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Non-driving related tasks' effects on takeover and manual driving behavior in a real driving setting: A differentiation approach based on task switching and modality shifting

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ABSTRACT

Many studies on effects of non-driving related tasks in the context of SAE Level 3 automated driving have been conducted in driving simulator settings applying standardized tasks. Thereby internal validity is favored over external validity. To assess the influence of engagement in three natural non-driving related tasks on takeover behavior in the context of SAE Level 3 automated driving, we conducted an experiment on a test track with a sample of naïve participants from the general public. We used a Wizard-of-Oz vehicle to simulate a SAE Level 3 traffic jam function in a real driving setting. To measure effects of compatibility between non-driving related tasks and driving task on subsequent takeover behavior and following manual driving behavior, participants played Tetris, watched a documentary film and read a text and typed a summary of it. After approx. 15 min, each non-driving related task was interrupted by a request to intervene. In the manual driving phase after the third takeover, participants encountered a balloon car positioned on their lane which they had to evade. Results show longer takeover times in the film and text condition compared to the Tetris condition. Implications on theory and practice are discussed.

1. Introduction

Taking over the driving task after having engaged in a non-driving-related activity, such as watching a movie, is just the situation a driver faces at the end of a Level 3 automated driving phase. The take-over situation has been investigated intensively especially in driving simulator settings. The current experiment contributes to literature on non-driving related tasks in Level 3 automated driving by (1) applying a real driving setting and (2) investigating a theoretical framework based on task switching and modality shifting to differentiate non-driving related tasks' effects. Specifically, the experiment at hand investigates takeover behavior and following manual driving behavior depending on previous non-driving related tasks' characteristics using a Wizard-of-Oz vehicle to simulate Level 3 driving automation in a real driving situation on a test track. A recent meta-analysis (Shi and Bengler, 2022) points toward the possibility to differentiate non-driving related tasks' effects on takeover behavior based on Rubinstein et al.'s stage model of executive control for task switching (2001) and the modality shifting effect (Spence et al., 2001). Hence, the combination of the respective task switching theory and the modality shifting effect served as the basis for selecting the non-driving related tasks investigated in the current experiment. Results corroborate the meta-analytic finding that the combination of task switching and modality shifting is suitable to differentiate non-driving related tasks' effects on following takeover behavior. Additionally, the experiment provides an indication that the approach might not only be suitable to differentiate effects post hoc, but might also be suitable to explain and predict non-driving related tasks' effects.

1.1. What is Level 3 automated driving?

Driving automation functions can be divided into those providing sustained driving automation, those providing temporary intervention and those providing warning and information to the driver (Gasser et al., 2017; Shi et al., 2020). Sustained driving automation functions are described in detail in the SAE International Standard J3016 (2021). The standard distinguishes driving automation functions in six categories from Level 0 to Level 5. This experiment's focus lies on SAE Level 3

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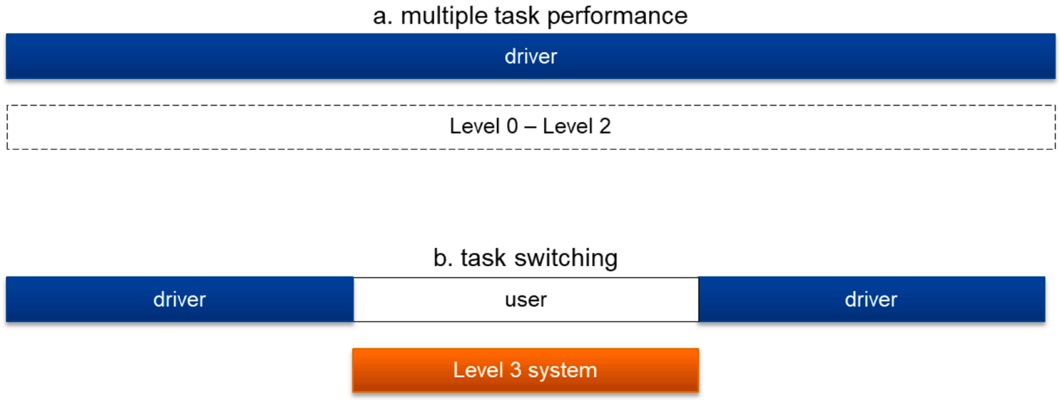

Fig. 1. a. performing non-driving related tasks during active SAE Level 0 – 2 phases results in a multiple task performance situation for the driver as the driver needs to perform the driving task and the non-driving related task in parallel. b. performing non-driving related tasks during active SAE Level 3 phases results in a task switching situation for the user. While the Level 3 system is active, the user is released from the driving task, thus, the non-driving related task may be the primary activity. Upon a request to intervene, the user needs to switch to the driving task again.

functions under routine/normal operation (SAE J3016, 2021). SAE Level 3 functions take over the entire driving task including the lateral and longitudinal vehicle motion control as well as the object and event detection and response. Consequently, while the Level 3 function is active, the driver is released from the driving task and does not need to supervise the function anymore. Thereby, the former driver becomes a user who may engage in other non-driving related activities. However, the user needs to remain receptive to alerts (fallback-ready user) because the Level 3 function can only perform the driving task within a specific domain, e.g. within a traffic jam on the highway. If a functional limit is being approached, e.g. when the traffic jam dissolves, the Level 3 function will timely request the fallback-ready user to take over the driving task again (SAE J3016, 2021; UN Regulation No. 157). The fallback-ready user is expected to respond to this request to intervene by first disengaging from any non-driving related activity and reorienting in the traffic situation, and then deactivating the function. After the driving automation function is deactivated, the former user continues the ride as the driver again (see also Fig. 1b).

1.2. Effects of non-driving-related activities in the context of Level 3 automated driving automation

It is expected that users of Level 3 driving automation will spend their newly acquired free time on activities not related to driving. These activities are likely to influence traffic safety at the latest when the driving automation system requires the user to take over the driving task again. Accordingly, takeover behavior upon a system-initiated request to intervene has been investigated thoroughly. Research shows that in this context non-driving related tasks can influence takeover behavior via two paths: First, they show *effects on fallback-ready users' state* (Feldhütter et al., 2018a; Frey, 2019; Weinbeer et al., 2019), and second, they immediately influence *takeover behavior upon a request to intervene* (for review see Jarosch et al., 2019b).

