Effect of non-Unified Interaction Design of in-car Applications on Driving Performance, Situational Awareness and Task Performance

Julia Manner, Christopher Kohl, Michael Schermann, Helmut Krcmar
Chair for Information Systems
Technische Universität München
Boltzmannstraße 3
85748 Garching bei München, Germany
Email: {julia.manner, christopher.kohl, michael.schermann, krcmar}@in.tum.de

***Abstract*—It is common understanding that human-computer interaction (HCI) systems should be designed unified. However, ensuring a unified interaction design (UID) is a cost intensive and time-consuming venture. Especially the automotive industry struggles with exceeding costs and time-to-market pressure as drivers want to stay connected and informed while driving. Therefore, we investigated the effect of non-unified interaction design (NUID). We report on a simulator study with 44 participants in which we studied the effect of a NUID within an automotive HCI system consisting of five in-car applications. We measured the effect on driving performance, task performance and situational awareness when carrying out tasks. We found no significant effect of UIDs. We offer an explanation based on HCI and cognitive ergonomics literature.**

***Keywords*-interaction design; in-car applications; cognitive load; multi-tasking; multiple-tasks; task complexity**

I. Introduction

It is common understanding that HCI systems should be designed consistently to reduce the effort to use the technology [1]. Since the mid-nineties [2], literature considers consistent and standardized HCI design to be desirable. Accordingly, software designers generally implement UIDs. To give an example: the button "x" at the top right of a window to close programs or the index tab with partial similar options like save have consistently been implemented. But, ensuring a UID for an IT system with various functionality is a cost intensive and time consuming venture [3], [4]. Every application not only needs to be tested on functionality and performance, but also on (subjective) characteristics like usability, design and compatibility which cannot be evaluated easily [4]. By contrast to this, the standard approach researchers acknowledge that usability needs to be engineered specifically for the context of use for the system under investigation [5]. In-car applications are now penetrating the automotive sector as it is widely recognized that drivers want to stay connected and informed while driving [6], [7]. Moreover, to serve this promising market, car manufacturers must provide various and innovative in-car applications [8], [9]. Consequently, the amount of money car manufacturers have to spend on providing in-car applications with a UID is exceeding [10]. We investigate the effect of a NUID for this new domain and – therefore - if the common understanding still holds in the automotive domain. We study the effect of a NUID of in car applications by proposing an experiment with two groups. The control group was provided with an in-car system that consists of five similarly designed applications with a UID. Therefore, the UID of a premium car manufacturer was imitated. The test group used the same applications but each application had a different interaction design. Besides, each group was instructed to carry out several tasks while driving in a simulator. A significant difference in consistency and standardization and hence the usability between the two groups was verified with a questionnaire after the usage including the empirically acknowledged construct of effort expectancy from the unified acceptance theory proposed by Venkatesh [1]. We measured the effect of NUID on driving performance, task performance, and situational awareness. No significant effect of NUID on driving performance or situational awareness was found. However, a significant effect on the driver's task performance was measured. The remainder of this paper is organized as follows. In the next section, the theoretical background of our study will be explained. We then outline the study completely. Henceforth, we report on the results of our study and conclude with a summary of our findings and prospects of future research.

II. Background and theoretical framework

Literature of usability design [11] and on cognitive ergonomics [3], [12] emphasize the importance of ease of use. Thereby, standards and conformity are considered as crucial as they reduce the effort to operate HCI systems. In non-safety critical environments ease of operation is considered an important factor for user's technology acceptance [13], but in a safety critical environment a NUID is endangering people [3]. Answering the need to measure the ease of use which is part of the acceptance, theory researcher proposed measuring instruments like the Technology Acceptance Model proposed by Davis in 1989 [13] or the Unified Theory of Acceptance and Use of Technology (UTAUT) model, which is a further development of the first [14]. Both models are empirically

 ISBN: 978-1-61208-250-9

validated and include a construct for measuring the effort users feel they need when operating the system. From this matured area of consumer behavior research, we use the construct of effort expectancy from the UTAUT model that evaluates the "degree of ease associated with the use of the IT system" and investigate if we provide a sound research design. Effort expectancy of users is measured by the following four items proposed by Venkatesh [15]:

1) Interaction with the system is clear and understandable
2) Ease of becoming skillful at using the system
3) Evaluation of the ease to use the system
4) Evaluation of the learnability of system use

Taking these in several domains [15], [16] applied indicators for effort expectancy into account, it is likely that a NUID increases the effort to use.

