to a potentially dangerous situation [4]. This emphasizes the importance for keeping the eyes constantly on the road and keeping attention on what happens on the street. This goal is often challenged by information and entertainment systems that accompany drivers on their daily car trips. Older IVIS, like tape decks, CD players and radio did not require much operation. Additionally, they may often be handled by simple buttons or wheels. Operating them is easy to learn and can be performed nearly automatically after some practice.

Today's IVIS are far more powerful and complex. Where a simple 10 character digital display sufficed for the handling of a CD player, the operation of a Mp3 player with different folders, playlists and a vast number of tracks requires a more sophisticated display. The problem of delivering much information on a small screen is often tackled by using menus that are guiding the user through the options. This is one main difference between older and modern IVIS.

With this menu based interaction new problems arise. Because of the alternating nature of the menu, the driver has to remember his current position in the menu structure. This involves a continuous cognitive engagement and periodical checks of the actual display configuration. New complex IVIS generally require more attention, because modern operation elements often change function (when buttons are placed beside the screen) and even location (if a touch-screen is used). These systems are accompanied by another problem - an increased probability of delays in menu interaction. The delay of a system's response after user input is called system response time (SRT). During such a SRT the system is not able to take new commands, and the user has to wait until the system is ready again [5]. SRTs occur when huge amounts of data have to be processed or a data source is not immediately available, e.g. when the system aggregates huge clusters of information (maps, mp3 songs, pictures traffic information, etc). The speed of the information delivery depends on local factors such as processing power and data access but also on external factors like connection quality, data transfer rate and service availability. SRTs lead to a delayed and fragmented menu interaction, which can be critical for the driving task. The idle period in menu interaction can only be used to some extent to attend the road scene. Long SRTs (about 8 sec) are correlated with higher electrodermal activity which is associated with emotional stress [6], negative mood, or higher pain sensations [5,7]. Burns and Lansdown [8] hypothesize that delays in menu interaction can lead to frustration which would distract the driver. It is therefore possible, that operating an IVIS with delayed menu interaction can increase the crash risk. Further, a system's SRTs are rarely constant. The effects of constant versus variable SRTs were investigated by Kuhmann et al. [9], they found no differences in terms of task type or error and response rate. The question arises, if the findings from previous investigations about SRT effects can be applied to driver-machine-interaction by means of menus. The number of sophisticated computer systems in our cars is increasing and so is the danger of getting distracted by them. Delays in menu-based driver-machine-interaction could be critical for driving safety. Therefore it is crucial to investigate the distraction potential of slow computer systems in our cars.

The goal of the experiment presented here was to find out how IVIS should be designed to minimize distraction caused by SRTs during menu-driver interaction. It was assumed that system-invoked delays would have a negative impact on driver's performance, because of the intermittent attention towards the street. It was hypothesized that a menu with varying delays would lead to more glances away from the road, because of their unpredictable nature. With constant delays, the driver would learn how long he would have to wait until the system is ready for input again, and thus minimize his occasional checks. Thus, variable delays should cause more distraction and poorer driving performance than constant delays, and menus without delays at all should cause least distraction. The uncertainty of the driver about the current state of the system during a waiting period could be diminished by an acoustic feedback which indicates input readiness. This way, the driver would only have to wait for the signal to know that the system is ready again. No intermittent glances would be necessary. So it was hypothesized, that driving performance under the delay condition would be less impaired, if an acoustic feedback was applied.

# 2 METHOD

## 2.1 Design

In this experiment a 3x2x2 repeated measure design was used. The three factors delay length, delay type and acoustic feedback were manipulated within subjects. To avoid order and learning effects, subjects were distributed randomly after the latin square method to the 12 conditions. Delay length varied in three levels of 0, 500 and 1000 ms. Delay type was either constant or variable, and the acoustic feedback was either applied or not. In the variable delay condition, a random value was generated for each trial. It was calculated by choosing one of the three original levels plus/minus a random value between 0 and half of the original value. Schaefer discovered that the differential threshold for delays in the operation of technical equipment lies around 30% [10]. So the used variation of up to 50% should be perceptible. The acoustic feedback consisted of a simple clicking sound.

