Effects of driving scenario on subjective workload and secondary task performance

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Abstract

Facing the digital revolution, new and extended functions will be available both on the smartphones and in in-vehicle information systems. To investigate the interaction effects of driving scenarios and the modality of a secondary task, a fixed-base simulator study was conducted (*N* = 42). Driving scenarios differed in perceived willingness to engage in a secondary task. Modalities of secondary task were visual-manual, Surrogate Reference Task, and cognitive-auditory, n-back task, both in three levels of difficulty versus no secondary task. Subjective workload was found to significantly differ between driving scenarios and the secondary task modalities. Meeting the predictions, scenarios subjectively eliciting a lower subjective engagement willingness were perceived higher in workload. Moderate task difficulty provoked the highest subjective workload in the driving scenario of a low perceived engagement willingness. Reaction time for the visual-manual task was highest in the driving scenario with the highest subjective workload. Ratio of hits, independent of difficulty, yielded no significant effect between the driving scenarios, indicating compensatory behaviour.

Introduction

As technology increases throughout our daily lives, we are faced with new chances and challenges, also as car drivers. Extended availability and functionality of in-vehicle information systems (IVIS) and driver assistance systems in addition to mobile device functions tempt the driver into distraction from the primary driving task. European drivers were found to engage in secondary tasks for 10.2% of the driving time, mostly in using their mobile phones (Carsten et al., 2017). It was found that 22% of all secondary tasks performed were texting, representing the third most obtained secondary task. Naturalistic Driving Studies both in Europe and the USA revealed that drivers' engagement in non-driving related tasks differed between driving situations and manoeuvres (Carsten et al., 2017; Dingus et al., 2016; Huemer & Vollrath, 2017). Regarding the demand of the driving environment, medium, e.g. reading, and difficult tasks, e.g. engaging in the phone, were more likely to be executed in demanding situations and also longer in duration (Carsten et al., 2017). Engagement in secondary task was most likely on urban roads and country motorways, but little on country roads. Huemer and Vollrath (2017) and Ferreira et

In D. de Waard, K. Brookhuis, D. Coelho, S. Fairclough, D. Manzey, A. Naumann, L. Onnasch, S. Röttger, A. Toffetti, and R. Wiczorek (Eds.) (2019). Proceedings of the Human Factors and Ergonomics Society Europe Chapter 2018 Annual Conference. ISSN 2333-4959 (online). Available from http://hfes-europe.org

al. (2012) found drivers to rather engage in their smartphones on highways than in cities. Further, modality of the executed secondary task influences the probability of a crash. Whereas hand-held mobile phone usage (visual-manual) increased the crash risk by an odds ratio of 3.6 (Dingus et al., 2016), speaking on the phone or with a passenger (cognitive-auditory) did not have a negative effect on crash risk and was even found to decrease the crash risk's odds ratio to below 1.0, indicating a protective effect (NHTSA, 2012; Young, 2018). According to the Multiple Resource Theory (Wickens, 2003), the primary task of driving demands visual-manual resources, hence, simultaneously executing tasks demanding the same resources decreases performance in both tasks. As a visual-manual task, driving interferes negatively with additional visual-manual tasks, such as texting or dialling, leading to poorer driving behaviour (e.g. Reimer, 2009; Tsimhoni et al., 2004, Wandtner et al., 2016) and an increase of crash risk (Dingus et al., 2016; Fitch et al., 2013). Tasks of a different modality, e.g. talking to a passenger as of cognitive-auditory modality, do not directly interfere with driving and can therefore better be executed simultaneously. A less varying lateral and longitudinal vehicle control was found for the parallel execution of cognitive-auditory tasks (e.g. Engström et al., 2005). In comparison to no secondary task, Young (2015) found visual-manual secondary tasks to increase reaction times up to 450 ms and cognitive-auditory tasks up to 200 ms.

Task Demands and Drivers' Capability

If task demands, evoked by both primary and secondary driving tasks, exceed the driver's capability, a loss of control can occur and potentially result in a crash (Fuller, 2000, 2005, Figure 1).