Regarding *users' state*, results show that engagement in non-driving related tasks has the potential to reduce development of fatigue in fallback-ready users (Frey, 2019; Wu et al., 2020) compared to conditions where users did not engage in any tasks (Feldhütter et al., 2018b). In contrast, not engaging in non-driving related tasks increases fatigue and the risk to even fall asleep (Feldhütter et al., 2018b; Frey, 2019; Weinbeer et al., 2019). Yet, demands of the executed non-driving related task should match users' capacities (May and Baldwin, 2009). For example, engaging in monotonous non-driving related tasks increases fatigue compared to engaging in activating non-driving related tasks (Jarosch et al., 2019a). In summary, engagement in activating non-driving related tasks during active Level 3 automated driving phases supports maintaining users' receptiveness to requests by the function, if demands of the in non-driving related task match users' capacities.

Regarding *takeover behavior* following a request to intervene, engagement in non-driving related tasks may hamper both takeover behavior and following manual driving behavior (Wu et al., 2020; Zeeb et al., 2016). Inadequate takeover and poor manual driving behavior following requests to intervene increase the risk of accidents and physical harm which is opposed to the original aim and purpose of pursuing driving automation. Takeover behavior has been investigated intensively in the literature and has been defined as the time between onset of a request to intervene and the moment the driver has regained control of the vehicle. The operationalization of the moment the driver has regained control of the vehicle differs between studies. Mostly, regained control of vehicle motion was defined by either deactivation of the driving automation system (e.g. Dogan et al., 2019; Naujoks et al., 2019; Vogelpohl et al., 2020; Vogelpohl et al., 2018; Wandtner et al., 2018) or stabilizing vehicle motion shortly after deactivation of the driving automation system (e.g. Zeeb et al., 2017). Influences of non-driving related tasks performed during a Level 3 automated driving on manual driving behavior after takeover has been accomplished has not been investigated as thoroughly yet, to the authors' knowledge.

Based on numerous studies investigating how non-driving related tasks affect takeover behavior, researchers try to summarize and systematize these primary studies. Jarosch et al. (2019b) provides a review on non-driving related tasks' effects based on a primary characteristic, respectively. They point out that most research on non-driving related tasks focusses on the involved sensorimotor and cognitive processes. Furthermore, arousing and motivational characteristics have been examined. However, literature on non-driving related tasks' effects still seems inconclusive. Besides reviews, meta-analyses have been conducted to gain further insights into how non-driving related tasks influence takeover behavior (Shi and Bengler, 2022; Soares et al., 2021; Weaver and DeLucia, 2020; Zhang et al., 2019). Regarding systematization, the meta-analyses follow different approaches. Zhang et al. (2019) examine effects of single features of a non-driving related task, which is a similar to the approach by Jarosch et al. (2019b). Weaver and DeLucia (2020) combine the two features "handheld" and "visually demanding". Both meta-analyses find that handheld as well as visually demanding non-driving related tasks increase takeover time (Weaver and DeLucia, 2020; Zhang et al., 2019). However, with regard to natural activities, differentiation based on a single main feature does not seem satisfactory. For instance, watching a movie and watching the environment are both primarily visually demanding tasks. It seems obvious that chances for a good takeover are higher after watching the environment compared to watching a movie since the driving situation might be perceived concurrently when watching the environment, whereas watching a movie does not allow for this advantage. We

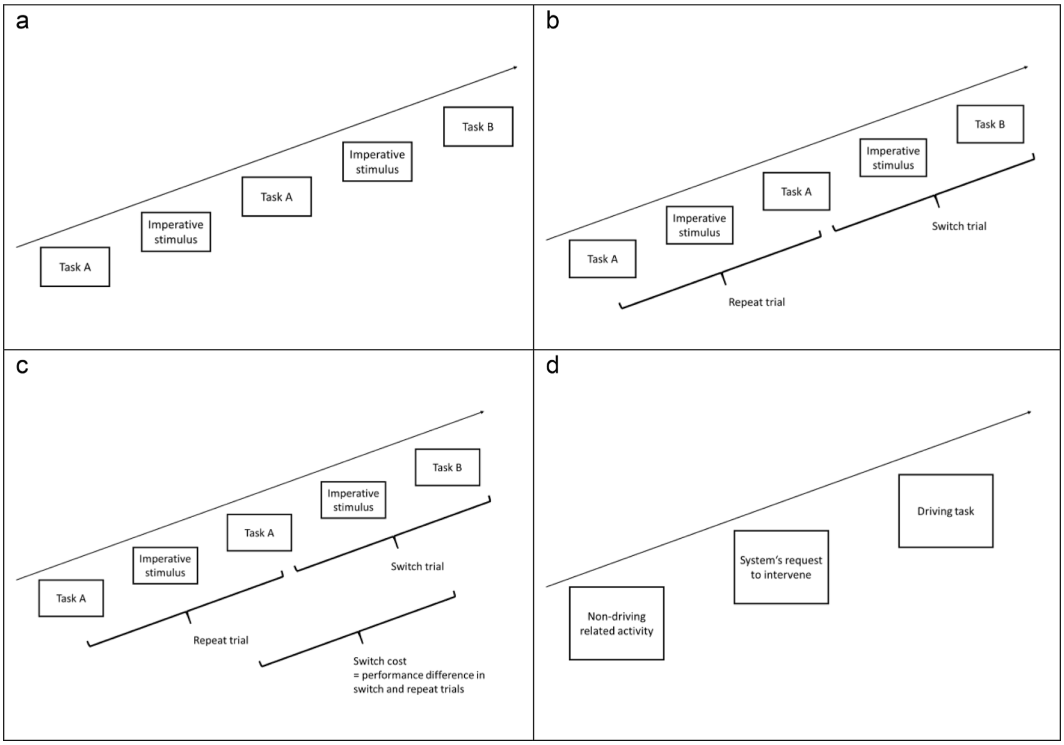

Fig. 2. Task Switching in Level 3 automated driving. (a) basic task switching paradigm. (b) repeat and switch trials in the task switching paradigm. (c) switch costs in the task switching paradigm. (d) task switching in Level 3 automated driving.

contribute to previous efforts of summarizing and systematizing effects of non-driving related tasks by examining a theory-based approach that does not rely on a non-driving related task's single feature.