## 2.2 Setting

36 subjects (11 male, aged 19 to 43 years, mean age 21.7 years) participated in this study. Most of them were students at the Technische Universität Braunschweig, Germany. To avoid distortion of the results, two subjects were excluded from the analysis because of poor performance. All subjects except one had a driving license.

The subjects drove in a simple driving simulator, consisting of the LCT driving simulation [11] and a force feedback steering wheel with pedals. The wheel was attached to a desk. A 17'' flat screen monitor with a screen resolution of 1024x768 pixels and two speakers for driving sounds were located in front of the driver. The LCT program was run on a standard personal computer. A second computer ran a menu program, which was shown on a 17'' CRT monitor, also with 1024x786 pixels. The menu was operated with a standard german keyboard. The menu screen and keyboard were located to the right of the subject (Fig.1 left). Screens for both tasks were located in a 30° angle to each other. The room was dimly lit, without illumination from outside.

## 2.3 General Task

One session lasted approximately 90 minutes. While doing the LCT, the subjects had to handle the steering wheel with the left hand. Simultaneously they operated the menu system with the right hand. Each condition consisted of three lane change sections. These straight sections were separated by curves. Data was only collected in these straight sections between curves. Before the beginning, the subjects were given a brief introduction. They first practiced both menu and LCT task separately. Afterward, they were trained simultaneously. The menu training was finished when 25 correct responses were given in a row. The LCT training was accomplished by driving six sections or aborted if driving performance was satisfactory. Preceding research had shown that after six sections of LCT training, no significant additional performance is gained [12]. The dual task training was completed in the same way as the menu training. The lane change sections differed in the order of lane changes. For the training session extra sections were used to avoid learning effects.

After training, the subjects were left alone until the end of each condition. Every session started in a curve. Subjects were instructed to drive three sections of lane change tracks, to try to stay in the middle of the current lane and to change to the new lane as fast as possible, when indicated by signs at the side of the road. Additionally they were to operate a menu, which they started by pressing the spacebar after leaving the curve. Contrary to the recommendation of Mattes [11], the subjects were told to give the driving task first priority. This was to resemble a more realistic driving situation. After each condition, the subjects called for the experimenter and answered a brief questionnaire with six items about the usability of the menu system. A 15-point scale for each item was used, were subjects selected one of five categories first and then differentiated their rating within this category using a 3-point scale (-/0/+). After 12 conditions an additional section was driven without secondary task. The average values of this track and the last of the training session were used as a control condition. Subjects were not told that delays and an acoustic feedback would occur during the experiment. Instead it was said, that the experiment was about measuring driver distraction by the execution of a secondary task.

## *2.4 The Lane Change Task*

To measure driver distraction, the standardized LCT was used. The LCT is a driving simulation which was developed by Mattes [11] to quantify the level of distraction of secondary tasks, which are executed while driving. In the LCT the driver has to follow a three lane straight track without any traffic, at a constant speed of 60 km/h. He is supposed to stay in the middle of the current lane, until a lane change is indicated. This is done by traffic signs. At a distance of 40 meters the new target lane appears suddenly and is indicated by an upward arrow (Fig.1 right). At this moment, the lane has to be changed as quickly as possible. The driving quality is determined by comparing the actual driven path with a simple normative model.

Besides this overall measure, lane keeping and lane change phases were treated separately. A lane change episode began 80 meters in front of a sign and lasted until 50 meters behind it. The rest of the track in between was declared as lane keeping episode. For both phases, the mean deviation from the normative model was computed separately. Additionally, the standard deviation of lane position (SDLP) was computed as a measure for lane keeping. A reaction time was computed for the lane change from the point where the driver could see the lane change cue to the first turn of the steering wheel. All variables were continuously recorded. High values indicate bad driving, low values good driving.

**Fig.1. Experimental setup on the left, the drivers view on an indicated lane change on the right**

## 2.5 The Menu Task

As a secondary task the subjects had to navigate through a menu. They had to select a certain entry which was announced over the speakers by a female voice. In each trial one random target of a total of 64 items was presented. In order to create some similarity to the situation in the car, the menu items were classified in the sections navigation, music, phone and background image. It was programmed in Javatm and ran on a Windows computer. The menu structure was organized in three hierarchical levels. Each level consisted of four items. The driver operated the menu using the four arrow keys. An entry was selected with the right CRTL-Key. After an item had been selected the next lower level (sub-menu) appeared to the right. Backward moves (moving up in the menu) were possible. The delays were inserted, when subjects moved from one layer to the next or back to a previous one.