H1: A NUID leads to higher effort expectancy.

A. Driver's distraction by an additional task

Driving is a cognitively demanding multi-tasking activity [17], [18] which is competing for the limited resource of cognitive capacity [12] when an additional task like operating in-car applications or speaking on the phone take place simultaneously. Hence, it is not surprising that several studies show a negative effect of additional tasks on driving performance revealed by distraction [19], [20]. According to the American Automobile Association for Traffic Safety, a driver is distracted when he is "delayed in the recognition of information needed to safely accomplish the driving task because some event, activity, object or person within or outside the vehicle compelled or tended to induce the driver's shifting attention away from the driving task" [21]. A study by Lee et al. [22] even found out that by increasing the operating complexity of an IT system, likewise an increase of cognitive resources of the operator needed is recorded. Similar results were reported by Gkikas and Richardson [23] as they found out that an increasingly demanding conversation has a negative impact on driving performance. Moreover, Besnard and Cacitti [3] discovered that interface changes in a working environment cause accidents. Going along with these results, it can be concluded that an IT system which causes more effort to operate has a negative effect on driving performance [12]. Following this argumentation, we expect a NUID to have a negative effect on driving performance. This leads us to the following hypothesis:

H2: A NUID leads to a decreased driving performance

B. Task performance

Task performance is defined by the time a user needs to complete a task and the quality the user has performed [24]. Task quality can be measured by the number of mistakes made. According to Burns et. al. [25], a driver needs to maintain an overview of his overall plan. Task duration is a measure that needs to be monitored when studying such an effect. This is because an additional task competes with the driving task for limited cognitive resources. A negative effect on task performance can be assumed when the effort of carrying out the task is significantly higher through a NUID. Hence, we propose the following hypothesis:

H3: A NUID leads to a lower task performance

C. Situational Awareness

Proactive safe driving without considering additional tasks can be considered as multi-tasking [26]. Not only must the driver drive, but he also needs to monitor and process the environment. A concept that integrates this aspect is called "situational awareness". Endsley [27] simply defines it as "knowing what is going on around you" or in more detail he [28] defines it as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". The concept was introduced in aviation psychology more than 24 years ago. Therefore, in this study, not only the driving performance was measured, but also the situational awareness. A poor system design, which disregards usability guidelines such as unified interaction and therefore demands more effort to carry out an instruction, leads to a limited situational awareness [29]. Ma and Kaber (2005) found a similar result. They were able to prove that reducing the effort to drive by an adaptive cruise control leads to an improvement of situational awareness. For this reason, we claim that the working memory of an individual is limited [12], [19] which is in accordance to Baumann et al. [19] who state that cognitive load "withdraws resources necessary for comprehension of the current situation" which often leads to a phenomena called "looked but did not see". Therefore, we propose the following hypothesis:

H4: A NUID leads to a lower situational awareness

III. User Study

A. Experiment design

The study participants were undergraduate and graduate students from Technische Universität München with a mean age of 26 years. Each volunteer with a driver license was eligible to participate in the study. The study was announced in lectures as well as in flyers around the campus. We attracted participants by raffling an Apple iPhone 4S. In order to test the hypotheses, we divided the participants into two groups. Each group had to operate the same five in car applications to complete the same three tasks but with a different interaction design approach. In the control group, each application displayed the interaction design of a major car manufacturer. In the test group, the applications had different interaction designs. The experiment was conducted as follows. First, some general information about in-car applications and an agenda of the experiment was given to the participants. Then, each participant filled a questionnaire containing questions about demographics and driving experience. After completing the survey, the participants were shown how to drive the driving simulator and how to operate the given applications. After completing all tasks, a second questionnaire had to be filled out which contained questions regarding the tasks. These questions were applied to measure the situational awareness.

 ISBN: 978-1-61208-250-9

Figure 1. Driving Simulator

The answers were graded from 1 (wrong answer) to 3 (correct answer) because the participants could answer the questions in their own words. We also asked questions regarding the effort expectancy. Moreover, in this experiment, the participants were advised that the odds of winning the iPhone increase according to their driving performance. This incentive was used for substituting the natural human avoidance of suffering damage, which we would otherwise not be able to attain realistically with a simulator study. Furthermore, a constant speed of 40 km/h was required. All participants obeyed this request. Thus, it can be determined that throughout the whole experiment the complexity of the driving task is constant between the groups. The similarity of the tasks the participant had to perform and understand is ensured by an instruction and procedure document for the experiment supervisor. The instructions were read to all participants.