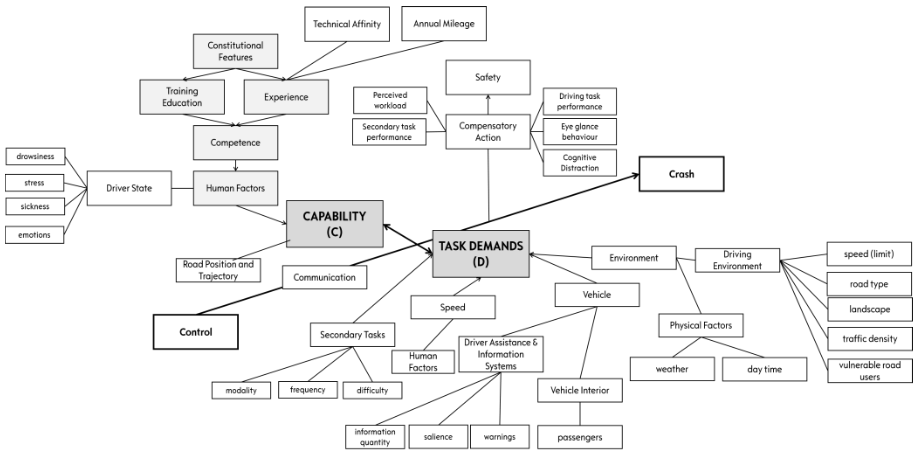


Figure 1. Task Capability Interface Model (modified and extended based on Fuller, 2000, 2005).

According to the task capability interface model (Fuller, 2000, 2005), driving task performance is determined by the driver's road position, trajectory and speed. In case there is an incongruence of the *driver's capability* and the *task demands*, a crash can be the consequence. The *driver's capability* is determined by biological characteristics, e.g. information processing speed and capacity, physical constraints, and acquired characteristics, such as knowledge and skills (Fuller, 2005). These factors are vulnerable, as by the driver's state. Drowsiness, stress, sickness and emotions are only some factors affecting the driver's capability. *Task demands* in the driving task emerge from the environment, the vehicle and the speed. Bad road conditions and driving in bad weather possess further demand on the driver. Regarding the vehicle, the status of driver assistance and information systems as well as factors inside the vehicle, such as passengers, play a role. Active driver assistance systems can hereby lower the task demand by taking parts of the primary driving task over. As Fuller constituted, speed is a determining factor, restricted by a speed limit, traffic conditions and other road users as well as the driver. Since the driving task is self-paced, speed plays a crucial role as being controllable by the driver. As an extension of Fuller's model, secondary tasks add to the driving task demands depending on their modality, frequency of execution and difficulty. As previously mentioned, secondary tasks interfering with the primary driving task lead to a loss in task and driving task performance. Under high task demands performance both in the driving and secondary task suffer (Engström et al., 2005; Young, 2015). Even if the task demands exceed the driver's capability, a crash can still be avoided by compensatory behaviour by the driver or other road users. On the driving task side that can be adapting speed, road position and trajectory.

Driving scenario × Secondary tasks

In order to drive safely, drivers adopt their driving behaviour as a response to the circumstances the driving task invokes; they self-regulate their behaviour (Wandtner et al., 2016, Young et al., 2008). Given the opportunity, drivers chose to execute a secondary task in less demanding driving situations and showed better lateral and longitudinal vehicle control than drivers not being given the opportunity to decide themselves (Wandtner et al., 2016). The probability to self-regulate is influenced by some biological characteristics, such as age and gender. Older drivers were found to avoid driving under difficult circumstances as in bad weather, high traffic density or poor road-surface conditions (Charlton et al., 2006, Hakamies-Blomqvist, 1994, Stalvey & Owsley, 2003). Gwyther and Holland (2012) also identified an influence of age on self-regulating behaviour when controlled for driving experience, that is younger and older drivers rather reported self-regulating behaviour. Further, women rather engaged in self-regulation than men.