Before each trial, the female voice announced a target by asking for an action, for example, 'Choose Berlin as the destination of a route'. In order to achieve this aim, the driver had to select 'navigation' first, move to 'starting point', then to 'Berlin'. There was no time limit for the tasks. Subjects executed trials in the menu task until they finished a condition on the LCT which took them about three minutes.

The performance of the driver in this task was recorded online. From this record, several parameters were computed in order to describe the behavior: the number of correct trials, selection errors, the time needed to complete the trial, the number of steps, the chosen path, the deviation from the ideal (shortest) path and the electronically applied delay.

# 3 RESULTS

In the following analysis several ANOVAs were conducted. For each ANOVA sphericity was tested with mauchly tests and in case of violation F and p values were corrected after the Greenhouse Geisser method.

### *3.1 Dual task performance*

From the literature on secondary task effects in the LCT [12,14,15] one would have expected a negative effect of the menu selection task on performance in the LCT. Similar secondary tasks produce mean deviations of 1.03-2.6 m under dual task conditions and below 1.0 m in the baseline condition. However, as Figure 2 shows subjects reached deviations below 1.0 m in all 12 dual task conditions. This indicates that overall there was only a very small effect of the menu task on driving in the LCT.

To investigate if the secondary task actually had any effect to the LCT, baseline and dual task conditions were compared. A multivariate ANOVA for repeated measure designs with the 12 dual task conditions and the baseline condition as factors and the driving parameters as variables were conducted. In this analysis, overall performance was excluded as variable because it was calculated from lane keeping and lane change performance and therefore would not contain any additional information. The assumption of normal distribution was checked visually and was given approximately. The effect of condition was significant with ($F(48,1584) = 2.7$, $p < .01$). Univariate tests for all variables were performed, to test for effects in each parameter. They indicated significant differences between the conditions in all four variables: quality of lane keeping ($F(7.3, 242.2) = 4.0$, $p < .01$), quality of lane change ($F(7.1, 234.6)=5.5$, $p < .01$), SDLP ($F(4.6, 150) = 3.9$, $p < .01$), reaction time ($F(7.5, 246.4) = 5.4$, $p < .01$). To find out, which conditions were different, pairwise comparisons were conducted. They showed that the baseline condition differed significantly from the dual task conditions. The subjects performed better without the menu. The secondary task did have an influence, even if it was weak.