1.3. A switching approach to differentiate non-driving related activities regarding their effects on following takeover and manual driving behavior

Advancing to Level 3 automated driving is associated with a shift in paradigm from dual-task to task switching (Hecht et al., 2020; Weaver and DeLucia, 2020; Zeeb et al., 2017). This means, from Level 0 to Level 2, non-driving related tasks need to be performed concurrently to the driving task since the driver is never released from the driving task (dual-task, see Fig. 1a). In contrast, when using driving automation functions of SAE Level 3, non-driving related tasks can become the primary task since the driver does not need to perform the driving task anymore until a request to intervene is issued (task switching, see Fig. 1b).

It has been widely acknowledged that the takeover situation in Level 3 automated driving constitutes a *task switching paradigm* (Hecht et al., 2020; Weaver and DeLucia, 2020; Zeeb et al., 2017). Interestingly, theories addressing *multiple task performance* are applied to explain and predict effects of non-driving related tasks on takeover performance in Level 3 automated driving (e.g. Weaver and DeLucia, 2020). Considering that theories on multiple task performance have been successfully applied to explain effects of secondary task engagement in manual and assisted driving (SAE Levels 0 – 2), their unquestioned persistent application at Level 3 seems both comprehensible and challengeable. It is not in the scope of multiple task performance theories to explain and predict task switching effects. For instance, "Multiple resource theory is a theory of multiple task performance" (Wickens, 2002, p. 159).

In summary, we highlight that progressing to Level 3 automated driving functions (SAE J3016, 2021; UN Regulation No. 157), is accompanied by a new user role (Bundesanstalt für Straβenwesen, 2020; Shuttleworth, 2019) and paradigm shift (Hecht et al., 2020; Weaver and DeLucia, 2020; Zeeb et al., 2017) that also challenges the theories that are applied so far (e.g. Wickens, 2002).

Accordingly, for the Level 3 driving automation context, we apply task switching theory to describe and differentiate effects of non-driving related tasks on takeover and following manual driving. Currently, if task switching literature is cited in the context of non-driving related tasks' effects on takeover behavior, they mainly focus on Monsell (Weaver and DeLucia, 2020; Zeeb et al., 2017). In basic psychological research, however, besides Rogers and Monsell's (1995) task set reconfiguration approach, there is the task set inertia approach by Allport et al. (1994) for explaining task switching effects. Since there is empirical evidence for both approaches, focusing on one approach (i.e. Monsell) will neglect the other approach's explanatory potential. We therefore chose to apply the *stage model of executive control for task switching* by Rubinstein et al. (2001). This model integrates both the task set inertia approach and the task set reconfiguration approach and has found great recognition with over 900 citations in Scopus (lastly checked on Dec 30th 2021). In the following, first, we apply the task switching paradigm in general to the takeover situation in Level 3 automated driving, and second, we apply the task switching model by Rubinstein et al. (2001) to the takeover situation in Level 3 automated driving.

1.3.1. The takeover situation as a task switching paradigm

Kiesel et al. (2010) define task switching as follows: "In task-switching experiments, participants perform a discrete task on each trial. On some trials the task changes (switch trials), and on others it does not (repeat trials)." (Kiesel et al., 2010, p. 849; see Fig. 2a, b). A major finding from the task switching paradigm is the so called *switch cost*. The switch cost is the difference in performance on switch trials and repeat trials. Kiesel et al. (2010) define the switch cost as follows: "Performance in task switches is compared with that in repetitions. The basic phenomenon is that there is a highly robust "switch cost" in both reaction time (RT) and error rates." (Kiesel et al., 2010, p. 849; see Fig. 2c).

When applying the task switching paradigm to the context of

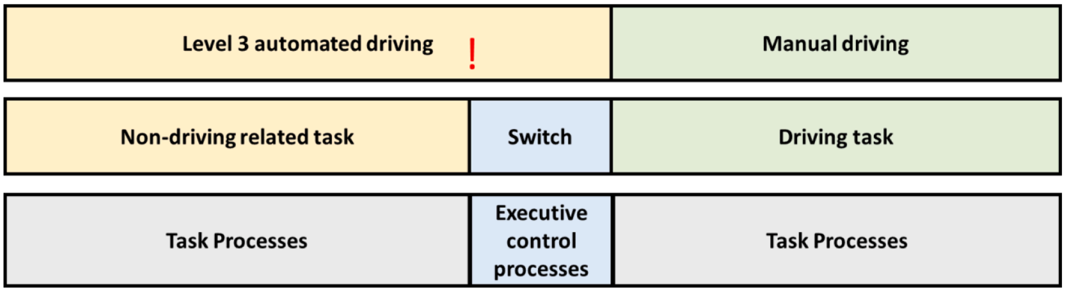

Fig. 3. Applying the stage model of executive control for task switching to the takeover situation in SAE Level 3. The exclamation mark symbolizes the request to intervene issued by the Level 3 driving automation system.

takeover in Level 3 automated driving, the antecedent task is the non-driving related task and the subsequent task is the driving task (see Fig. 2d). The driving automation system's request to intervene constitutes the imperative stimulus that calls for a task switch at the end of a Level 3 automated driving phase. It requests the user to switch from the non-driving related activity to driving. Since users of Level 3 automated driving need to switch to the driving task at the end of the automated driving phase, the second task to which the user needs to switch, is always known in advance. This constitutes a distinctive characteristic of the task switching setting in Level 3 automated driving and allows early preparation compared to other task switching settings where the second task is not known before the onset of the imperative stimulus (e.g. Koch, 2005; for an overview see section on preparation in task switching in Kiesel et al., 2010).

Switches take place on physical and cognitive level. On the physical level, for instance, seating position and lighting conditions need to be adjusted and potential non-driving related tasks need to be put away. meta-analyses show that physical switches have a strong effect on takeover times (Shi & Bengler, 2022; Weaver & DeLucia, 2020; Zhang et al., 2019). We will focus on switches on the cognitive level in the following, for which we assume that they take place in addition to the physical switches.