Pre-Studies

A previous online survey (N = 384) investigated the drivers' perceived willingness to engage in a secondary task depending on both the task's modality and the driving scenario (Pätzold et al., 2018). Driving scenarios were defined by road type, landscape, traffic density, weather and day time. As secondary tasks, read a text message, type a text message, watch a video, talk on the phone hands-free, make a shopping list mentally and adjust music volume were to be rated. A choice-based conjoint analysis was used to assess participants' perceived willingness to engage in a secondary task. Across all tasks, road type and weather were identified as the two main factors influencing the perceived willingness. Participants assumed to rather decide against engaging in a secondary task on a city road, whereas it was most likely on country roads. Regarding the task modality, visual-manual tasks (e.g. read a message) and cognitive-auditory tasks (e.g. talk on the phone hands-free) differed in the degree of influence of the context factors. Road type was found to have the biggest impact, except for the cognitive-auditory task. For the cognitive-auditory task, weather influenced the decision the most. The percentage of participants assuming to engage in the secondary task in all driving scenarios can be found in table 1.

Table 1. Perceived willingness to engage in the secondary task in every driving scenario

secondary task	percentage of participants
read a text message	6.7 %
type a text message	2.5 %
watch a video	2.1 %
talk on the phone hands-free	58.1 %
making a shopping list mentally	32.0 %
adjust music volume	70.4 %

Based on the choice-based conjoint analysis, five scenarios were chosen for the current study and the perceived willingness to engage in a secondary task was calculated, shown in Figures 2 and 3.

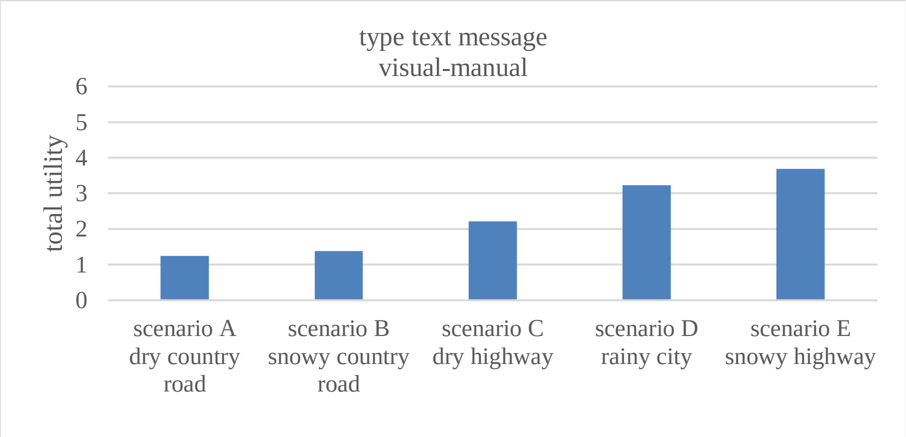


Figure 2. Perceived willingness to engage in typing a text message while driving. Note: A high total utility indicates a low perceived willingness to engage in the secondary task.

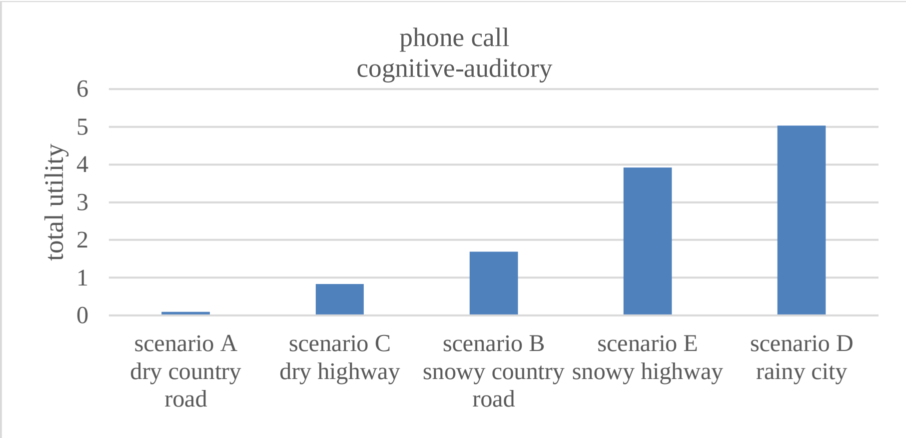


Figure 3. Perceived willingness to engage in making a phone call hands-free while driving.
Note: A high total utility indicates a low perceived willingness to engage in the secondary task.

