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Effectiveness and user acceptance of infotainment-lockouts: A driving simulator study

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ABSTRACT

Lockout is a system-initiated distraction mitigation strategy that renders certain features of in-vehicle information systems (IVISs) non operable while the vehicle is in motion. The aim of this driving simulator study was to examine the influence of lockouts on driving performance and user acceptance. Overall, 52 participants performed six tasks with fully unlocked, partially locked, and completely locked IVIS. Within a repeated-measures design, we assessed user acceptance. As participants were free to decide where to conduct a secondary task, we could only analyse driving performance of 26 drivers. After each driving section, the participants rated the respective system with respect to acceptance. Driving performance with regard to lateral control was better when the system employed partial or complete lockouts as compared to the unlocked system. In contrast, longitudinal control did not benefit from a lockout. User acceptance decreased with an increasing number of disabled system functions while driving. Thus, lockout as a distraction mitigation strategy comes at the price of reduced user acceptance. To improve acceptance, one could attempt to make the secondary tasks less attractive (e.g., by public campaigns) rather than prohibit them through lockout. In addition, human-machine interfaces in the vehicle could be improved in order to reduce their demands on attentional resources.

1. Introduction

In recent years, the number and variety of functionalities provided by in-vehicle information and infotainment systems (IVISs) (Harvey & Stanton, 2013) has increased dramatically. Lansdown (2012) reported that 81 percent of drivers use in-car entertainment systems on a daily basis. On the one hand, these devices offer the potential to improve comfort, efficacy, and safety while driving (Vollrath & Krems, 2011; Wierwille, 1993). On the other hand, driver distraction resulting from these technologies represents an important threat to driving safety (Dingus et al., 2016; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). Consequently, there is growing public concern and interest regarding strategies that mitigate driver distraction associated with IVISs (Alliance of Automobile Manufacturers, 2006; Burnett, Summerskill, & Porter, 2004; Engström & Victor, 2009; European Commission, 2014; National Highway Traffic Safety Administration, 2013). To date, little research has focused on distraction mitigation strategies, such as a *lockout*. A lockout means disabling functionalities such as those of an

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IVIS to prevent visual, manual, and cognitive distraction during times when drivers need their attention to conduct the primary task of driving (Donmez, Boyle, & Lee, 2003; National Highway Traffic Safety Administration, 2013). A lockout of functionalities could be defined in advance, or it could be based on the traffic situation, or on the drivers' previous behaviour (Donmez, Boyle, & Lee, 2006; Donmez, Boyle, Lee, & McGehee, 2006; National Highway Traffic Safety Administration, 2013; U.S. Patent No. 7,463,961 B2, 2005).

For the current driving simulator study, we have chosen three pre-defined lockouts applied to the same IVIS. The objective of this experiment was to assess the effects of lockout severity on driving performance and user acceptance.

1.1. Distraction mitigation strategies

The complex task of driving can be described with respect to the primary tasks such as lane keeping, speed regulation, and traffic awareness (Regan, Young, & Lee, 2009; Vollrath & Krems, 2011). Sometimes, subtasks of the primary task are clustered into three or four main tasks, such as navigating or steering the vehicle (Donges, 1982; Hollnagel & Woods, 2005; Johannsen, 1977; Michon, 1985). With respect to secondary tasks, a large body of evidence suggests that they interfere with the primary task of driving. Distracted drivers have difficulties maintaining their speed (e.g., Horberry, Anderson, Regan, Triggs, & Brown, 2006; Lansdown, Brook-Carter, & Kersloot, 2004; Rakauskas, Gugerty, & Ward, 2004) and controlling their cars' lateral position (e.g., Anttila & Luoma, 2005; Engström, Johansson, & Östlund, 2005; Horrey, Lesch, & Garabet, 2008; Jamson & Merat, 2005). At the same time, drivers underestimate their crash risk (DeJoy, 1989; McKenna, Stanier, & Lewis, 1991; Svenson, 1981; Wogalter & Mayhorn, 2005). Several solution approaches aim to reduce the detrimental effects of secondary tasks on driving performance (Donmez et al., 2003; Engström & Victor, 2009). In their taxonomy of mitigation strategies, Donmez et al. (2003) distinguished system-based and driver-initiated methods that either aim to support driving-related tasks or to reduce secondary tasks that are not driving-related. The operation of an IVIS is an example of a secondary task. Fig. 1 illustrates the system-based distraction mitigation methods that refer to secondary tasks. The strategy *advising* can also be categorised as *realtime mitigation* (Engström & Victor, 2009) and incorporates feedback for the driver about his/her involvement in secondary tasks (Donmez et al., 2003). Other methods (e.g., *prioritizing/filtering* and *locking*) can be considered as *real-time prevention* (Engström & Victor, 2009). Through prioritization or filtering, a system could allow certain system interactions or functionalities only in non-complex driving situations (e.g., an incoming telephone call, Donmez et al., 2003).

Previous research showed positive effects of the advising-strategy (Donmez, Boyle, & Lee, 2007, 2008). Visual feedback based on participants' glance duration decreased their frequency of glances towards the IVIS, however, their driving performance did not improve (Donmez et al., 2007). A combination of retrospective and concurrent as well as solely retrospective feedback, in contrast, also led to reduced accelerator release times (Donmez et al., 2008). Mere knowledge of an incoming telephone call, which was not explicitly expected during an experiment, might cause distraction (Holland & Rathod, 2013). Thus, a delayed notification about a received call or e-mail could be an effective example for the prioritizing and filtering strategy to reduce workload (Donmez et al., 2003; Engström & Victor, 2009). To the best of our knowledge, besides the studies performed by Donmez' group, there is no published research that has examined lockout in general or its effect on driving performance.

Notwithstanding this lack of research, in the U.S., automobile manufacturers have put the lockout strategy into practice. Their implementations are based on activities around the Statement of Principles formulated by the Alliance of Automobile Manufacturers (2006). Broadly speaking, when performing a task with an IVIS while driving, a single glance towards the IVIS-display should not exceed the duration of two seconds. At the same time, the total eyes-off-road time required to complete the whole task should not last longer than 20 s. Tasks that did not meet these criteria in standardized test procedures and system functions, like videos or automatically scrolling texts, are recommended to be unavailable as long as the vehicle is in motion. Previous research provided evidence for the positive effect of system-initiated lockouts of visual and auditory secondary tasks on driving performance (Donmez, Boyle, & Lee, 2006). This study took place in the U.S., thus, participants could have been familiar with a lockout strategy. Lockouts only occurred during certain traffic situations, such as a braking lead vehicle or a curve entry, rather than being lockouts of predefined functionalities. However, this study did not focus on typical IVIS tasks. Our study is among the first studies to investigate infotainment lockouts in general, and a lockout that roughly corresponds to the Alliance of Automobile Manufacturers' Statement of Principles (2006). Additionally, we aimed to examine drivers' initial contact with lockouts as distraction mitigation strategy. This object of investigation has practical implications as there is growing public concern with regard to driver distraction as traffic hazard in Europe. European drivers are still unfamiliar with this distraction mitigation strategy. Therefore, it seems highly likely that our European participants would encounter IVIS with locked functions for the first time either in their own car or in a friend's or rental car. There are several assumptions about how a lockout affects driver performance. Overall, we assume that deactivation of IVIS tasks while driving eliminates their potential detrimental effects on driving performance, as a lockout renders an IVIS glance ineffective. In contrast, a reduction of the positive effect of a lockout on driving performance might occur if drivers have to search for a possibility to stop their vehicle in order to accomplish their task. As discussed by Donmez, Boyle, and Lee (2006), the positive effects of lockouts on driving performance could also be counteracted as some drivers might vainly try to use a function of an IVIS that is locked out. In sum, we formulate the following hypothesis:

Driving performance in the lateral (a) and longitudinal (b) direction improves with an increased number of disabled IVIS functions while driving.

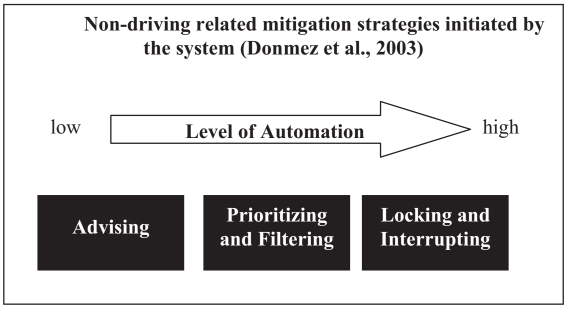

Fig. 1. Summary of system-initiated strategies to reduce distraction associated with secondary tasks.

1.2. User acceptance

Even if a lockout is able to improve driving performance, it can only be successfully implemented if user acceptance can be ensured (e.g., Regan, Stevens, & Horberry, 2014; Roberts, Ghazizadeh, & Lee, 2012). Previous research demonstrated the importance of acceptance for related areas such as seat belt reminders (Kidd, McCartt, & Oesch, 2014), congestion assistants (Brookhuis, Van Driel, Hof, Van Arem, & Hoedemaeker, 2009; Van Driel, Hoedemaeker, & Van Arem, 2007), or speed assistance systems (Zhao & Wu, 2013).

The present research uses the technology acceptance model (Davis, 1986; Davis, Bagozzi, & Warshaw, 1989) to evaluate user acceptance regarding the lockout strategy. The technology acceptance model is based on the theory of reasoned action. It involves a psychological model to predict behaviour (Fishbein & Ajzen, 1975). The technology acceptance model is a widely spread and empirically founded acceptance model (Ma & Liu, 2004; Schepers & Wetzels, 2007), which has already been used to explore and predict acceptance in the vehicle context (Chen & Chen, 2011; Larue, Rakotonirainy, Haworth, & Darvell, 2015; Meschtscherjakov, Wilfinger, Scherndl, & Tscheligi, 2009).

According to the technology acceptance model (Davis et al., 1989; Davis, 1986), the best predictor for *actual system use* is *behavioural intention to use*. As can be seen in Fig. 2, external variables (e.g., limited availability of IVIS functions) affect the main two determinants or beliefs of technology acceptance, *perceived usefulness* and *perceived ease of use.* Perceived usefulness refers to the user's perception of a system as being helpful when carrying out a task (Davis et al., 1989). Perceived ease of use, in contrast, is the expected amount of required effort to use the system (Davis et al., 1989). These two beliefs form the *attitude toward using,* which in turn predicts behavioural intention to use. The model further postulates a direct effect of behavioural intention on the system use. That is, behavioural intention predicts actual system use.

For exploratory reasons, Donmez, Boyle, Lee et al. (2006) carried out a focus group on acceptance of strategies to prevent distraction. Within this group, concerns were raised regarding highly automated distraction mitigation strategies such as a lockout. A driving simulator study that investigated driver attitudes towards a locking versus an advising strategy showed that drivers equally accepted the two distraction mitigation strategies at least in complex situations (Donmez, Boyle, Lee et al., 2006). Overall, user acceptance is expected to decrease, the more a system forces user behaviour (Van der Laan, Heino, & de Waard, 1997). If a lockout leads to functional impairments such that drivers feel restricted in the efficacy of their behaviour (Donmez, Boyle, & Lee, 2006), user acceptance might further decrease. This leads to our second hypothesis:

User acceptance decreases with increased number of disabled IVIS functions while driving.

2. Method

2.1. Participants

Overall, 53 employees of a car manufacturing company (Opel Automobile GmbH) participated in the study. One participant failed to follow instructions and stopped the (simulator) vehicle for every IVIS task. Upon inquiry at the end of the study, this participant admitted that he did not notice that we used three experimental conditions with some IVIS tasks that were available while driving. We excluded him from statistical analysis. The remaining 52 participants (15 female and 37 male) were between 22 and 57 years old ($M = 39.44$, $SD = 11.26$). On average, participants had held their driver's license for $M = 21.29$ years ($SD = 11.21$) and had covered a distance of $M = 19{,}657$ km per year ($SD = 12\ 030$). Participants indicated to have "no" to "little" prior knowledge about lockout ($M = 1.59$ on a 7-point Likert scale, $SD = 1.03$) at the end of the experiment. The propensity to use an IVIS while driving was rated as high ($M = 6.39$; $SD = 1.12$; 1 = *very unlikely*, 7 = *very likely*). Each participant had to complete at least one short simulator training to get used to the driving simulator beforehand. As the study took place during paid working hours, participants did not receive extra monetary compensation. The analysis of the driving data includes only data of $n = 26$ participants. We explain the reasons for the data loss and the insights gained despite these reductions in the results and in the discussion.

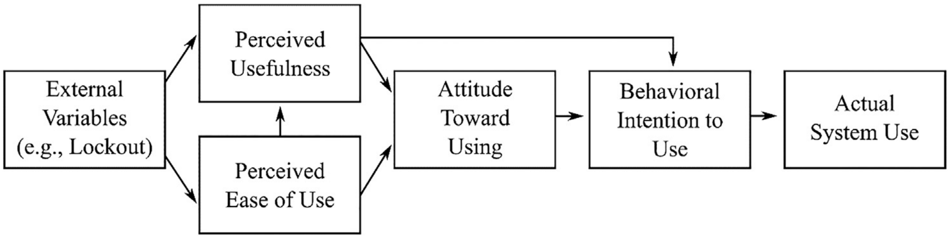

Fig. 2. Technology acceptance model. Adapted with permission. Copyright 2016 INFORMS. Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. Management Science 35 (8), 982–1003. https://doi.org//10.1287/mnsc.35.8.982, the Institute for Operations Research and the Management Sciences, 5521 Research Park Drive, Suite 200, Catonsville, Maryland 21228, USA.