1.3.2. The takeover situation from the perspective of Rubinstein et al.'s (2001) stage model of executive control for task switching

After applying the task switching paradigm to SAE Level 3, we transfer the task switching theory by Rubinstein et al. (2001) to the takeover situation at Level 3. Rubinstein et al.'s model assumes two processes: task processes and executive control processes. Task processes take place whenever working on a task. Hence, in the context of takeover at Level 3, they take place when engaging in non-driving related activities and when performing the driving task. Executive control processes take place when tasks need to be switched. Hence, they take place as soon as the imperative stimulus requires a task switch. In the context of takeover at Level 3, executive control processes take place when the system issues a request to intervene.

Task processes include the three stages of stimulus identification, response selection and movement production. At the stimulus identification stage, the stimuli for task execution are perceived and encoded. On the next stage of response selection, the perceived stimuli are converted into "abstract response codes" (Rubinstein et al., 2001, p. 770). On the stage of movement production, these abstract response codes are converted to "motor commands that generate overt physical action" (Rubinstein et al., 2001, p. 770). When repeating tasks, Rubinstein et al. (2001) assume that stimulus identification stage is directly followed by response selection stage, however, when a task switch is required, they assume a little pause between those two task processes during which executive control processes are assumed to take place (see below).

Executive control processes include the two stages of goal shifting and rule activation. "The goal-shifting stage keeps track of current and future tasks, inserting and deleting their goals in declarative working memory as needed." (Rubinstein et al., 2001, p. 770). The stage of goal shifting is assumed to take place flexibly compared to concurrent task processes. Rubinstein et al. (2001) explicitly state that "goal shifting may occur before stimulus identification starts for the next task" (Rubinstein et al., 2001, p. 771), with one prerequisite being "prior information is available about what the next task will be" (Rubinstein et al., 2001, p. 771). The stage of rule activation is assumed to take place after goal shifting and stimulus identification for the current task is completed, but before response selection for the current task. "Two complementary functions are served by rule activation: enabling the rules for selecting the current task's response and disabling the rules for selecting the prior task's response." (Rubinstein et al., 2001, p. 771).

Based on the assumption that the takeover situation in Level 3 automated driving constitutes an example for the task switching paradigm, and applying the stage model of executive control for task switching (Rubinstein et al., 2001) (see Fig. 3), we hypothesize: (1) Non-driving related tasks can be differentiated regarding their effects on (a) following takeover behavior and (b) subsequent manual driving behavior. (2) A non-driving related task is accompanied by (a) shorter takeover times and (b) higher takeover quality when the task allows for executive control processes and task processes related to the subsequent driving task to take place earlier compared to when the task does not allow so.

1.3.3. The takeover situation from a modality shifting perspective

Regarding the task process of stimulus identification (Rubinstein et al., 2001), the modality shifting effect may play an additional role. The modality shifting effect describes the relative cost in error rates and reaction times when a target stimulus is presented in a different modality than a previous stimulus compared to when the modality of the previous stimulus matches the current stimulus (Spence et al., 2001; Töllner et al., 2009). Transferring this effect to the takeover situation in Level 3 automated driving, we hypothesize: In a takeover situation in Level 3 automated driving, non-driving related tasks that are similar to the driving task in terms of the involved modalities are accompanied by (a) lower reaction times (i.e. lower takeover times) and (b) lower error rates (i.e. higher takeover quality) compared to non-driving related tasks that are dissimilar to the driving task in terms of the involved modalities.

1.3.4. Similarity between non-driving related task and driving task

As outlined in the previous sections 1.3.2 and 1.3.3, we differentiate tasks in terms of when they allow for task processes and executive control processes to take place. If a non-driving related task allows for task or executive control processes to take place earlier compared to another, we would expect a benefit for the respective task in terms of takeover time and quality. In case two non-driving related tasks do not differ in terms of when task and executive control processes take place, we assume that on the level of task processes, shifting the modality is accompanied by costs (see 1.3.3 on modality shifting effect). Transferring the modality shifting effect to the Level 3 takeover situation requires a theory that is suitable to describe the non-driving related task and the driving task respectively in order to depict their differences and similarities. We chose the working memory model by Baddeley (Baddeley and Hitch, 1974) as it differentiates between modules for e.g. auditory, visual and spatial information. The model originally assumes one module for visual-spatial information, however, research suggests visual and spatial information to be processed in two different modules instead of one integrated module (Klauer and Zhao, 2004; Logie and van der Meulen, 2009; Smith and Jonides, 1997).

An example for a non-driving related task that is similar to the driving task in terms of the involved modalities is playing Tetris (Agren et al., 2021; Ecker et al., 2010; Haier et al., 2009; Jarosch et al., 2019b; Metz et al., 2011). Similar to the driving task, playing Tetris puts visual and spatial demands and requires cognitive processes such as updating. An example for a less similar task is watching a film, which requires the visual modality, but does not put spatial and further cognitive demands, such as updating.

1.4. Aim and scope of the current experiment

It is expected that the first Level 3 automated driving system will exert their influence on traffic safety soon since the first system has been granted type approval in Germany (Kraftfahrt-Bundesamt, 2021). The aim of the present experiment is to contribute to research on differentiation of non-driving related tasks regarding their effects on following takeover and manual driving behavior in case of a system-initiated request to intervene. Specifically, we contribute to the theoretical basis of such differentiation. Our approach is based on psychological theories and empirical findings on task switching and modality shifting. In a previous meta-analysis, this approach has been shown to be effective to differentiate between effects (Shi and Bengler, 2022). The current experiment will examine the approach's potential to not only differentiate post hoc (as in the meta-analytic approach), but also to predict effects a priori. This would provide further support for the switching approach's potential to differentiating non-driving related tasks' effects. Since relevance to traffic safety guides our research, the experiment is conducted in a real driving setting and applies a non-destructive collision scenario to evaluate the quality of manual driving upon takeover in a realistic hazard situation. This allows comparison of data derived from real driving setting to driving simulator studies.

Besides the main focus on task switching in the context of takeover, we address two further aspects: First, we found that most literature on takeover behavior has been conducted at daytime or under simulated daytime conditions. We therefore aim at extending current literature by providing first insights into whether takeover behavior differs in the dark. Second, when planning the study, we found a lack of literature on motivational factors in the takeover process compared to cognitive factors. Therefore, we include a question on flow experience (Nakamura and Csikszentmihalyi, 2014) as a side research question. Flow is described as the experience when challenges of a task matches the capabilities of the person performing the task (Csikszentmihalyi and LeFevre, 1989).