Aim of the study

The current study investigated the effects of secondary task engagement in different driving scenarios on the subjective workload and the secondary task performance. It was of interest whether the previously assessed perceived willingness to engage in the secondary task is reflected in the subjective workload and secondary task performance. Based on these findings it was assumed, that:

> 1. The higher the perceived willingness to engage in the secondary task, the lower is the subjective workload.
> For visual-manual tasks, it is the lowest in scenario A (dry country road) and the highest in scenario E (snowy highway). For cognitive-auditory tasks, it is the lowest in scenario A and the highest in scenario D (rainy city).

and

> 2. The higher the perceived willingness to engage in the secondary task, the better is the secondary task performance.
> For the visual-manual task, it is best (lower reaction time, higher ratio of hits) in scenario A and worst in scenario E. For cognitive-auditory tasks, it is best (higher ratio of hits) in scenario A and worst in scenario D.

Method

Sample

A total of N = 42 (n = 11 females) took part in the fixed-base driving simulator study. Participants were recruited from Opel's internal participants pool, all being experienced in driving in a simulator. All participants held a valid driver's license, drove M = 22 000 km (SD = 13 000 km) per year, and were M = 42.7 years (SD = 9.1, Range = 24-59 years) old.

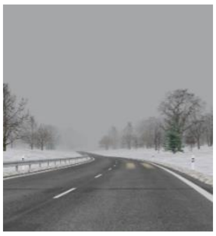
Driving simulator and driving scenarios

The driving simulator uses Silab 5.0 (WIVW, 2015) as simulation software. Three displays in front of the integrated Opel Insignia give a 180° view, one display in the back provides the back view and LCD displays are used as side mirrors (Figure 4).

Figure 4. Fixed-base driving simulator at Opel Automobile GmbH.

Five driving scenarios that differed in perceived engagement willingness were chosen (Pätzold et al., 2018). Screenshots of the scenarios from the driving simulator and their descriptions are shown in table 2.

Table 2. Driving scenario descriptions

scenario A	dry country road		• country road • dry weather • hills • moderate traffic density	• speed limit: 70 km/h • scenario length: 5.83 km
scenario B	snowy country road		• country road • snow, visible and invisible icy segments to simulate drifting • trees • no traffic	• speed limit: 70 km/h • scenario length: 5.83 km
scenario C	dry highway		• highway • dry weather • hills • high traffic density	• speed limit: 120 km/h • scenario length: 4.17 km
scenario D	rainy city		• city • rain • flat environment • moderate traffic density	• speed limit: 50 km/h • scenario length: 10.00 km
scenario E	snowy highway		• highway • snow, visible and invisible icy segments to simulate drifting* • flat environment • high traffic density * only on road leading to the highway	• speed limit: 120 km/h • scenario length: 4.17 km

Secondary tasks

In order to test different task modalities, the Surrogate Reference Task (SuRT, ISO14198, 2012) as a visual-manual, and the n-back task (Mehler et al., 2009, 2011) as a cognitive-auditory task were chosen.

The *SuRT* is a visual searching task, requiring participants to search for the biggest circle within 50 distractor circles (Figure 5). Here, participants were instructed to select the half of the display where the biggest circle appeared. The task was presented in three levels of difficulty, with a ratio of circle sizes of 150/80 as the easy, 150/100 as the moderate and 150/110 as the hard condition (Schwalm, 2009).