B. Driving simulator

To measure the driver's distraction, the study participants had to sit in a driving simulator as shown in Figure 1. They were instructed to fasten the seat belt and to use the provided Logitech Driving Force GT steering wheel and pedals. While the driving simulation was shown on a 27-inch screen, the applications were displayed on a separate screen. Both groups operated the in-car applications with the same controller with a jog dial to eliminate potential confounding influences from the controller [30]. The controller allowed the users to rotate and push the jog dial or nudge it in a specific direction. The controller also provides direct access to the functions "menu", "back", and "navigation" when enabled in the active application.

C. Application development

We used three different interaction designs among five in car applications. For example, one interaction design is to rotate the jog dial clockwise to select the next item. The items were always arranged vertically with the first item at the top of the screen. The applications were implemented with the SDK of a major car manufacturer to ensure the same design and functionality for both groups. We specifically excluded any signs of the manufacturer's brand to avoid any brand-specific prejudices or preferences. The applications were designed to help the participants to go through a predefined scenario consisting of three tasks which should make the experiment as realistic as possible. We also developed a logging application which recorded specific decisions the participants could take in the scenario while using the applications. The study participants were instructed to memorize as much of the displayed information as possible. Each participant operated a movie rental service before starting the actual experiment. This was to ensure that all participants were familiar with the controller and the general concept of using applications in a car-like environment. The first task in the scenario was to book a hotel room in a given hotel. The application displayed the most important information like the price for a room, a rating (1 to 5 stars) of the hotel and a short description which required the driver to look on the screen for a longer time span in order to get all necessary information and complete the booking process. After having completed the booking process, the hotel had to be set as the new navigation target and the route had to be displayed on a map in the navigation application. The second task was to book a table for two people in a restaurant near a tourist attraction in Munich at 9 pm. The restaurant then had to be added to the navigation targets and a map with the current route had to be displayed on a map in the navigation application. Again, many details were provided in the restaurant application, out of which some had to be remembered. The last task was to display the weather for the evening. The weather application displays the weather forecast with large symbols so that a short glance at the screen was sufficient to get the information.

TABLE I
DEFINITION OF MDEV

Description	Definition
Number of measured data points	N
Distance difference	$\Delta y_i = \frac{y_{i+1} - y_{i-1}}{2}$ (1)
Actual-Reference-Deviation	$x_{a,i} = \lvert x_i - x_{i,ref} \rvert$ (2)
Length of trip	$S = \sum_{i=1}^{N} \Delta y_i$ (3)
Mean Reference-Actual Deviation (MDEV)	$\overline{x_a} = \frac{1}{S} \sum_{N}^{i=1} x_{a,i} \Delta y_i$ (4)

D. Measurement instruments

The lane change test (LCT) is acknowledged by the International Organization for Standardization for being cost-efficient, reliable and a simple tool to measure driver's performance while carrying out an additional task [31], [32]. The LCT

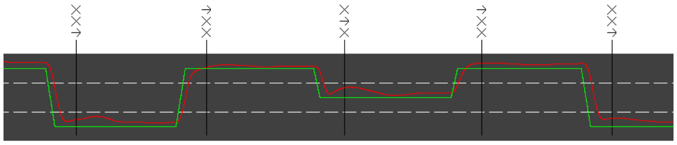

Figure 2. Driving Simulator

measures the mean reference-actual deviation (MDEV), i.e. the mean deviation between the reference lane and the actual driven lane. The formal definition of MDEV is shown in Table I. Figure 2 shows a graphical representation of a section of a LCT file. The test was applied by several authors which acknowledged the suitability of the tool [25], [32]. Bruyas et al. [33] reviewed the sensitivity of the LCT and found it excellent for differentiating between the execution of an additive task and the sole driving task. The LCT also allows setting a specific maximum speed and enables to provide the same driving challenge for each participant so that a direct comparison is possible and thus makes it especially suitable for experimental studies with simulators [31]. Hence, we chose the LCT for measuring the driver's distraction in our study. The LCT tool was configured to allow a maximum speed of 40 km/h in order to simulate a typical driving situation in Munich with an average speed of 32 km/h [34]. The study participants were instructed to accelerate fully in order to maintain the same speed throughout the driving part of the experiment. We incentivized serious driving by including the driving performance as a criterion for winning the iPhone. The LCT was started after each participant indicated that he or she was ready.