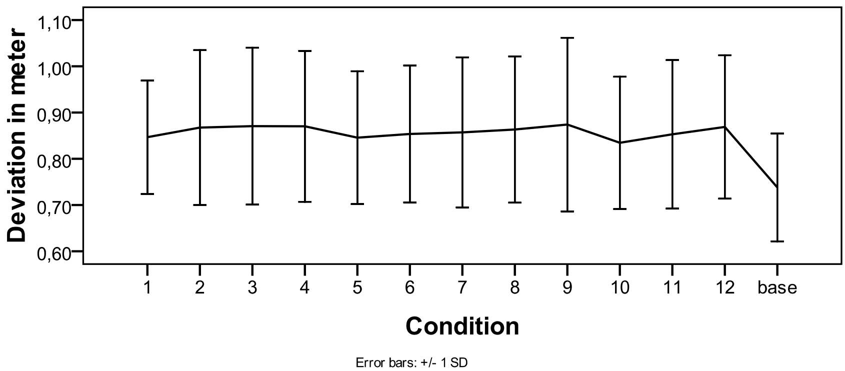


**Fig.2. Mean deviation in overall performance from ideal LCT path for all dual-task conditions and baseline**

### 3.2 The impact of delay length, delay type and feedback

To analyze whether participants were impaired by delay or benefited from the acoustic feedback, their performance was tested in the dual task conditions. It was tested for effects of the three main factors delay length (0, 500, 1000ms), delay type (variable, constant) and acoustic feedback (with, without). Three-way ANOVAs were conducted with overall performance, quality of lane keeping, quality of lane change, SDLP and reaction time as dependent variables. Contrary to the assumption, no significant interaction or main effect of delay length was found. Further, there was no significant interaction for delay type but a significant main effect in lane change quality ($F(1,33) = 9.1$, $p = .01$) and reaction time ($F(1,33) = 6.2$, $p = .02$). As figure 3 (left) shows, the subjects performed lane changes more accurately under the constant delay (M = 1.12 m, SD = 0.20 m) than under the variable delay (M = 1.14 m, SD = 0.20 m) and as can be seen in figure 3 (right) the reaction times to indicated lane changes were faster under constant (M = 100.1 ms, SD = 67 ms) than under variable delays (M = 108.5 ms, SD = 73.9 ms). Additionally, there was a trend ($F(2,66) = 2.8$, $p = .07$) of an interaction between delay length and feedback in reaction time which is shown in Figure 4. There was no difference between the delay lengths with applied feedback. However, when no feedback was present, reaction time increased with the increasing delay. This effect is strongest for the longest delay without feedback.

## *3.3 Performance in the menu task*

On average, subjects needed seven seconds to select one correct item. They finished about 17 trials per LCT section. Subjects barely made any errors in the menu task, though it took them about 15 steps to find the correct item. To test if the menu performance was influenced by delay or feedback, a repeated measures ANOVA was conducted. It was tested for effects in selection time, which was corrected by the applied delay. There was no significant difference in the selection time between conditions.

## *3.4 Ratings*

After each condition, subjects were asked to rate the usability of the menu system. They rated the strain, anger, distraction, speed of performance and perceived trial duration. Additionally the overall usability was rated. The ratings for the delay conditions were compared with parameter free Friedman tests. The levels of delay length (0, 500, 1000 ms) were used as factors, the aforementioned rating dimensions as dependent variables. There were significant differences in five dimensions: strain ($X2(2) = 12.8$, $p < .01$), anger ($X2(2) = 21.5$, $p < .01$), distraction ($X2(2) = 8.8$, $p < .01$), speed ($X2(2) = 17.6$, $p < .01$) and usability ($X2(2)=19.4$, $p < .01$).

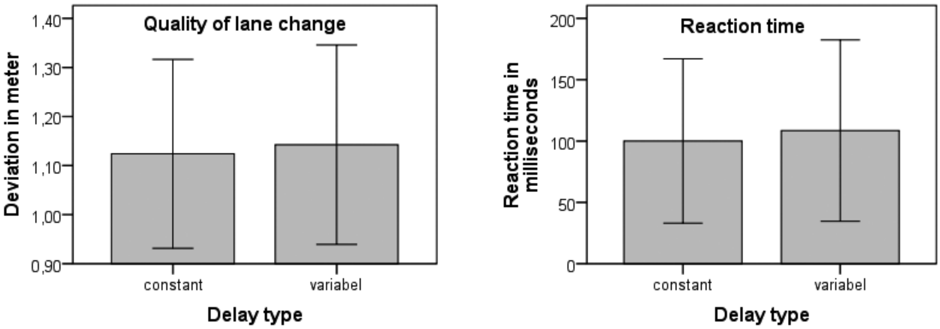


**Fig.3 Mean and standard deviation of the quality of lane change (average deviation) in meter at the left and mean and standard deviation of the reaction times in milliseconds at the right**

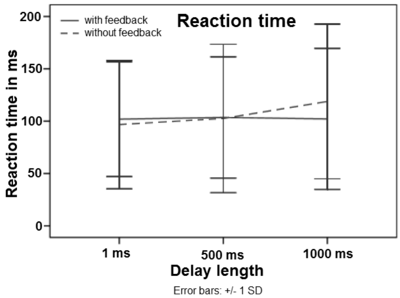


**Fig.4. Tendency of interaction between reaction time and delay length (mean and standard deviations of the reaction time)**

Although subjects were not told that delays would occur, they judged the menu interaction under longer delays as more exhausting, less usable and felt more angry about it as can be seen in Figure 5 (left). Under shorter delays, they felt less distracted and faster in selection time. After the experiment, subjects were asked about their impressions about the delays and the feedback. Figure 5 (right) shows, that most of them perceived the delay as annoying. The feedback made a more distinguished impression. The majority found it helpful, but there were also some who rated it as annoying.