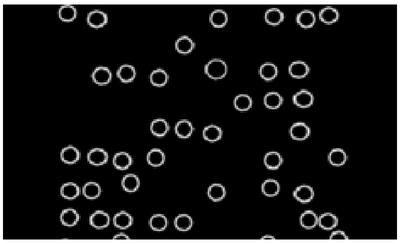


Figure 5. Surrogate Reference Task (SuRT, Petzoldt et al., 2014, p. 9).

The *n-back task* is a cognitive task, requiring participants to recall numbers from their short term memory. Following Mehler et al. (2009), participants were presented sequences of ten synthetically vocalized numbers ranging from 0 to 9 with 2.25 seconds pause in between the single numbers and 30 seconds between the sequences. A beep tone was played 2.5 seconds before the first number of a new sequence. The task was varied in three levels of difficulty, with 0-back as the easiest, 1-back as the moderate and 2-back as the hard condition. The easiest required participants to repeat the aforementioned number directly, which required a low level of cognitive attention. In the moderate condition, participants had to repeat the number that was presented before the current one, inducing a moderate load of cognitive attention by recalling an old and processing a new number in the short term memory. The hard required participants to repeat the number that was presented two values before the current one, provoking a high load on cognitive attention by recalling an old and encoding two new numbers in the short term memory.

Study Design

The order of conditions was balanced across the participants. The secondary tasks and their difficulty levels were randomly assigned to the driving scenarios. Participants were instructed that driving safely was the first priority, and that they shall maintain their position to the centre of the lane. They were asked to pay attention both to the driving and the secondary task. Within each scenario, the secondary task was executed for approximately five minutes while driving. Before each trial, the secondary task was practised for two times. After each scenario, participants were asked to fill in the questionnaire. In total, the study took 90 minutes.

Measures

Participants rated their subjective workload after each trial on the Driving Activity Load Index (DALI, Pauzié, 2008). The DALI measures workload on the subscales attention, visual load, auditory load, temporal load, interferences between the secondary and driving task and the perceived stress. As behavioural data, secondary task performance was measured. For the SuRT, the ratio of total number of hits in the total number of executed tasks (ratio of hits) and reaction times were assessed. The n-back task performance was measured as ratio of hits.

Results

Data was analysed using IBM SPSS statistics software (Version 22). The impact of the driving scenarios and the secondary task modality on subjective workload and secondary task performance was analysed with a repeated measures analysis of variance (rmANOVA). Further, the correlation of subjective workload and secondary task performance was analysed. The significance level for the analyses was defined as $\alpha = 0.05$.

Subjective Workload

A significant main effect for secondary task was found, $F(2, 74) = 107.85$, $p < .001$, $\eta_p^2 = .745$, Figure 6. Subjective workload was significantly higher when the SuRT, $p < .001$, or the n-back task, $p = .000$, were executed compared to no secondary task. Further, a significant main effect for driving scenarios was found, $F(4, 148) = 5.439$, $p < .001$, $\eta_p^2 = .128$. Overall, scenario D (rainy city), with a low willingness for both tasks, was rated significantly higher in workload than the other scenarios ($p < .032$).

Surrogate Reference Task

For the SuRT, a significant main effect for driving scenario was found, $F(4, 27) = 3.663$, $p = .017$, $\eta_p^2 = .352$. Both the scenarios with a high (B, snowy country) and moderate willingness (C, dry highway) were perceived significantly lower in subjective workload than the low willingness scenario (D). No significant main effect of task difficulty on the subjective workload was found, $F(2, 27) = 0.207$, $p = .815$, $\eta_p^2 = .015$. The interaction of driving scenario and task difficulty yielded a significant effect, $F(8, 27) = 3.293$, $p = .009$, $\eta_p^2 = .494$. For the easy task condition, the low willingness scenario (D) was rated higher in workload than the moderate willingness scenario (C). For the moderate task condition, the moderate willingness scenario (C) was higher in subjective workload than the high willingness scenario (B), and the low willingness scenario (D) was higher than the lowest willingness scenario (E, snowy highway).