The following research questions will be addressed:

RQ1: Do task switching and modality shifting effects cause differences in takeover behavior and following manual driving behavior in a real driving setting?

This research question is our main focus. We aim to investigate if task switching and modality shifting cause differences in takeover and manual driving behavior. Therefore, we chose natural non-driving related tasks that differ in similarity to the driving task regarding the involved modalities. In order to describe the similarity between a non-driving related task and the driving task, Shi and Bengler (2022) used Baddeley's working memory model (Baddeley and Hitch, 1974; Repovs and Baddeley, 2006) because it differentiates between processing modules based on the stimulus' modality. Since this approach to evaluate two tasks' similarity has proven to be useful in the meta-analysis, it will also be applied in this experiment for selecting non-driving related tasks.

RQ 2: Does takeover behavior in the dark differ from takeover behavior at daytime?

To gain first insights into effects of daytime/dark on takeover behavior and/ or the effect of non-driving related tasks, we also implement takeover situations in the dark.

RQ 3: Does flow experience while performing non-driving related tasks have an impact on takeover performance?

Besides our main focus on differentiating non-driving related tasks regarding their effects on following takeover and manual driving behavior based on cognitive characteristics, other motivational influences may contribute to differences. In contrast to experimental settings, users of Level 3 driving automation will not be instructed to perform a specific task, but rather might choose non-driving related activities that they intrinsically like. To gain insights into motivational influences, we examine participants' flow experience (Csikszentmihalyi and LeFevre, 1989; Nakamura and Csikszentmihalyi, 2014) while performing the instructed non-driving related task (Ko and Ji, 2018; Park et al., 2019).

2. Method

2.1. Sample

In total, 38 participants took part in the experiment. Two participants had to be excluded (one for technical problems and one for language comprehension reasons), leaving a total of 36 participants (15 women, 21 men; $M_{age} = 42.3$ years, $SD_{age} = 14.8$ years). Participants drove between 9,000 and 120,000 km annually, mostly for private reasons ($n = 18$ of whom $n = 7$ stated to mostly drive for professional reasons, and $n = 11$ drove for both private and professional reasons equally distributed). When asked about prior experiences with automated driving, $n = 27$ indicated to have no prior experience, $n = 8$ confused Level 1 and Level 2 systems with automated driving and one participant had taken part in a driving simulator study on automated driving for which we could not evaluate the automation level. Participants were allocated to the daylight or dark group depending on their availability and otherwise randomly. Order of non-driving related tasks was randomly assigned.

2.2. Apparatus and materials

2.2.1. Questionnaires

To assess participants' motion sickness susceptibility, the *Motion Sickness Susceptibility Questionnaire – Short Version* (MSSQ-S; Golding, 2006) was used. Participants' driving style was assessed by the Multidimensional Driving Style Inventory (MDSI; Taubman-Ben-Ari et al., 2004). MSSQ-S and MDSI served as filter criteria. In case participants had reported risky driving styles or were very prone to motion sickness, they would have been excluded so as to not cause inconvenience to participants and to not jeopardize the experimenters and the participants. However, no participant had to be excluded for these reasons. The German version of the *Checklist of Trust between People and Automation* (Jian et al., 2000) by Pöhler et al. (2016) was used to measure trust in the driving automation system. The *Flow Kurzskala* (FKS) (Rheinberg et al., 2003) was used to assess flow experience.

2.2.2. Daytime and nighttime condition

The experiment took place in February 2020. One group of participants was tested at daytime (between 9 a.m. and 5p.m.), another group was tested in the dark (between 8p.m. and 11p.m.). Experimental rides took place under all weather conditions (e.g. fog, snow, rain, wind), with

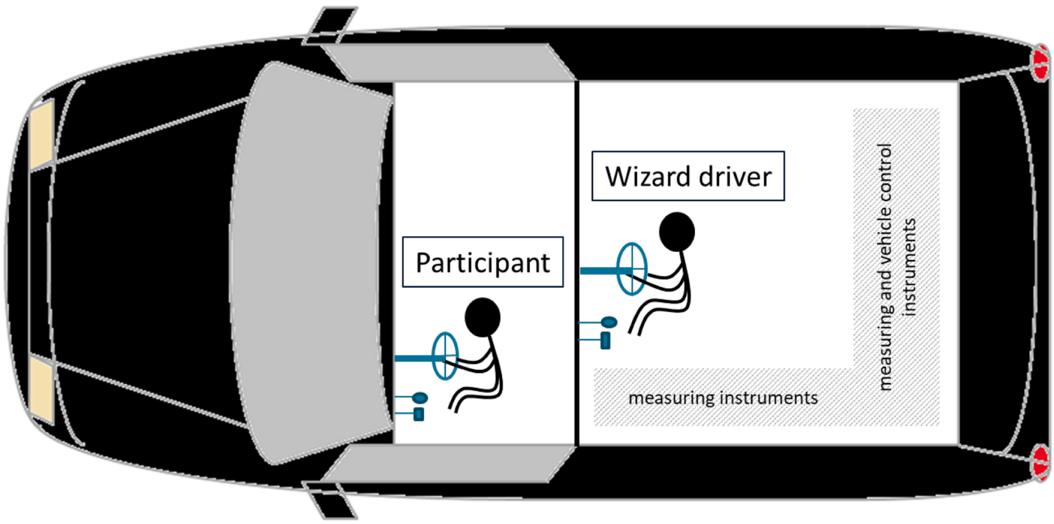

Fig. 4. Schematic setup of the Wizard-of-Oz vehicle (figure originally from Shi and Frey (2021), CC BY-NC-ND 4.0). Participant is seated in the driver's seat, the wizard driver simulates the automated driving function and is seated in the rear. A tinted window separates the driver's cabin from the rear and is only transparent from the rear, masking the Wizard-of-Oz principle from the participant.