2.2. Apparatus

We conducted the study in a fixed-based driving simulator (Opel Insignia, model year 2012) with simulated automatic transmission (Fig. 3). The simulator used three 70″ thin film transistor (TFT) screens providing a 130° frontal field of view. A complete rear-view was furnished by an additional 70″ TFT screen that was visible when looking into the rear-view mirror. Each 70″ TFT screen had a resolution of 1920 × 1080 pixels. Additionally, there were two simulated side mirrors with 7″ TFT screens and a resolution of 800 × 480 pixels. A 10″ TFT screen was located above the steering wheel and displayed the tachometer, the fuel level, the motor temperature, and the r.p.m. gauge. A 5-channel audio system broadcasted vehicle sounds, such as turn indicators. The traffic scenario was simulated by using the software SILAB 4 (Wuerzburg Institute for Traffic Sciences, 2013). It featured a country route with evenly distributed traffic and a speed limit of 70 km/h. Every two kilometers, there was one out of three different parking bays. Thirteen PCs were required for the simulation.

We used an 8″ Samsung tablet (model SM-T310) with Android operation system (version 4.4.2) for the IVIS-software simulation. This software was an English language test version not available on the market. We used semi-transparent bars on top of the relevant icons to mark disabled functions. If participants pushed the icon anyway, a pop-up window appeared for 3.5 s above the menu icons that indicated a deactivation of functionality while moving.

2.3. Design

We used a repeated-measures design with lockout condition as the independent factor with three levels: all tasks performed with the IVIS were operable while driving (no lockout), three out of six tasks were operable while driving (partial lockout), and one out of six tasks was operable while driving (complete lockout). The following tasks were available while driving during the no lockout condition: 1: "Tune the radio station "xy", please.", 2: "Switch off the air condition, please.", 3: "Please call "xy", who is already saved in your favourite list.", 4: "Adjust the driving mode, please.", 5: "On the center console, you can find a business card. Dial the number written on the business card, please.", and 6: "Navigate to the closest restaurant "xy", please" (name was indicated). In the partial lockout condition, task 1, 2, and 6 were available while driving, whereas in the complete lockout condition only task 2 was operable while the vehicle was in motion. The partial lockout condition roughly resembled the lockout implementation on the American market (Alliance of Automobile Manufacturers, 2006), whereas no IVIS lockouts are currently required in Germany. In the complete lockout condition, the IVIS inhibited every interaction between driver and IVIS while driving, with the exception of climate settings. To control for transition effects, we permutated the sequence of the three lockout conditions, leading to six possible sequences. Subjects were randomly distributed across these sequences (each sequence with 8–9 participants).

2.4. Procedure

Prior to the simulator drive, the experimenter asked the participant to follow traffic regulations. In addition, the experimenter explained that the driver should behave and conduct the secondary task as if being in a natural driving environment. Participants were told that the aim of the study was "to experience different kinds of IVISs". To give necessary instructions, the experimenter sat in the passenger seat during the entire experimental drive.

First, each participant completed a short familiarization ride that incorporated a baseline stretch during which we assessed drivers' performance without parallel task processing. At the end of this course, the experimenter asked the participant to head for the next parking bay where the experimenter explained the following test procedure. Besides, the participant conducted a first task with the IVIS to get used to the present system. Thus, participants knew that there were parking bays throughout the course. In order to make the scenario more realistic, the experimenter instructed the participants prior to each condition to imagine that they would have the present IVIS in their own vehicle and that they are on their way to an important appointment. Furthermore, the experimenter mentioned that both safe and fast driving was important and pointed out that there was a clock on the right side of the middle screen for temporal orientation.

Fig. 3. Static driving simulator of Opel Automobile GmbH. Source: Opel Automobile GmbH.

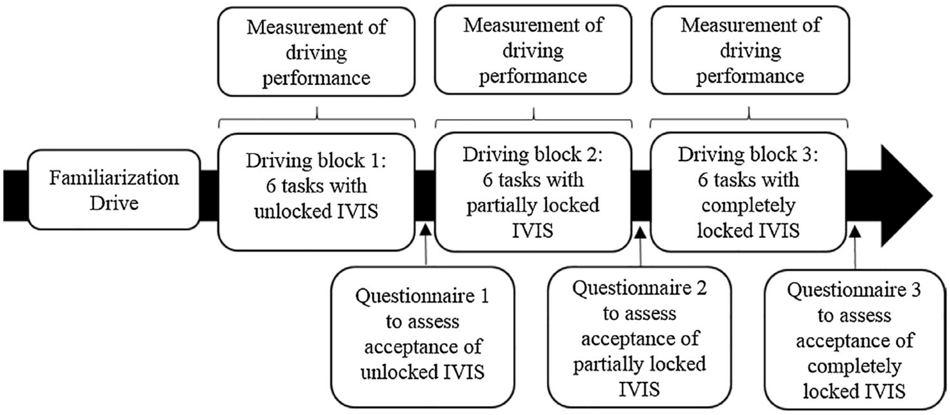

Fig. 4. Example of the test procedure.

Participants went through each of the three lockout conditions (Fig. 4). In each condition, participants had to perform six tasks with the IVIS. If a given function was locked out, they had to stop the vehicle. The aforementioned pop-up notification gave this information. Participants could decide themselves where and when they stopped the vehicle. We did not force them to drive to a parking bay if they decided to stop the vehicle on the shoulder or the road. If participants asked where to stop the vehicle, the experimenter said that they should act as if being in a natural environment. Thus, they had the choice between stopping immediately in a rather unusual place or losing some time because they had to head for a parking bay. Only within the familiarization ride and between the conditions, we explicitly instructed them to stop the vehicle in the parking bays that were regularly distributed along the course. For task processing of unlocked functions, participants could decide whether they would like to conduct the task while the vehicle was in motion or to stop the vehicle first.

In order to enable the extraction of the desired driving performance data sequences, an assistant of the experimenter was responsible for setting time stamps during the experimental drive. She marked the beginning of the task at the time of task instruction. For tasks that were operable while driving, she set the second time stamp after drivers had completed the tasks. In case of locked-out tasks, she set the second time stamp as soon as the parking bay was about to appear and before the drivers initiated braking, in order to avoid data distortion. Consequently, for the partially locked system, driving performance data are a conglomerate of the tasks that drivers were allowed to process while driving and an orientation phase that drivers passed through while they waited for an opportunity to pull over. In this phase, drivers realized that a specific task was not available while driving. For the completely locked system, parameters for driving performance comprised the orientation phase of five tasks and the conduction of task number 2 (air conditioning) while driving. The assistant further registered potential irregularities during the experiment that were important for correct data processing afterwards.