n-back task

For the n-back task, a significant main effect for driving scenario was found, $F(4, 27) = 3.267$, $p = .026$, $\eta_p^2 = .326$. The scenario of the highest willingness (A, dry country road) was perceived significantly lower in workload than the scenario of the lowest willingness (D, $p = .019$). Further, task difficulty significantly influenced subjective workload, $F(2, 27) = 5.927$, $p = .007$, $\eta_p^2 = .305$. The hard condition was rated significantly higher in workload than the easy condition ($p = .006$). The interaction of driving scenario and task difficulty yielded no significant effect, $F(8, 27) = 1.812$, $p = .119$, $\eta_p^2 = .349$.

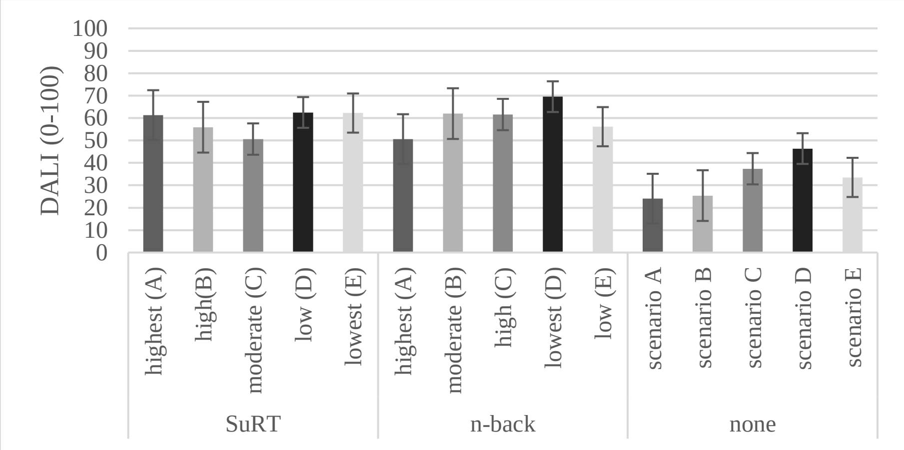


Figure 6. Subjective workload scores (DALI) for perceived willingness in driving scenarios and secondary tasks. Error bars reflect Standard Error.

Secondary task performance

Surrogate Reference Task

Reaction times differed significantly between the driving scenarios, $F(4, 35) = 11.459$, $p < .001$, $\eta_p^2 = .647$, Figure 7. In scenarios of a high (A, B) and low (E) willingness, reaction time was significantly shorter than under the lowest willingness (D, $p < .001$). No significant interaction effect with task difficulty, $F(2, 25) = 0.360$, $p = .701$, $\eta_p^2 = .028$, or driving scenario and task difficulty, $F(8, 25) = 0.940$, $p = .502$, $\eta_p^2 = .231$, was found.

The ratio of hits for the SuRT did not differ significantly between driving scenarios, $F(4, 25) = 1.424$, $p = .255$, $\eta_p^2 = .186$. Task difficulty had neither a significant effect on the ratio of hits for the SuRT, $F(2, 375) = 2.889$, $p = .068$, $\eta_p^2 = .135$, nor on the interaction with the driving scenario, $F(8, 25) = 2.038$, $p = .083$, $\eta_p^2 = .395$.

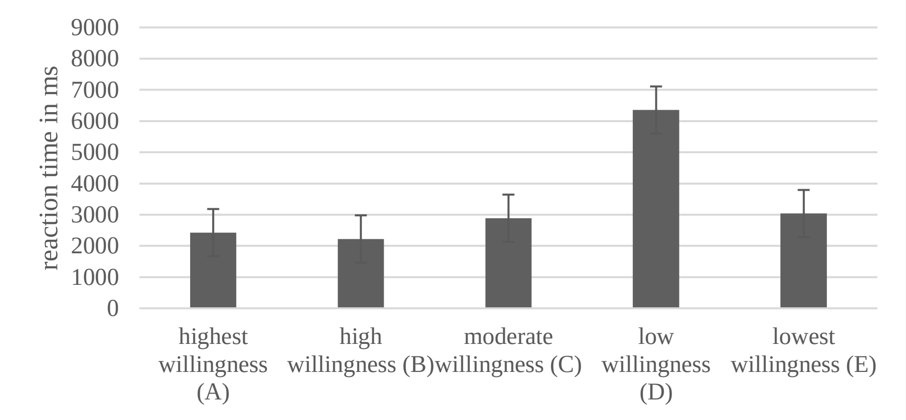


Figure 7. Reaction times for the SuRT. Error bars reflect Standard Error.