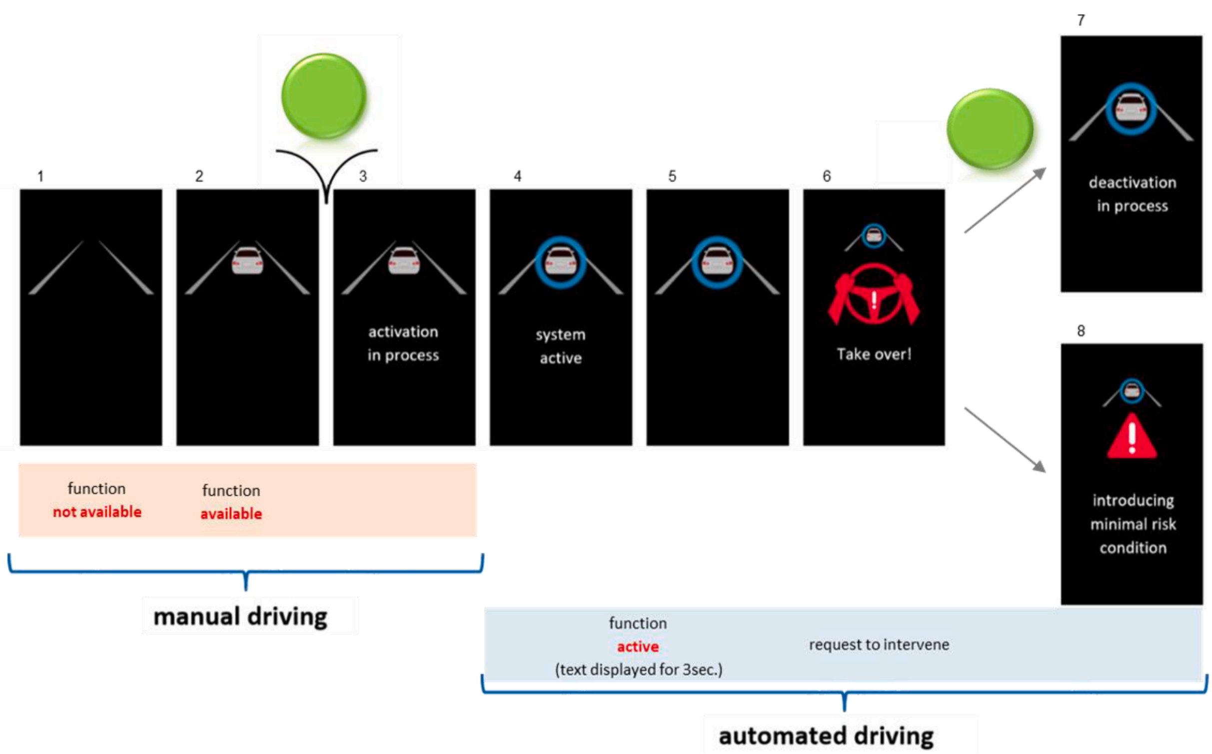

Fig. 5. Human-machine-interface of the automated driving function in the Wizard-of-Oz vehicle (Klamroth et al., 2019). The verbal information has been translated into English. The original display was in German language. Green button indicates button press for activation or deactivation, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the one exception of European windstorm Ciara (in German "Orkan Sabine").

2.2.3. Experimenters

In total three experimenters were needed. Experimenter 1 was the wizard driver, experimenter 2 drove the lead vehicle, experimenter 3 placed the balloon car on the middle lane for the final circuit.

2.2.4. Wizard-of-Oz vehicle

The Wizard-of-Oz vehicle of BASt was used to simulate the Level 3 driving automation function. It is based on a Volkswagen Caddy Maxi (automatic transmission, 140 HP, year of manufacture: 2013) which has been equipped with a second steering control in the vehicle's rear (Marx and Frey, 2018). Fig. 4 shows a schematic setup of the Wizard-of-Oz vehicle. The rear is separated from the driver's cabin by a tinted window. The participant is seated in the driver seat, a wizard driver is seated in the vehicle's rear and uses the second steering control to simulate the driving automation system. The wizard driver has unobstructed view through the tinted window, whereas the participant in the driver's seat cannot look through the tinted window to see the rear. The participant

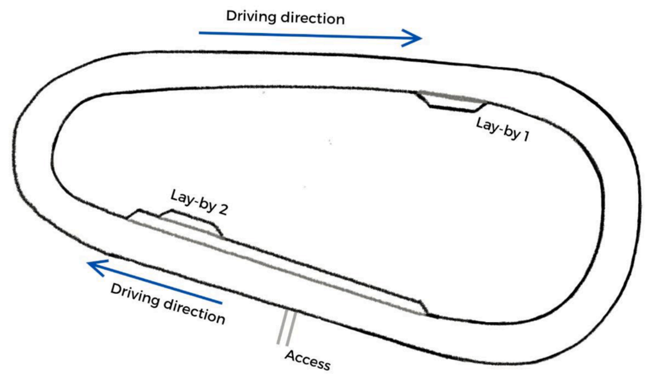

Fig. 6. Oval circuit of the Aldenhoven Testing Center.

was unaware of the Wizard-of-Oz principle until debriefing at the end of the experiment.

The human–machine-interface (HMI) of the automated driving function is depicted in Fig. 5: The left display (1) indicated the function was not available. When the automated driving function became available, a vehicle icon appeared additionally in the HMI (display 2 in Fig. 5). To activate the system, participants pressed the green button on the steering wheel. An additional text display "activation in process" appeared to confirm activation by the participant (display 3 in Fig. 5). Quickly after, a blue circle appeared around the vehicle icon in the HMI together with the verbal notice "system active" (display 4 in Fig. 5). The text disappeared after 3 sec., leaving the vehicle icon and the blue circle to indicate Level 3 automated driving mode (display 5 in Fig. 5). When a system limit was approached, a request to intervene was issued (display 6 in Fig. 5). The request to intervene consisted of a change in the HMI icon and a tone. Participants deactivated the system by pressing the green button on the steering wheel again. Deactivation was confirmed by the text display "deactivation in process" (display 7 in Fig. 5). When deactivation was completed, the HMI changed back to display 1 in Fig. 5. Participants could also deactivate the function of their own accord, however, were asked not to do so. Display 8 was explained to participants but never appeared. In case participants did not take over the driving task or in case of other emergency situations that required to seek a minimal risk condition, display 8 would be shown. Generally, the blue circle surrounding the vehicle icon indicated that the automated driving function was still active.