After each driving block, the experimenter instructed the participant to stop at the next parking bay in order to fill out a questionnaire about system acceptance. The simulator drive ended with a second baseline condition during which we assessed drivers' performance without using the IVIS in parallel.

We decided not to inform our participants about a lockout beforehand because in Europe, customers are unfamiliar with this method. Thus, participants should resemble typical customers who are confronted with an IVIS with locked functions for the first time either in their own car or in a friend's or rental car. It was also part of the study to observe drivers' reactions to the lockout in terms of when and where they stopped the vehicle after having read the pop-up notification. That is why we did not give any instructions concerning the place and point in time they should stop the vehicle to perform the locked-out tasks. Results might be different for customers who are familiar with lockouts due to an existing law or an awareness campaign.

2.5. Measures

2.5.1. Driving performance

We chose five indicators to measure driving performance, which have been shown to be particularly sensitive to distraction associated with secondary tasks (Young, Regan, & Lee, 2009). Steering wheel reversal rate (SWRR), the rate of lane infringements (LAN) and the standard deviation of lateral position (SDLP) were measures of lateral control, whereas the mean velocity (MV) and the standard deviation of velocity (SDV) represented measures of longitudinal control. To assess the SWRR, steering wheel movements of greater than three degrees were recorded (Markkula & Engström, 2006). Under non-distracted driving conditions, drivers only slightly correct their steering wheel movements. However, when distracted, drivers make larger corrections of their steering wheel movements typically exceeding 3° (Young et al., 2009). LAN measured how often drivers crossed the lane delimitations per minute of driving. With the SDLP, we calculated their deviations from the ideal mean position of the vehicle in the lane.

MV comprised drivers' average speed while driving and conducting secondary tasks, whereas we measured their standard deviation of velocity (speed variability) with SDV.

2.5.2. User acceptance

Our acceptance questionnaire was composed of four scales, based on the technology of acceptance model (Davis et al., 1989; Davis, 1986) and one additional item to measure global product evaluation (Minge & Riedel, 2013). We assessed perceived usefulness (three items; e.g., "Using this in-vehicle infotainment system enhances my effectiveness during the drive"; $\alpha = 0.76–0.79$) and perceived ease of use (four items; e.g.; "I find this in-vehicle infotainment system to be easy to use"; $\alpha = 0.76–0.84$) with items developed by Davis et al. (1989) and Venkatesh and Bala (2008). To measure behavioural intention (one item; "I would intend to use such an infotainment-system, if I had the chance to"), we referred to previous research (e.g., Venkatesh, Morris, Davis, & Davis, 2003). To assess attitude toward usage (two items; e.g., "Using the in-vehicle infotainment system is a wise idea"; $\alpha = 0.58–0.71$), we adapted items of Taylor and Todd (1995). All items were presented in German Language. Except for global product evaluation, we used a 7-point Likert scale ranging from 1 (*strongly disagree*) to 7 (*strongly agree*). For global evaluation, we used a Likert scale ranging from −5 (*very bad*) to +5 (*very* good) to be compatible with Minge and Riedel (2013) (one item; "Please indicate an overall rating for the infotainment system that you have used just now").

3. Results

We could only analyse driving data of 26 out of 52 participants due to stopping behaviour ($n = 23$) and technical reasons ($n = 3$; e.g., with the IVIS). Overall, 28 participants stopped at least once on the road immediately after the task instruction. Because participants stopped the vehicle on the road or the shoulder instead of driving to a parking bay, no driving data were measurable regarding the specific IVIS task. To maintain the originally aspired difference between our three lockout conditions, we decided to exclude the whole set of driving data of drivers who stopped on the road or on the shoulder instead of waiting for the next parking bay, either more than once in the lockout condition or in the partial lockout condition. This affected 23 out of the 28 aforementioned participants. Due to the reasons mentioned above, we also applied these exclusion criteria to participants with missing values based on technical failures. For the unlocked condition, we only used the data if at least four out of six tasks were available. With regard to the acceptance data, only a few values were missing because one or two participants overlooked items on the questionnaire. We report the acceptance data of the entire sample because the data still allowed us to make statements about participants' subjective rating of lockout configurations. Table 1 shows descriptive data for all variables.

3.1. Driving performance

We analysed the driving performance data (SWRR, LAN, SDLP, MV, SDV) via a mixed design 3 (lockout condition) × 6 (sequence) MANOVA with lockout condition as within-subject factor and sequence as between-subject factor and control variable.

Table 1
Descriptive statistics for all variables for each condition.

	No lockout		Partial lockout		Complete lockout	
	M	SD	M	SD	M	SD
Steering wheel reversal rate	28.36	12.01	24.71	10.82	19.53	6.31
Lane infringements	1.46	1.43	0.67	0.83	0.56	0.73
Standard deviation of lateral position	0.23	0.08	0.21	0.06	0.20	0.05
Mean velocity	74.68	4.25	73.43	4.02	74.90	4.28
Standard deviation of velocity	2.12	1.02	3.05	1.67	3.39	1.07
Perceived usefulness	4.60	1.11	3.74	1.29	3.01	1.45
Perceived ease of use	5.18	0.97	4.65	1.29	4.56	1.23
Behavioural intention to use	5.49	1.33	4.33	1.89	3.29	2.04
Attitude toward using	5.06	1.00	4.32	1.46	3.76	1.57
Global satisfaction	8.18	1.83	6.29	2.75	4.12	2.75

Note: Driving characteristics: $n = 26$. Acceptance: $n = 51–52$.

The more functions were locked out, the better in terms of improved driving performance. The MANOVA revealed that there was a positive and significant multivariate main effect of lockout condition on driving performance, Wilks' $\lambda = 0.13$, $F(10, 12) = 8.16$, $p = .001$, $\eta p^2 = 0.87$. There was no effect of sequence on driving performance, Wilks' $\lambda = 0.43$, $F(20, 57.33) = 0.83$, $p = .67$, $\eta p^2 = .19$,[1] nor was the interaction of lockout condition $\times$ sequence significant, Wilks' $\lambda = 0.04$, $F(40, 47.36) = 1.51$, $p = .09$, $\eta p^2 = 0.54$. Sphericity was given for each variable. Table 2 shows the univariate tests, whereas Fig. 5 illustrates means (M) and standard error of means (SEM). According to our hypothesis, we applied one-tailed post-hoc pairwise comparisons (Fisher's least significant differences test; $\alpha = 0.05$). With regard to driving performance in lateral direction, results show that SWRR scores in the completely locked condition were lower than in the unlocked and the partially locked condition. The SWRR scores were also lower in the partially locked than in the unlocked condition. The LAN was higher for the no lockout than for the partial and complete lockout condition. Furthermore, results revealed that the SDLP was higher in the unlocked than in the completely locked condition. In sum, these data indicate a positive effect of locking IVIS functions on driving performance with respect to lateral vehicle control.