IV. Data analysis

A. Sample characteristics

44 licensed drivers (36 male and 8 female) with a mean age of 26 participated in this study. This particular age range was selected to represent the generation of future drivers. The mean mileage was 5,200 kilometers per year. In the study, there were 30 smartphone user and ten participants had experience with in-car applications. In each group there were 22 participants. Although we assigned each participant with a random distribution, there were some differences. In the NUID group the amount of females was slightly higher (5) than in the group with the UID (3). Furthermore, the mean mileage per year in the group with UID was higher (12.368km) than in the group with NUID (8.840km).

B. Statistical analysis

We first inspected the boxplots of the data, if there were any outliers. We found outliers in the measurements of MDEV, task completion time and effort expectancy (see Figure 3-6). We checked that we did not make an error and therefore chose to keep the outliers. As the distributions of these values have the same shape in both groups, we applied a Mann-Whitney test to determine, if there are differences between the groups.

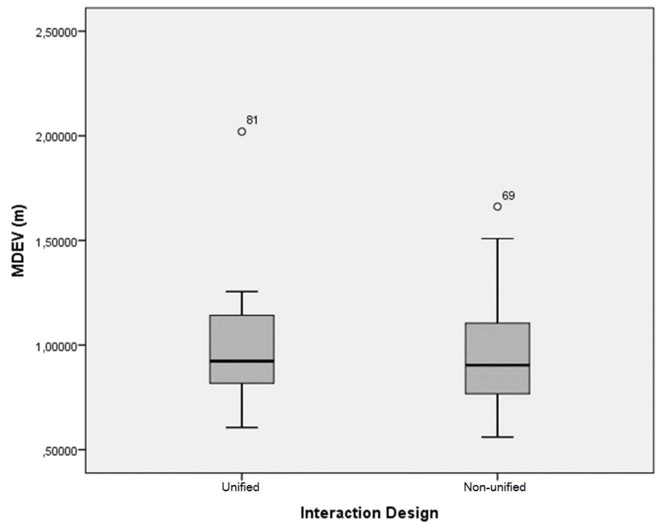

Figure 3. Boxplot of the MDEV distribution

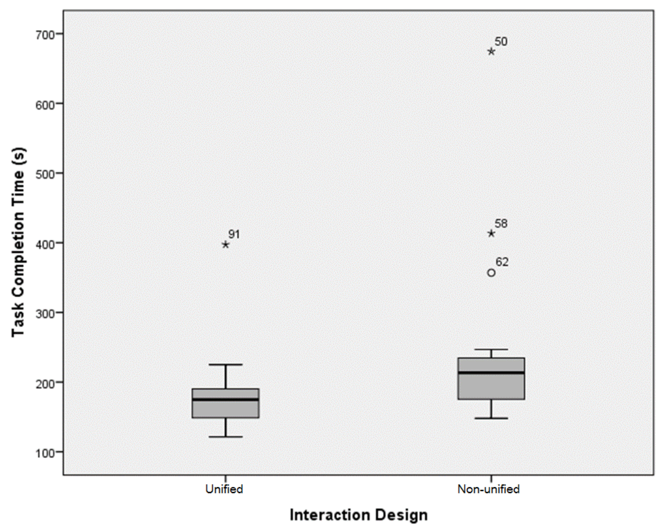

Figure 4. Boxplot of the task completion time distribution

MDEV: The test did not show significant differences in MDEV between the UID (Mdn = 0.923m) and the NUID (Mdn = 0.904m), U = 221, z = -0.493, p = 0.662. The NUID group even has a slightly lower MDEV (see Figure 3) i.e. the participants in this group drove slightly better than in the UID group.