2.2.5. Lead vehicle

A lead vehicle was used to simulate a traffic jam situation on the test track. The experimenter driving the lead vehicle followed a script to simulate the same traffic jam to all participants (cf. Appendix A: Standardized traffic jam for all conditions). During the first two weeks the lead vehicle was a Volkswagen Golf Variant of silver color. During the last two weeks, the lead vehicle was a Volkswagen Passat of silver color.

2.2.6. Driving automation system

The driving automation system was simulated by the wizard driver. Participants were told that the driving automation system could operate in traffic jam situations and stop-and-go traffic with a max. speed of 60kph. When the traffic jam dissolved, that is, when the lead vehicle accelerated to a speed above 60kph and the gap between the lead vehicle and ego vehicle increased, a request to intervene was issued. The participant then had to regain vehicle motion control and continue the ride in Level 0. This functionality is based on UN Regulation No. 157.

2.2.7. Test track

The experiment took place at the Aldenhoven Testing Center of RWTH Aachen University GmbH (ATC) (see Fig. 6). The oval circuit and both lay-bys were used. The oval circuit with a total length of approx. 2 km represents a three-lane German highway mock up. The straight sections are each 400 m in length. Lay-by 1 served as the parking space for the balloon car. The balloon car was hidden behind another vehicle to limit participants' conspicuousness and was employed only in the last circuit before exiting the test track. Lay-by 2 served as the starting and end point for all conditions, except the last condition that ended with leaving the test track.

2.2.8. Traffic jam

The lead vehicle simulated a standardized traffic jam on the test track (cf. Appendix A: Standardized traffic jam for all conditions). All participants experienced the same traffic jam in each condition.

2.2.9. Non-driving related tasks

Participants engaged in three non-driving related tasks (order counterbalanced across participants). They watched a nature documentary film on a convertible laptop, they read a text and typed a summary of it on the same convertible laptop, and they played Tetris on a tablet. The respective tasks were chosen due to different extent of compatibility to the driving task (see Table 1). Tetris is a visual and spatial task that requires a manual reaction depending on the visual-spatial processing of the input. Reading a text and typing a summary of it is a visual, but not spatial task that requires a motoric output (typing a summary) depending on the visual input (text) and its processing. Watching a documentary film is a mainly visual task that does not require any reaction.

2.3. Procedure

The experiment consisted of a pre-interview, the experimental ride and a post-interview that ended with a debriefing. Participants were tested individually.

2.3.1. Pre-interview

Upon arrival at the Aldenhoven Testing Center (ATC), participants were seated in an office and first watched a short film by ATC that explained their terms of use. Next, participants gave written informed consent and answered the questionnaires on motion sickness (MSSQ-S)

Table 1
Overview on demands of non-driving related tasks and their similarity to the driving task.

		driving task	playing Tetris	reading & typing a summary	watching a film
input	visual	✓	✓	✓	✓
	spatial	✓	✓		
	phonological			✓	✓
	central executive	✓	✓	✓	
output	motoric	✓	✓	✓	
	time of output execution depends on input	✓	✓		
	type of output depends on input	✓	✓	✓	

Note. ✓ marks the working memory modules that are central for performing the respective task. The aim is to describe similarity between the non-driving related task and the driving task.

Table 2
Overview on dependent variables for quantitative analysis.

variable	abbrev.	unit	operationalization
takeover time	TOT	[s]	time span from onset of request to intervene to deactivation of the driving automation function by button press
time to collision	TTC	[s]	time span starting from point in time when Wizard-of-Oz vehicle has completely left the lane until the hypothetical point in time when the Wizard-of-Oz vehicle would collide with the balloon car assuming the current speed would be maintained
minimum / maximum lateral acceleration	min. / max. acc. lat.	[m/ s^2]	lowest (highest) lateral acceleration after participant is in control of vehicle motion. For first and second takeover: minimum (maximum) within a period of 30 s after completed takeover. For third takeover: minimum (maximum) during evading maneuver. For manual driving after third takeover: minimum (maximum) within a period of 30 s after completed evading maneuver (return to right lane)
minimum / maximum longitudinal acceleration	min. / max. acc. long.	[m/ s^2]	lowest (highest) longitudinal acceleration after participant is in control of vehicle motion. For first and second takeover: minimum (maximum) within a period of 30 s after completed takeover. For third takeover: minimum (maximum) during evading maneuver. For manual driving after third takeover: minimum (maximum) within a period of 30 s after completed evading maneuver (return to right lane)

and driving style (MDSI), and questions on sociodemographic factors and prior experiences in using driver assistance systems or automated driving systems. After answering the questionnaires, the experimenter explained specifics of the Wizard-of-Oz vehicle and how to use the automated driving system. Participants were informed in detail about their role as a fallback-ready user during the automated driving phases. The three non-driving related tasks were explained and participants familiarized themselves with each task. After that, participants were seated in the Wizard-of-Oz vehicle and were again shown the specifics of it and how to engage and disengage the automated driving function.

2.3.2. Experimental ride

First, participants drove four circuits for the purpose of **training and familiarization** with the Wizard-of-Oz vehicle. In the first two circuits, participants familiarized with manual driving without following a lead vehicle. The driving automation system was not available. In the third and fourth circuit, participants followed the lead vehicle with a max. speed of 60 kph and they familiarized with using the driving automation system. Participants engaged the driving automation system, experienced automated driving phases and requests to intervene and disengaged the automation upon system request. At the end of the fourth circuit, the lead vehicle braked to standstill and the participant was instructed to perform a lane change and to evade to the left. After the fourth circuit, participants stopped at lay-by 2.

The **experimental ride** included three conditions per participant. For each condition, participants engaged in one non-driving related task (order counterbalanced across participants). Only the last condition involved the balloon car scenario. Every experimental condition started and ended at lay-by 2 (Fig. 6), except for the last condition that ended with leaving the test track. At lay-by 2, the experimenter (wizard driver) got off the vehicle, opened the door on the passenger's seat side and prepared the non-driving related task and the flow questionnaire (FKS) for the next condition. The device for the non-driving related task and the questionnaires were placed in the box on the passenger's seat. The box was fastened with a seat belt to prevent sliding or moving during the ride. The experimenter asked the participant if they remembered the non-driving related task. If necessary, the non-driving related task was explained again. After the experimenter got on the vehicle again and took the role of the wizard driver, she signalized the experimenter in the lead vehicle to start the next experimental condition. Experimenters communicated by walkie-talkie unheard by participants.