With regard to the measurements of longitudinal control, the data show that participants drove significantly slower in the partially locked than in the unlocked and locked condition. Besides, the unlocked condition led to a smaller standard deviation of mean velocity than the partially and completely locked condition. Fig. 6 presents the corresponding means (M) and standard errors of mean (SEM).

3.2. User acceptance

With respect to user acceptance of the three different lockout variations, the experimental data were also analysed via a mixed-design MANOVA. Lockout condition (3 levels) served as a within-subject factor and sequence (6 levels) served as a between-subject and control factor. The dependent variables perceived usefulness, perceived ease of use, behavioural intention, attitude toward using, and global satisfaction were included in this analysis. The MANOVA showed a highly significant multivariate main effect of lockout condition on user acceptance, Wilks' $\lambda = 0.29$, $F(10, 34) = 8.26$, $p \leq .001$, $\eta p^2 = 0.71$. Participants did not appreciate the lockout. Furthermore, there was a marginally non-significant multivariate main effect of sequence on user acceptance, Wilks' $\lambda = 0.42$, $F(25, 146.38) = 1.55$, $p = .06$, $\eta p^2 = 0.16$, and a marginally non-significant interaction between lockout condition and sequence, Wilks' $\lambda = 0.19$, $F(50, 158.43) = 1.38$, $p = .07$, $\eta p^2 = 0.28$. Table 3 shows univariate effects of the factor lockout on perceived usefulness, perceived ease of use, attitude toward using, behavioural intention to use, and global satisfaction. Degrees of freedom were corrected according to Huynh-Feldt wherever sphericity was violated (Huynh & Feldt, 1976).

Fig. 7 shows corresponding means (M) and standard errors of mean (SEM) of the variables in the described analysis. Except for perceived ease of use, pairwise comparisons (Fisher's least significant difference) showed that the unlocked system received significantly higher scores than the partially locked and the completely locked system. The partially locked system, in turn, received better ratings than the completely locked system. Regarding perceived ease of use, the unlocked system was rated better than the partially and the completely locked systems. Here, participants rated the partially and the completely locked system as equal. As for the driving characteristics, we applied a one-tailed test for the pairwise comparisons ($\alpha = 0.05$).

4. Discussion

We sought to measure two things, firstly whether a lockout improves driving performance by preventing distraction, and secondly whether users are willing to accept lockout. The results confirm the suspicion that lockout improves driving per-

[1] Only a limited amount of participants was left for each sequence

Table 2
Results of univariate tests to compare the no lockout, partial lockout, and complete lockout condition with regard to driving performance.

	df1	*df2*	*F*	*P*	η_p^2
Steering wheel reversal rate					
Lockout condition	2	42	18.13***	≤**.001**	0.46
Lane departures					
Lockout condition	2	42	7.93***	≤**.001**	0.27
Standard deviation of lateral position					
Lockout condition	2	42	2.28	.12	0.1
Mean velocity					
Lockout condition	2	42	2.69	.08	0.11
Standard deviation of velocity					
Lockout condition	2	42	12.06***	≤**.001**	0.37

Note. MANOVA = multivariate analysis of variance. $n = 26$. The within-subject factor was lockout condition (no lockout, partial lockout, and complete lockout). The between-subject factor was sequence (6 levels). Partial η^2 indicates the strength of the association. Bold *p*-values indicate significant effects. * $p \le .05$; ** $p \le .01$; *** $p \le .001$.

formance, in particular as far as lateral vehicle control was concerned. Contrary to our assumptions, mean velocity was not affected; it was lowest during the partially locked condition. In addition, drivers were able to maintain their velocity best when completing secondary tasks in the no lockout condition. In accordance with our hypotheses, drivers rated the unlocked system better in terms of acceptance when compared to the partially locked and the completely locked system. They also preferred the partially locked system to a completely locked one.

Extending previous research regarding advising (Donmez et al., 2007, 2008) and locking mitigation strategies in complex traffic situations (Donmez, Boyle, & Lee, 2006), our results support the notion that lockout has a positive preventive effect on driving performance. American automotive manufacturers already make use of a lockout in their current models. In contrast, European manufacturers have not yet adopted this measure. In accordance with our hypotheses, driving performance in the lateral direction was better when using a completely locked system compared to an unlocked one. This finding is in line with prior research that found a distracting effect of IVIS secondary tasks on the lateral driving performance (Anttila & Luoma, 2005; Engström et al., 2005; Jamson & Merat, 2005). In addition, SWRR was higher in the partially locked than in the completely locked condition. For LAN and SDLP, there were no further differences in driving performance between the completely locked and partially locked system. However, we found a difference in performance between the unlocked and partially locked condition for the rate of lane departures, namely a lower rate when operating the partially locked IVIS while driving. Thus, a complete lockout seems to produce the best effects on driving performance, but partial lockout already goes a long way. Of the measures used, only LAN represents an objective driving error. Lane departures were equally probable in the partial and complete lockout condition. If one thinks about a lockout in order to reduce lane departures, this research indicates that it may not be necessary to disable all IVIS tasks.

We did not expect that the mean velocity would be the lowest in the partially locked condition. Previous research had shown a decrease in velocity when drivers conduct secondary tasks (Horberry et al., 2006; Lansdown et al., 2004; Rakauskas et al., 2004). It was also contrary to our hypothesis that drivers were best able to maintain their speed while conducting secondary tasks with the unlocked system. One explanation for these results arises from our observations. Participants did not like partially and completely locked systems and therefore strongly accelerated on their way to the parking bay. While they were heading towards a parking bay, however, they sometimes got close to other vehicles and therefore had to brake.

As illustrated in the technology acceptance model, actual system use is defined by acceptance measures such as perceived ease of use, perceived usefulness, attitude toward using, and behavioural intention to use (Davis et al., 1989; Davis, 1986). For this reason, studies in the vehicle context were interested in measuring user acceptance (Brookhuis et al., 2009; Kidd et al., 2014; Van Driel et al., 2007; Zhao & Wu, 2013).