Relation with subjective workload

As shown in Figure 8, there is no clear indication of a relation between the ratio of hits, r = .043, or reaction time, r = -.122, and the subjective workload in the scenarios.

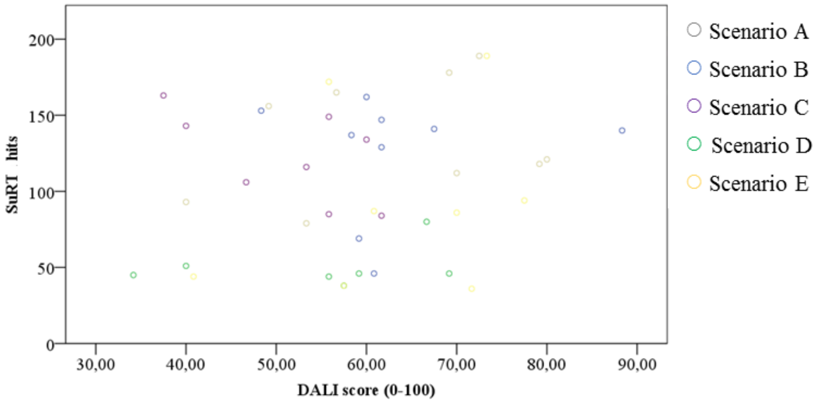


Figure 8. Relation of total number of hits and subjective workload scores (DALI).

n-back task

The ratio of hits revealed no significant effect of the driving scenario, $F(4, 27)$ = 0.728, p = .580, η_p^2 = .097. Task difficulty significantly influenced the ratio of hits, $F(2, 27)$ = 3.693, p = .038, η_p^2 = .215, but not the interaction with the driving scenario, $F(8, 27)$ = 0.402, p = .909, η_p^2 = .107. The ratio of hits was significantly lower for the hard difficulty (2-back) versus the easy (0-back) condition (p = .037).

Relation with subjective workload

No significant correlation of n-back ratio of hits, DALI score and driving scenario could be obtained, r = -.238, Figure 9.

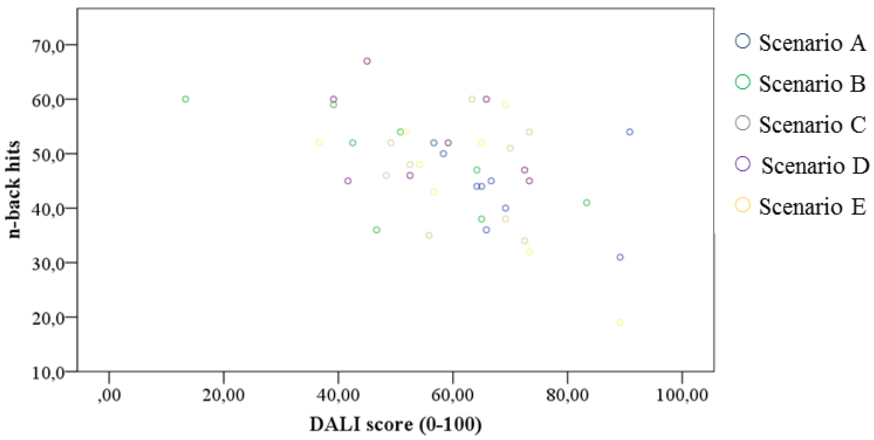


Figure 9. Relation of total number of hits and subjective workload scores (DALI).