Task performance: Task performance is measured by the quality of execution and the failures occurring by carrying out the tasks., e.g., booking a table only for one person instead of two. The test shows a significant difference between the UID (Mdn = 175s) and the NUID (Mdn = 213s), U = 363, z = 2.840, p = 0.005. Therefore, the UID group completed the tasks significantly faster. Figure 4 shows that there are also more outliers in the non UID group. The circle indicates a normal outlier, that has a distance of 1.5 box lengths to the edge of their box whereas the star indicates an extreme outlier,

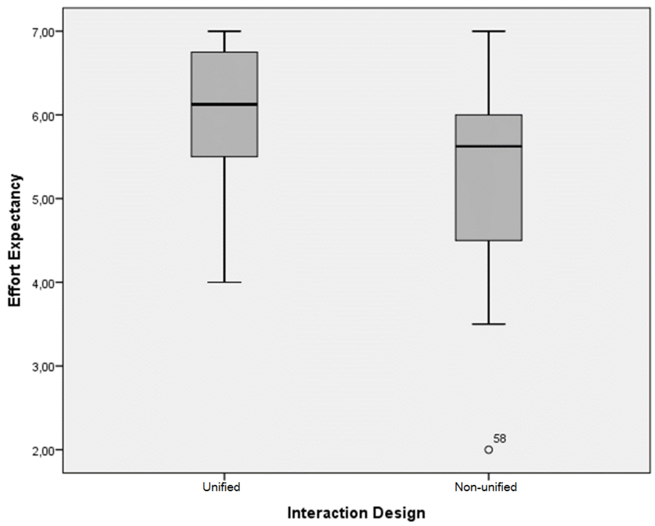

Figure 5. Boxplot of the effort expectancy distribution

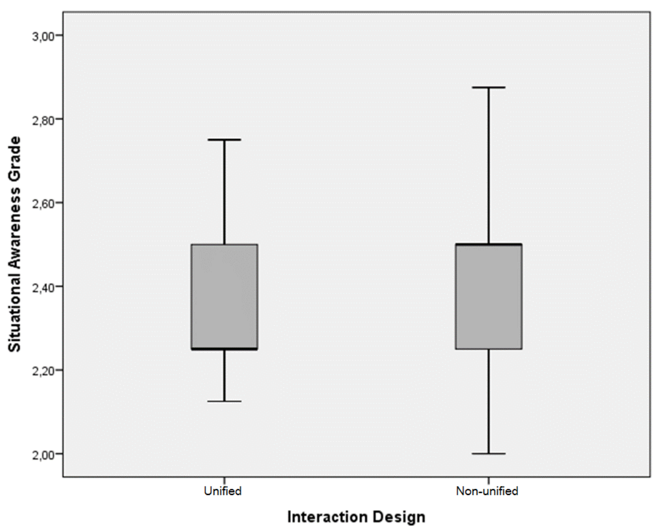

Figure 6. Boxplot of the situational awareness grades distribution

that has a distance of 3 box lengths to the edge of their box. We assume that the outliers had serious difficulties to operate the applications. The second aspect of task performance, the quality of task completion, showed no difference at all. In both groups, we had two participants who deviated from the given scenario in one aspect by e.g. booking a room in the wrong hotel. We therefore only consider the task completion time for measuring task performance.

Effort expectancy: The test shows significant differences in the mean of all four dimensions of effort expectancy (see theoretical background) between the UID (Mdn = 6.13) and the NUID (Mdn = 5.63), U = 158, z = -1.982, p = 0.047. So the participants in the NUID group recognized a decrease of the ease of use as they have rated it significantly lower than the participants in the UID group (see Figure 5).

Situational awareness: In order to measure situational awareness, the participants had to answer several questions about the characteristics of the hotel they had booked or the restaurant where they freely chose to book a table. The answers to the questions were graded and we examined the mean grade of all questions. There were no outliers in the boxplot of the mean grades (see Figure 6), the Q-Q plot showed a normal distribution and Levene's test for equality of variances showed the homogeneity of variances for the mean grades (p = 0.657). Therefore, we applied an independent samples t-test. The t-test did not show a significant difference between the UID (M = 2.39, SD = 0.200) and the NUID (M = 2.43, SD = 0.195); t(42) = -0.667, p = 0.508 . Both groups showed good results regarding situational awareness as the grade 3 was the best possible grade if every answer was answered correctly.