Extending previous research on distraction mitigation strategies (Donmez, Boyle, Lee et al., 2006), our research demonstrates that ratings of user acceptance decreased with an increasing number of non-operable system tasks while driving. As assumed, the unlocked IVIS received significantly higher scores regarding perceived usefulness, perceived ease of use, behavioural intention to use, attitude toward using, and global satisfaction than the partially and completely locked systems. Drivers preferred the partially locked system to the completely locked system. All acceptance indicators, except of perceived ease of use, were lower for the completely locked system than for the partially locked system. The results support concerns of the previous focus group (Donmez, Boyle, Lee et al., 2006) and prior assumptions that system acceptance decreases the more a system forces users' behaviour (Van der Laan et al., 1997). Reasons for the low user acceptance of a lockout could also be that drivers usually have to pay for a wide range of features integrated in the IVIS. If these features are disabled while the vehicle is in motion, drivers might be disappointed. The low acceptance could also be attributed to the insufficient education about the benefits of a lockout. However, even if participants are aware of the reasons behind a lockout, they could underestimate their own risk when using the IVIS while driving (DeJoy, 1989; McKenna et al., 1991; Svenson, 1981; Wogalter & Mayhorn, 2005). Another reason for the low acceptance might be that users did not feel efficient when having to stop the vehicle in order to conduct an IVIS task (Donmez, Boyle, & Lee, 2006). More than half of our drivers ($n = 28$)

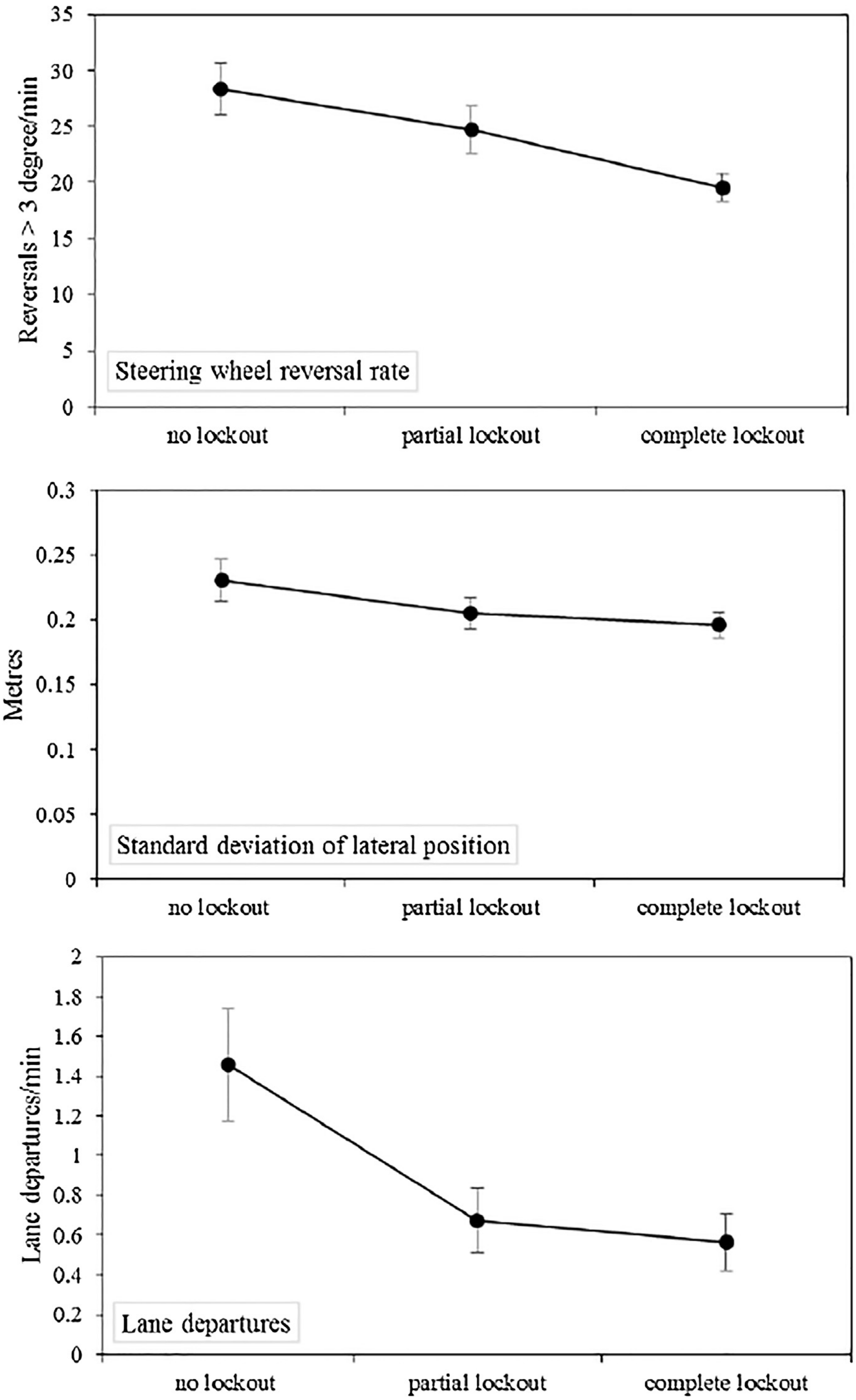

Fig. 5. Means of lateral control for each lockout condition. Error bars show SEM. For each lockout condition $n = 26$, listwise deletion.

stopped the simulator vehicle at least once at an inappropriate position at the side of the road in order to conduct a task that was disabled by the IVIS. Participants showed this behaviour instead of waiting for a parking bay. This is a potentially troublesome unintended consequence of lockout. If the motivation to use the locked out function is overbearing, drivers seem to be willing to risk potentially unsafe stopping manoeuvres, which impose new risks. This observation would indicate that drivers' opposition to system lockouts may not merely reflect an annoyance of having to pull over, but rather include real-