Summary

Subjective Workload

The hypothesis that the willingness to engage in the secondary task perceived in the driving scenarios predicts the subjective workload cannot fully be accepted. For the visual-manual task, the hypothesis was only partly supported. Contrary to the hypothesis, the scenarios inducing the lowest (scenario E, snowy highway) and the highest perceived willingness (scenario A, dry country road) were rated equally high in subjective workload. Workload was perceived the highest in the scenario of low engagement willingness (scenario D, rainy city), and following the assumptions being significantly higher than in the scenarios of high (scenario B, dry highway) and moderate (scenario C, snowy country road) willingness. Supporting the hypothesis for the cognitive-auditory task, workload was rated the highest in the rainy city scenario (D) and the lowest in the dry country road scenario (A). The hypothesis, that the driving scenario dependent willingness determines the subjective workload for a cognitive-auditory task was supported. Drivers seem well capable of predicting their engagement willingness based on the workload they perceive within that driving scenario.

Secondary Task Performance

The hypothesis that secondary task performance depends on the perceived engagement willingness in that driving scenario was only partly supported. Ratio of hits for both the visual-manual and the cognitive-auditory secondary task yielded no significant difference between driving scenarios. Reaction times for the SuRT yielded a significant effect between driving scenarios. Partly supporting the hypothesis, reaction times in the scenario of low engagement willingness (D, rainy city) were significantly higher than in the other scenarios. The results of ratio of hits for both the secondary-manual and cognitive-auditory task indicate compensatory behaviour. Drivers were able to sustain their secondary task performance regardless of the driving scenario's demand and secondary task difficulty.

Since the results on subjective workload and reaction times supported the assumptions made on the online survey results, it can be assumed that drivers are capable of predicting their willingness on engaging in a secondary task.

Limitations and further research

There are some limitations to this study. First, it is important for the interpretation and comparison of secondary tasks that the possibility of self-regulation differed between the two tasks. Whereas the execution of the SuRT was self-paced by the drivers, the n-back task was system-paced. In real life, some cognitive-auditory secondary tasks can be controlled, e.g. by pausing before replying to the interlocutor or suppressing the conversation. Therefore, the results for the n-back task can only be transferred within limits to other cognitive-auditory task. The same accounts for the SuRT, since it was a low-involving visual-manual task, it cannot be applied unrestrictedly to a visual-manual task of high involvement, such as typing a text message.

Second, participants were instructed to execute the secondary task throughout the whole trial while prioritising the primary driving task. This way, extreme behavioural adaptations could be obtained, but further limited self-regulation. Thereby, it was not possible to measure the participants' strategy and engagement in secondary task execution under real-world conditions (Young, 2018).

Third, due to differences in subjective workload but the sustained secondary task performance, effects of the driving scenario and secondary task performance on driving and gaze behaviour should be further investigated.

Fourth, the relationship between the online study results and the current simulator study and its reliability should be investigated. Therefore, the assessed utility values should be investigated as predictive factors for both the subjective and behavioural data.

Conclusion and recommendations

In order to be able to make an appropriate comparison, subjective workload for the secondary tasks was compared to the no-secondary-task-condition (Young, 2018). It was shown, that drivers seem to adopt to the driving scenario. Supporting the Multiple Resource Theory (Wickens, 2008), the cognitive-auditory task lead to less subjective workload than the visual-manual task in some driving scenarios, whereas in others, the visual-manual secondary task lead to less subjective workload. Due to the different effects of task modalities on subjective workload depending on the driving scenario, an IVIS should consider the task-and-scenario-varying workload. Since drivers adopt their driving behaviour in order to avoid a collision when task demands exceed his or her capability (Fuller, 2000, 2005), that compensatory behaviour shall be supported. In case of an overload by a visual demanding driving scenario and an interfering visual demanding IVIS task, the task modality can either be changed or the information within the IVIS can be adapted in quantity and position based on the relevance of the information for the driving scenario. Further research is needed to investigate the potential of adapting IVIS concepts.

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