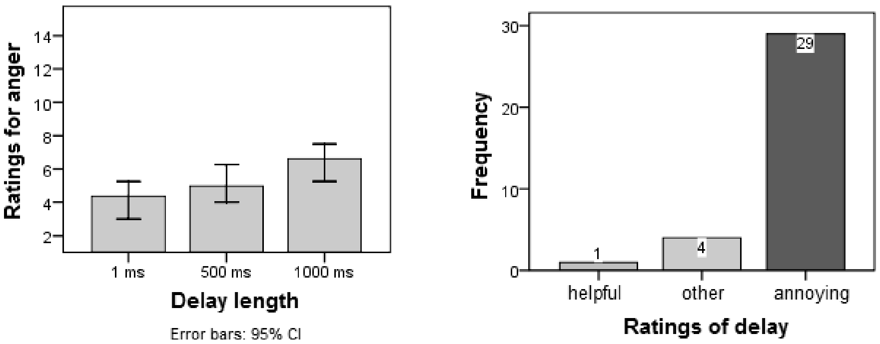


**Fig.5. Ratings of anger for delay length (median and 95% confidence interval) on the left and general ratings of delay on the right**

# 4 CONCLUSIONS

The goal of this research was to find out, if delays in menu interaction could have a negative impact on driving behavior. Although subjects felt more distracted with longer delays, there was no main effect for delay length on driving performance. This finding stands in opposition to the work done by Rassl [15]. He finds that longer delays in menu interaction (>2 s) increase handling time and cumulative gaze duration towards a display, but not average gaze duration, as compared to short delays (<0.2 s). As the overall effect of menu operation in the LCT was very small it may be that the menu task was too easy as it did not result in a strong distraction of the subjects. Some subjects stated that they could operate the menu from the corner of the eye, without the need to look away from the road. A real menu system would be much smaller and it would be difficult to operate it without looking directly towards it. Thus it would be interesting to replicate this study using a more realistic menu task with smaller displays. However this study showed that variable delays in menu interaction have the potential to distract the driver as compared to constant delays. Subjects performed lane changes better and faster when delays were constant. Because a constant delay can be anticipated, lesser glances away from the road are needed. Thus lane change signs can be better perceived and reacted to. Additionally, these tasks with constant delays can be better integrated in the overall action planning including driving and secondary task. Considering that this study used a very simple driving simulation we can say with reservation, that if there are any delays in an IVIS one should try to keep these constant even if this means to artificially prolonging some delays. The majority of subjects perceived the delays as annoying. This indicates that the delays induced stress. This finding is similar to previous research on personal computers [6,7]. It shows that research findings from outside the driving context can at least partially be generalized into it. The applied delays were rather short and their occurrence was not previously announced. Nonetheless subjects clearly noticed them and rated the menu interaction with longer delays as more disturbing. This emphasizes that delay length in menu interaction is an essential factor of the usability of an IVIS. This should be considered by manufacturers in the design process. It is advisable to minimize possible delays, to improve the consumer's acceptance of their products. This ambition stands in opposition to the above mentioned lengthening of the delays and creates a challenge in interface design. A possible compromise could be to generally minimize the delays, but then match the slower to the longest ones. It was further hypothesized, that an acoustic feedback, which indicates input readiness, would reduce negative effects of the delay. This assumption was only supported by a tendency of an interaction between delay length and feedback. Hence, further research in this direction may be reasonable. The ratings of the feedback differed almost equally between useful and disturbing. Thus, implementing an acoustic feedback in an IVIS could impair sale rates, because some of the customers may not like it. An important factor that would be worthwhile to investigate, is the sound used. We used a clicking sound. A less intrusive and harsh signal could gain higher acceptance. For now it is best to say that if acoustic feedbacks are used in an IVIS, the customer should be given the opportunity to turn it off. Another method to investigate the distraction potential of delayed menu interaction could be the occlusion technique. Especially the variant in which subjects regulate occlusion time for themselves proved feasible to differentiate between easy and complex displays [16]. This method could be used to measure the number and duration of glances away from the road, which are needed to operate menus with different delays during driving.

In summary it can be stated that delay type is important for driving safety, while delay length is crucial for consumer acceptance.