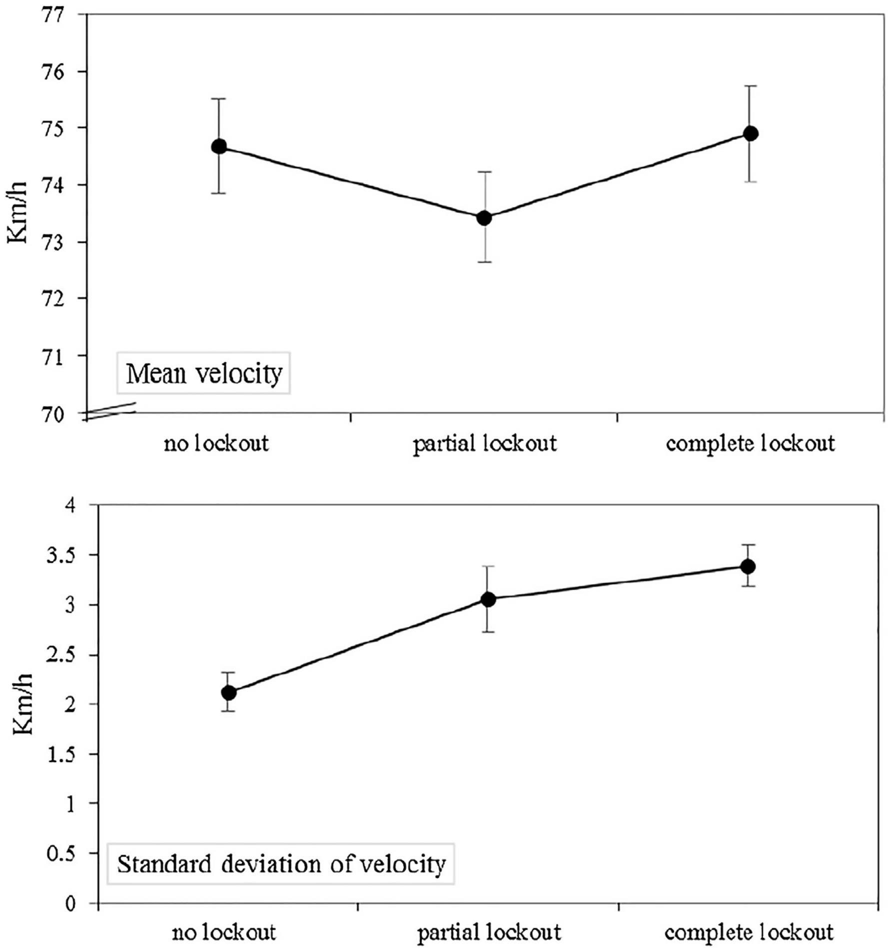

Fig. 6. Means of longitudinal control for each lockout condition. Error bars show SEM. For each lockout condition $n = 26$, listwise deletion.

Table 3
Results of univariate tests to compare the no lockout, partial lockout, and complete lockout condition on perceived usefulness, perceived ease of use, behavioural intention, attitude toward using, and global satisfaction.

	df1	*df2*	*F*	*P*	η_p^2	ε (Huynh-Feldt)
Perceived usefulness						
Lockout condition	2	83.67	30.67***	≤**.001**	0.42	0.97
Perceived ease of use						
Lockout condition	2	86	8.71***	≤**.001**	0.17	1.00
Attitude toward using						
Lockout condition	2	86	22.52***	≤**.001**	0.34	–
Behavioural intention to use						
Lockout condition	2	86	36.57***	≤**.001**	0.46	1.00
Global satisfaction						
Lockout condition	2	86	48.91***	≤**.001**	0.53	1.00

Note. MANOVA = multivariate analysis of variance. $n = 49$. The within-subject factor was lockout condition (no, partial, and complete lockout). The between-subject factor was sequence (6 levels). Due to missing sphericity a Huynh–Feldt correction for the degrees of freedom (*df*) was used (Huynh & Feldt, 1976), and the value of ε is reported. Partial η^2 indicates the strength of the association. Bold *p*-values indicate significant effects.
* $p \le .05$; ** $p \le .01$; *** $p \le .001$, listwise deletion.

izations of the potential danger of forcing such behaviour. Some drivers ($n = 14$), however, chose to conduct at least one IVIS task in a safe parking zone (thus stopped the simulator vehicle), although the task would have been available while driving. This is in line with research showing a preference to perform navigation entries when the vehicle is not moving or in slow motion (Metz, Schoch, Just, & Kuhn, 2014).

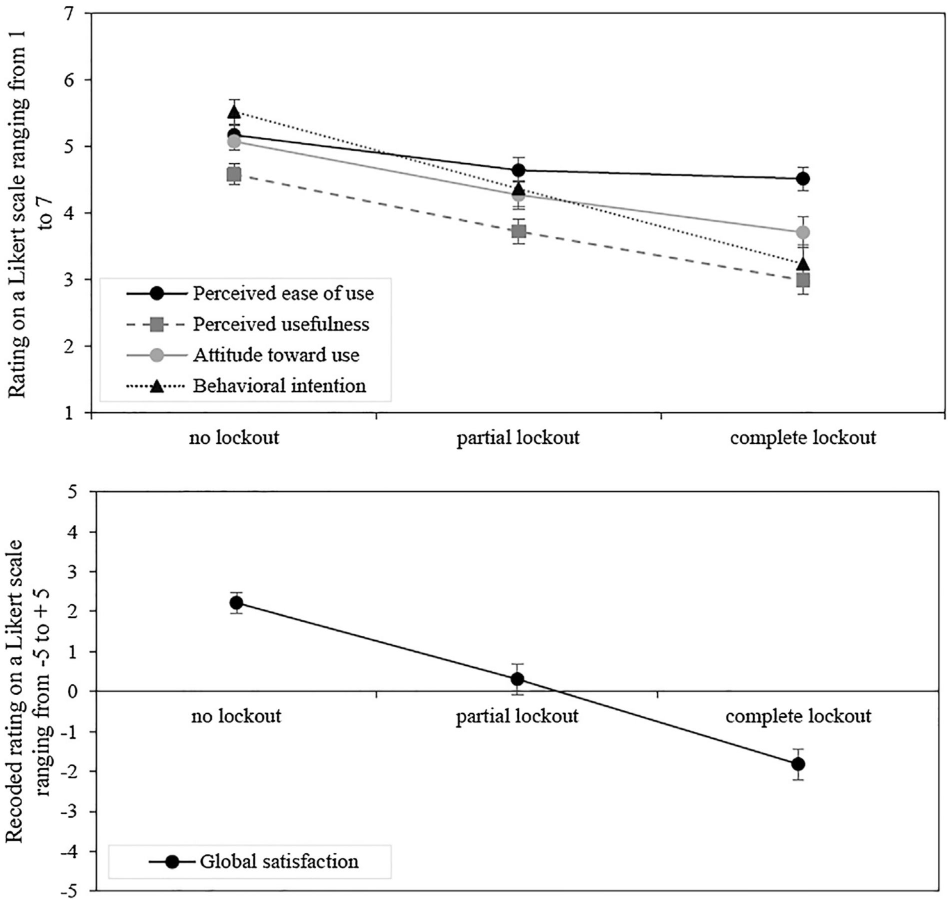

Fig. 7. Means of perceived usefulness, perceived ease of use, behavioural intention to use, attitude toward using, and global satisfaction for each lockout condition. Error bars show SEM. For each lockout condition n = 49; listwise deletion.

The current study is among the first to focus on the impact of system lockouts on driving performance and user acceptance. It shows that lockouts of IVIS functionalities might be an effective mitigation strategy to improve driving performance. However, user acceptance surfaces as a major problem. We have tested three configurations. One IVIS roughly followed the recommendations regarding lockouts proposed by the Alliance of Automobile Manufacturers. Thus far, no laws or regulations explicitly require lockouts in Germany. Therefore, we had the opportunity to conduct this research using participants who were mostly unfamiliar with mitigation strategies. The advantage of the lockout could be measured although our participants had been unfamiliar with the lockout method and the experimenter had not provided further information beforehand. For tasks that were available while driving, our participants were free to choose if they would like to conduct the secondary tasks while driving or in a parking bay. In this respect, our experiment was similar to a realistic setting outside the simulator.