C. Result discussion

Our proposed hypotheses about the effect caused by a NUID in the automotive domain, were derived from the fields of situational awareness, marketing and previous studies of driver's distraction and cognitive ergonomics. We could confirm our first hypothesis. Indeed, a NUID leads to a significantly higher effort expectancy perceived by drivers. Contrary to that, we could not confirm H2 and H3. There was neither a significant difference in driving performance nor in situational awareness detected by the applied statistical tests. H4 however was confirmed. The task performance is reduced by a NUID. Although there was no difference in task quality, the second measure of task performance the time to complete the tasks was measured to be significantly longer. According to Burns et al. [25], task completion time is only an indirect measure that does not have an impact on driver's safety. Literature is consistent that the cognitive capacity of humans is limited [35]. When humans perform multiple tasks simultaneously, these tasks are in competition to each other for the limited resource of cognitive capacity. Based on Besnard and Cacitti [3], we notice that humans allocate that resource according to their respective goals. Based on our results, we claim that performing a task with a NUID causes not only more effort but also a different cognitive load for the participants. Complexity is an acknowledged increase factor for cognitive capacity [20]. Hence, we conclude a NUID that leads to a higher number of user interactions for successful selection of bookings or categories. This not only enhances complexity but also cognitive load. This conclusion is also in agreement to Bensard and Cacitty [3] who report the changing interface design increases the cognitive resources needed for operating a task. Our observations of the effect of an additive task cognitive load increase are in harmony with previous research and suggest that drivers allocate their existing limited cognitive capacity proactively according to their goals [3]. We found no evidence that drivers change the allocation of cognitive resources for driving and situational awareness while driving, if the task complexity of the additive task is increased. Our results rather show that drivers start to multiplex the additive task. Based on the assumption of a limited cognitive capacity, we conclude that this is the only option for drivers to carry

 ISBN: 978-1-61208-250-9

out the task without enhanced failure rate or a performance decrease in driving or situational awareness. Moreover, we assume a connection between cognitive load intensification and task completion time in a multi-task situation where the additive task has a low priority for the user as shown in Figure 4. We emphasize that this correlation is only appliciable for additive low priority tasks. In safety critical evironments where multi-tasking is necessary, the allocation decision of the user may not be possible as presented [3]. Results observing from other authors like Ma and Kaber [36] which study the effect of increasing conversations complexity while driving reveal opposing results. However, we argue that a driver needs to answer his conversation partner. That is why a conversational task while driving cannot be easily multiplexed. This assumption is also in accordance with previous results. According to Broadbent [37] and Salvucci et al. [17], the concept of multi-tasking is always carried out by a series of temporal multiplexing. People are multiplexing when they are "sequentially allocating the available attention on a task" [17]. Our results indicate that the time slots allocated for situational awareness, driving and accomplishing tasks remain the same as the respective goals of the participants do not change [3]. Thus, the attention that is left to allocate for the tasks remain the same, users need more time when the task is more complex. The presented discussion shows that although our results may surprise, they can be integrated very well in the previous research and complement it with new insights. However, there are some limitations to our study. First, we examined the effect of ignoring standard and conformity only on one example: the UID. Although this is an outstandingly important example [11], there are different manipulations possible whose effects could be completely different in the automotive domain. Second, we provided a sound research design to achieve the presented expected results. The two treatments presented were demonstrated to cause significantly different effort expectancy. Although effort expectancy is an empirically tested construct that is widely acknowledged measure, it is not a measurement instrument to measure cognitive load. An experimental design also has a severe drawback. Building an artificial environment like proposed does not reflect the real world. Especially, events while driving are difficult to simulate due to many unpredictable factors. Therefore, the external validity of our experiment design is only partly fulfilled [38]. Furthermore, although the LCT is an ISO standard [31], it only simulates driving to a certain degree. For this experiment, we propose a speed of 40 km/h. Thereby, we were simulating the average speed of driving in a city like Munich [34]. Due to this fact, the results may not be generalized for other driving situations. At last, this study is limited by a gender bias as we recruited more male than female students. According to Petzold et al. [39] the comparison of simulator studies shows a difference between driving and task performance regarding the gender.

V. Conclusion and Future Work

We investigated the effect of a NUID of in-car applications on drivers. As driving solely can be considered as multitasking [18] since the driver must not only drive, but also realize and comprehend the situation around him, we measured the driving performance as well as the situational awareness. Besides, the task performance was measured to cover also this factor of cognitive capacity consumer. Surprisingly, we could not find a significant effect on driver's performance and situational awareness. Only the task performance decreased. Although, the task failure rate showed no significant effect between the groups, task completion time of the drivers increased significantly. According to Burns et al. [25], task completion time is only an indirect measure that does not have an impact on driver's safety.