# 5 REFERENCES

[1] Neale, V. L., Dingus, T. A., Klauer, S. G., Sudweeks, J., & Goodman, M. (2002). An Overview of the 100-car naturalistic study and findings. National Highway Traffic Safety Administration.

[2] Dingus, T.A., Klauer, S.G., Neale, V.L., Petersen, A., Lee, S.E., Sudweeks, J., Perez, M.A., Hankey, J., Ramsey, D., Gupta, S., Bucher, C., Doerzaph, Z.R., Jermeland, J. & Knipling, R.R. (2006). The 100-Car Naturalistic Driving Study, Phase II - Results of the 100-Car Field Experiment. Washington, D.C.: National Highway Traffic Safety Administration.

[3] National Highway Traffic Safety Administration (1997). An investigation of the safety implications of wireless comunications in vehicles: Report DOT HS 808-635. Washington, D.C.

[4] Rognin, L., Alidra, S., Val, C., & Lescaut, A. (2007). Occurence of Secondary Tasks and Quality of Lane Changes. In D. Harris (Ed.), Engineering Psychology and Cognitive Ergonomics (pp. 397–406). Berlin, Heidelberg: Springer.

[5] Kohlisch, O., & Kuhmann, W. (1997). System response time and readiness for task execution - the optimum duration of inter-task delays. Ergonomics, 40(3), pp. 265–280.

[6] Schaefer, F., Kuhmann, W., Boucsein, W., & Alexander, J. (1986). Beanspruchung durch Bildschirmtätigkeit bei experimentell variierten Systemresponsezeiten. Zeitschrift für Arbeitswissenschaften, 40, pp. 31–38.

[7] Thum, M., Boucsein, W., & Kuhmann, W. (1995). Standardized task strain and system response times in human-computer interaction. Ergonomics, 38(7), pp. 1342–1351.

[8] Burns, P. C., & Lansdown, T. C. (2000). E-Distraction: The Challenges for Safe and Usable Internet Services in Vehicles. National Highway Traffic Safety Administration. Retrieved March 19, 2009, from http://www-nrd.nhtsa.dot.gov/departments/Human%20Factors/driver-distraction/PDF/29.PDF. p. 4.

[9] Kuhmann, W., Boucsein, W., Schaefer, F., & Alexander, J. (1987). Experimental investigation of psychophysiological stress-reactions induced by different system response times in human-computer interaction. Ergonomics, 30(6), pp. 933–943.

[10] Schaefer (1985) in Schaefer, F., Kuhmann, W., Boucsein, W., & Alexander, J. (1986). Beanspruchung durch Bildschirmtätigkeit bei experimentell variierten Systemresponsezeiten. Zeitschrift für Arbeitswissenschaften, 40, pp. 31–38.

[11] Mattes, S. (2003). The Lane Change Task as a Tool for Driver Distraction Evaluation. In H.Strasser, H. Rausch, & H. Bubb (Eds.), Quality of Work and Products in Enterprises of the future. Stuttgart: Ergonomia Verlag.

[12] Vollrath, M., Nowak, P., & Huemer, A. (2009, April 01). LCT und Nebenaufgaben - Welches Training trainiert was? 51. Tagung experimentell arbeitender Psycholog|innen. Jena.

[13] Bär, N. (2008). Die Auswirkungen von Training auf die Spurwechselperformanz. Diplomarbeit, Technische Universität, Chemnitz.

[14] Wynn, T., & Richardson, J. H. (2008, April 03). Comparison of subjective Workload Ratings and Performance Measures of a Reference IVIS Task. European Conference on Human Centered Design for Intelligent Transport Systems. Lyon, France.

[15] Rassl, R. (2004). Ablenkungswirkung tertiärer Aufgaben im Pkw Systemergonomische Analyse und Prognose. Dissertation, Technische Universität München, München, from http://www.rassl.org/ereignisse/promo_robert/downloads/praes_doktorpruefung_rassl.pdf.

[16] Gelau, C., Keinath, A., Baumann, M., Bengler, K., & Krems, J. F. (1999). Die Okklusionsmethode als Verfahren zur Bewertung von visuellen Displaydarstellungen in Kraftfahrzeugen. Zeitschrift für Arbeitswissenschaft, 53(1), 51–57.