4.1. Limitations and future research

In the present study, we measured driving performance and acceptance for three approaches to the functionality of an IVIS. However, as only six tasks represent each system configuration and overall 52 drivers participated in the study, one should use caution when generalizing to other IVIS functions or other driver populations. When interpreting our data in terms of distraction, one should consider that we incorporated only some measures of driving performance. These are no absolute metrics for driver distraction; however, it could be worth considering driver workload or gaze behaviour in future research.

Even though driving simulators offer advantages such as a safe and standardized environment (Young et al., 2009), it is possible that our participants took the simulator driving less seriously than they would an actual traffic situation. We assume that drivers are less likely to stop in traffic or break laws in the 'real world' than in a simulator. Predominantly due to stopping behaviour, data of only 26 participants contributed to our findings regarding driving performance. Future research should extend these findings to larger populations.

We instructed the participants to adhere to the traffic regulations and to act, as they would when driving in a natural environment. This might have been a conflicting instruction for some of our drivers. In addition, we asked them to stop in a parking bay after their familiarization drive, to show them implicitly the possibility to stop their vehicle there. On the one hand, the low acceptance or annoyance with lockout could explain why some of the 28 participants stopped after task instruction, rather than looking out for a parking bay. On the other hand, one might interpret this behaviour as the spontaneous reaction to the unannounced lockout. Half of the subjects attempted to comply with the instruction to enter data into the information system to such an extent that they immediately pulled over and stopped rather than looking for the next parking bay. The remaining subjects waited until they had reached the next bay. Thus, there could have been a great pressure to comply with the system. For the remaining subjects ($n = 26$), we were able to compare driving performance of the lockout condition (during which subjects intensely looked for an opportunity to stop) to driving performance of the no lockout condition, during which subjects used the IVIS while driving along the same stretch of road.

One might alternatively explain this behaviour as a result of a misleading instruction. To avoid data loss in future research, one could formulate a clearer instruction by stating that participants should find a safe place to operate the IVIS. In addition, one might consider introducing a token system that sets an incentive for both rule-consistent but fast driving behaviour. With this, one could replace our story regarding the important appointment, and potentially avoid drivers' stops in inadequate positions. Conducting a similar study in a real vehicle could increase the inhibition threshold for participants to violate traffic rules thoughtlessly. Within future research, one might additionally include self-regulatory processes that could affect drivers' handling of locked out IVIS tasks.

Our participants were employees of an automobile manufacturer. Therefore, their interests and previous experience with IVISs might differ from persons who work in other professional fields. However, as our results were highly significant, we do not expect these differences to vanish when investigating other customers. As we conducted our study in Germany, participants were unfamiliar with distraction mitigation strategies. To extend our findings, it would be interesting to conduct a study with U. S. participants who are already familiar with system lockouts. User acceptance of system lockout may change with extended experience due to a product launch or increased background information. If differences between U.S. and German customers occur, one might interpret these results as a learning effect that could arise due to a greater familiarity with lockouts.

Two of the three systems disabled functionalities while driving. Participants had to stop the vehicle to perform these tasks. For the lockout systems, driving performance consisted of a conglomerate of driving while conducting short secondary tasks and some kind of orientation phase while driving. This method might have some difficulties, as it assesses drivers' usage behaviour with unknown systems. Drivers did not know which task the system allowed them to operate while driving. Instead of simply knowing that their system was completely locked or unlocked, drivers had to find out system configurations and might have felt uncertainty. Driving performance might be better, if drivers are familiar with their system configuration. In everyday life, however, a lockout could also impair driving performance. A lockout might distract drivers, as they have to search for a parking lot in order to conduct a task with a locked IVIS. Participants with prior knowledge of locked IVIS functions in their vehicle might normally complete their settings before they start driving. However, there are possible scenarios where something unforeseeable might occur during a drive (e.g., urgent phone call due to a traffic jam, change in destination or routing due to navigational uncertainties in the area of the destination (Burnett, 1998)). In this case, drivers with a locked IVIS find themselves in a situation similar to our experimental setting, where they would need to stop their vehicle in order to use an IVIS.

Future studies could focus on the acceptance and effectiveness of locking out certain input methods (e.g., touchscreen) but enabling other control elements to operate a system (e.g., voice control, steering wheel switches). It is also imaginable that drivers are more likely to accept adaptive lockout strategies such as proposed in a patent (U.S. Patent No. 7,463,961 B2, 2005). Here, the locked functions are not set in advance but depend on drivers' present distraction state, as determined by the vehicle system. The specific realization of possible lockouts, if the legislator requires them, is also an open question.

4.2. Practical implications

As measured by improved driving performance, the overall insights gained from this research show that lockout is an appropriate mitigation strategy in order to prevent or reduce a decrease in driving performance, which is associated with the use of IVISs. However, as user acceptance is an important requirement for the effectiveness of a strategy and for the eventual system use (Davis et al., 1989; Davis, 1986), the lacking acceptance is a problem. The effectiveness of locking out functionalities of IVISs would be doubtful if participants are still allowed to switch to smartphones or nomadic devices instead. Customers could also circumvent lockout by switching to manufacturers that have not implemented lockout, possibly resulting in competitive disadvantages of those that have. If the legislator opts for restriction, all manufacturers and all devices would have to be considered.

Drivers accepted the partially locked system more compared to the completely locked system. With regard to the driving characteristics, the partially locked system already reduced the rate of lane departures significantly. Consequently, locking out difficult or particularly long tasks seems to be one realization possibility. In future research, one needs to address the question, which specific IVIS tasks should be locked out.

With an increasing traffic safety culture, acceptance of system lockouts while driving could increase, too. A public campaign that calls attention to consequences of driver distraction might increase the traffic safety culture and decrease the motivation to engage in secondary tasks. Even if some drivers avoid conducting secondary tasks while driving, they still want to be responsible for choosing the tasks they would like to conduct while driving.

In parallel, manufacturers could also contribute to a reduction of driver distraction by improving usability, implementing systems that are easy to learn and operable as secondary tasks.

5. Conclusion

Lockout as a distraction mitigation strategy had a positive effect on driving performance, in particular on lateral vehicle control. This was the case even for partial lockout. In the longitudinal direction (velocity control), however, there was no clear advantage for one out of the three system configurations. With regard to user acceptance, the data clearly indicate that acceptance decreased with the number of disabled functions.

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