The proposed results also contribute to literature. Although situational awareness and cognitive capacity are seen as important concepts for understanding driving performance, they are not well understood [35], [36]. There are key gaps in literature as researchers still wonder what compromises situational awareness while driving [35]. Although, this research does not provide factors compromising situational awareness, it shows that an IT system that can be suspended and respectively can be operated slower have not a significant negative factor on drivers. Moreover, it indicates that there is a correlation between task complexity and therefore cognitive demand and task completion time for additive tasks in the automotive domain.

Our results also have a practical value. We could not find evidence of an endangering of a NUID. Consequently, this results leads in-car application designer to further test the topic. As the costs of ensuring UID are enormous, a lesson of some tests for usability could be a promising perspective. Besides, the experiment shows that the adoption of results from other domains is critical and some guidelines for design should be tested again in this domain.

Finally, we suggest two further research directions. According to Endsley [12] and others [40] the cognitive load needed for operating a system can be reduced by experience and further enhance performance on the primary driving task. Repeating the experiment with participants that are trained to operate the in-car applications could provide further insights. Furthermore, the effect of predefined pauses when operating the system while driving, forcing more attention to the road should be investigated. As the allocation of attention for multiple tasks is a key sub-skill of situational awareness [26] new insights for road safety could be detected.

References

[1] V. Venkatesh, M. G. Morris, G. B. Davis, and F. D. Davis, "User acceptance of information technology: Toward a unified view," *MIS Quarterly*, vol. 27, no. 3, pp. 425–478, 2003.

[2] J. Nielsen, L. A. Blatt, J. Bradford, and P. Brooks, "Usability inspection methods," p. 2, 1994.

[3] D. Besnard and L. Cacitti, "Interface changes causing accidents. an empirical study of negative transfer," *Human-Computer Studies*, vol. 62, p. 20, 2005.

[4] K. Ehrlich and J. Rohn, "Cost justification of usability engineering: A vendor's perspective," pp. 73–110, 1994.
[5] C. Harvey, N. A. Stanton, C. A. Pickering, M. McDonald, and P. Zheng, "A usability evaluation toolkit for in-vehicle information systems (iviss)," *Applied ergonomics*, vol. 42, no. 4, p. 12, 2011.
[6] F. Alt, D. Kern, F. Schulte, B. Pfleging, A. S. Shirazi, and A. Schmidt, "Enabling micro-entertainment in vehicles based on context information," p. 8, 2010.
[7] D. Basacik, N. Reed, and R. Robbins, "Smartphone use while driving - a simulator study," Transport Research Laboratory, Tech. Rep., 2012.
[8] Mercer, "Future automotive lndustry structure (fast) 2015," Heinrich Druck + Medien, Tech. Rep., 2004.
[9] R. Reichwald, H. Krcmar, and S. Reindl, *Mobile Dienste im Auto der Zukunft Konzeption, Entwicklung, Pilotierung*. Lohmar-Köln: Reichwald, R., Krcmar, H., Reindl, S., 2007.
[10] A. Zauner, H. Hoffmann, J. M. Leimeister, and H. Krcmar, *Automotive Software and Service Engineering (ASSE) - an exploration of challenges and trends in an industry experts' view*. Norderstedt: Books on Demand, 2010, pp. 61–74.
[11] J. Nielsen, *Usability engineering*, 1st ed. Boston: Academic Press, 1993.
[12] M. R. Endsley, B. Bolté, and D. G. Jones, *Designing for Situation Awareness: An Approach to User-Centered Design*. New York: Taylor & Francis Inc., 2003.
[13] F. D. Davis, R. P. Bagozzi, and P. R. Warshaw, "User acceptance of computer technology: A comparison of two theoretical models," *Management Science*, vol. 35, no. 8, pp. 982–1003, 1989.
[14] V. Venkatesh, V. Ramesh, and A. P. Massey, "Understanding usability in mobile commerce," *Communications of the ACM - Mobile computing opportunities and challenges*, vol. 46, no. 12, pp. 53–56, 2003.
[15] V. Venkatesh and V. Ramesh, "Web and wireless site usability: Understanding differences and modeling use," *MIS Quarterly*, vol. 30, no. 1, pp. 181–205, 2006.
[16] M. Williams, N. Rana, Y. Dwivedi, and B. Lal, "Is utaut really used or just cited for the sake of it? a systematic review of citation of utaut's originating article," pp. 1–13, 2011.
[17] D. Salvucci, E. Boer, and A. Liu, "Toward an integrated model of driver behavior in cognitive architecture," *Transportation Research Record*, vol. 1779, no. 1, p. 7, 2001.
[18] A. Sethumadhavan, "In-vehicle technologies and driver distraction," *Ergonomics in Design: The Quarterly of Human Factors Applications*, vol. 19, no. 4, p. 3, 2011.
[19] M. Baumann, T. Petzoldt, C. Groenewoud, J. Hogema, and J. Krems, "The effect of cognitive tasks on predicting events in traffic," p. 11, 2008.
[20] K. Young, M. Regan, and M. Hammer, "Driver distraction: A review of the literature," Monash University Accident Research Centre, Tech. Rep., 2003.
[21] J. R. Treat, *A Study of Precrash Factors Involved in Traffic Accidents*. Ann Arbor, MI: University of Michigan Highway Safety Research Institute, 1980.
[22] J. D. Lee, B. Caven, S. Haake, and T. L. Brown, "Speech-based interaction with in-vehicle computers: The effect of speech-based e-mail on drivers' attention to the roadway," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 43, no. 4, pp. 631–640, 2001.
[23] N. Gkikas and J. Richardson, "Behaviour & information technology the impact of verbal interaction on driver lateral control : an experimental assessment," *Behaviour & Information Technology*, vol. 31, no. 6, p. 12, 2012.
[24] A. Barón and P. Green, "Safety and usability of speech interfaces for in-vehicle tasks while driving," University of Michigan, Transportation Research Institute, Tech. Rep., 2006.
[25] P. C. Burns, P. L. Trbovich, T. McCurdie, and J. L. Harbluk, "Measuring distraction: Task duration and the lane-change test (lct)," p. 3, 2005.
[26] L. L. Gugerty, *Situation awareness in driving*. Boca Raton, FL: CRC Press, 2011, ch. 26, p. 25.
[27] M. R. Endsley, *Theoretical underpinnings of situation awareness: A critical review*. Mahwah, NJ, USA: Lawrence Erlbaum Associates, 2000, pp. 1–24.
[28] M. Endsley, "Design and evaluation for situation awareness enhancement," in *Human Factors Society Annual Meeting*. Human Factors Society, 1988, pp. 97–101.
[29] C. Bolstad, A. Costello, and M. Endsley, "Bad situation awareness designs: what went wrong and why," in *Proceedings of the 16th international ergonomics association world congress*. Elsevier Science, 2006.
[30] K. Bengler, M. Herrler, and H. Künzner, "Usability engineering accompanying the development of idrive," *Informationstechnik und Technische Informatik*, vol. 44, no. 3, pp. 145–152, 2002.
[31] S. Mattes and A. Heallén, *Surrogate distraction measurement techniques: The lane change test*. Florida: CRC Press, 2009.
[32] J. L. Harbluk, J. S. Mitroi, and P. C. Burns, "Three navigation systems with three tasks: Using the lane-change test (lct) to assess distraction demand," pp. 24–30, 2009.
[33] M.-P. Bruyas, C. Brusque, H. Tattegrain, A. Auriault, I. Aillerie, and M. Duraz, "Consistency and sensitivity of lane change test according to driving simulator characteristics," *IEET Intelligent Transport Systems*, vol. 2, no. 4, p. 306–314, 2008.
[34] P. Olson and K. Nolan, "Europe's most congested cities," 2008.
[35] P. M. Salmon, N. A. Stanton, and K. Young, "Situation awareness on the road: review, theoretical and methodological issues, and future directions," *Theoretical Issues in Ergonomics Science*, vol. 13, no. 4, p. 22, 2012.
[36] R. Ma and D. B. Kaber, "Situation awareness and workload in driving while using adaptive cruise control and a cell phone," *International Journal of Industrial Ergonomics*, vol. 35, pp. 939–953, 2005.
[37] D. E. Broadbent, *Perception and communication*. London: Pergamon Press, 1958.
[38] L. Nilsson, *Contributions and limitations of simulator studies to driver behavior research*. London, Washington DC: Taylor & Francis, 1993, ch. 401-407.
[39] T. Petzoldt, N. Baer, and J. Krems, "Gender effects on lane change test (lct) performance," pp. 90–96, 2009.
[40] K. S. O'Brien and D. O'Hare, "Situational awareness ability and cognitive skills training in a complex real-world task," *Ergonomics*, vol. 50, no. 7, p. 27, 2007.