The participant followed the lead vehicle to access the oval course. The driving automation system became available at the beginning of the oval course's first curve. Participants were instructed to activate the driving automation system as soon as it was available and they felt comfortable to activate it. After activation of the driving automation system, participants engaged in the non-driving related task. Each condition consisted of five circuits and lasted approx. 15 min. In each condition's third circuit, the wizard driver asked the participant to answer the flow questionnaire (FKS). The questionnaire was answered during the ride. After completing the questionnaire, participants engaged in the non-driving related task again. Seated behind the participant, the wizard driver could see whether participants engaged in the non-driving related task. If they had stopped the task for a longer period of time, the wizard driver asked participants to re-engage in the respective task. A request to intervene was issued in each condition's fifth circuit on the straight section of the oval course before lay-by 1. After takeover, participants drove half a circuit manually and stopped at lay-by 2, where the experimenter changed the non-driving related task. Then the next condition started.

Throughout the experiment, the right lane was used. Only in the final circuit (fifth circuit of the third condition), the middle lane was used. After takeover in the final circuit, the participant was confronted with the balloon car.

For the **balloon car scenario**, experimenter 3 moved the balloon car onto the oval course's middle lane after the participant drove past lay-by 1 in the fourth circuit of the third condition. To allow participants to evade to the left and right, in the beginning of the fifth circuit, the lead vehicle changed to the middle lane and the wizard driver followed. The request to intervene was issued at the same place as in the previous two conditions. The only difference was that the vehicles drove on the middle lane. The distance between the onset of the request to intervene and the balloon car was approx. 175 m. At a constant speed of 60kph, this leaves at least 10 s up to the collision with the balloon car. Participants did not see the balloon car at the moment of takeover because the lead vehicle blocked sight. The lead vehicle cut out to the left in short distance to the balloon car. Cutting out revealed the balloon car to the participant. After evading the balloon car, participants drove half a circuit manually, exited the test track and parked the vehicle in the parking lot.

2.3.3. Post-interview and debriefing

After the ride, participants were seated in the office again and answered the questionnaire on trust and received an allowance of 40 Euros. Participants were asked how they imagined the automation works (no participant assumed a second driver in the rear), and were led back outside to the Wizard-of-Oz vehicle for debriefing. The Wizard-of-Oz method and the second steering control in the rear were revealed to the participant and any remaining questions were answered.

2.4. Design and data-analysis

Our experiment follows a 3 × 2 mixed design with non-driving related task as a within subject factor and daytime/dark as a between subject factor. If not stated otherwise, two-tailed *p*-values are reported. Table 2 provides an overview on dependent variables and their definitions.

Table 3
Mean takeover times by order and by non-driving related task.

	by order			by non-driving related task		
	First takeover	Second takeover	Third takeover	Film	Reading & typing	Tetris
N	30	34	30	31	33	30
Min.	2.79	3.26	2.96	2.79	3.13	2.96
Max.	11.94	14.63	9.87	11.94	14.63	10.60
Mean	6.43	6.68	6.39	6.96	6.78	5.74
SD	2.60	2.62	1.86	2.53	2.39	2.05

Note. minimum, maximum, mean and standard deviation reported in seconds.

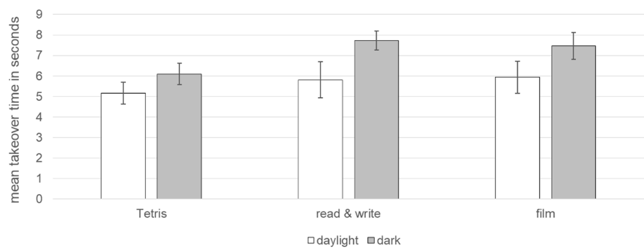

Fig. 7. Mean takeover times depending on non-driving related task and daytime/dark. Takeover times measured from onset of request-to-intervene until participant's button press to deactivate the automation. Error bars represent standard errors.

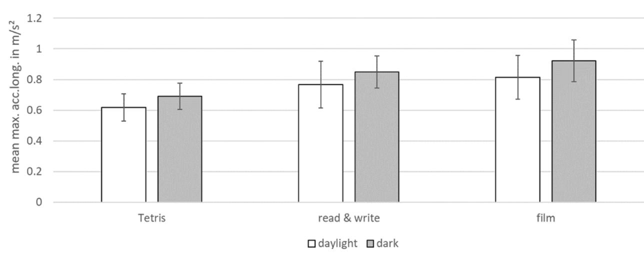

Fig. 8. Maximum longitudinal acceleration after takeover by non-driving related task and daytime/dark. max. longitudinal acceleration after takeover averaged across participants. Error bars represent standard errors.

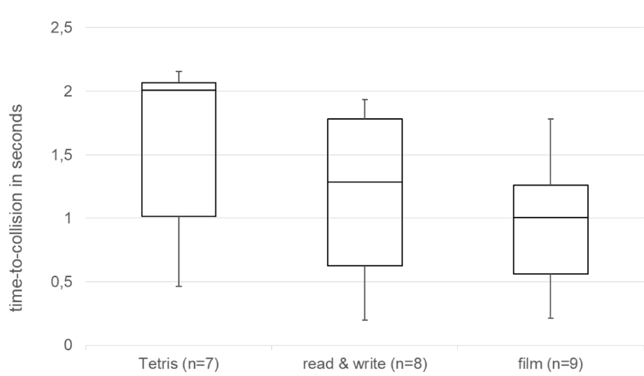

Fig. 9. Boxplots for time-to-collision by non-driving related task.

3. Results

3.1. Pre-analysis

The two groups of participants (daytime: 7 women, 11 men, M_{age} = 45.2 years, SD_{age} = 14.4 years; dark: 8 women, 10 men, M_{age} = 39.3 years, SD_{age} = 15.2 years) show no statistically significant differences regarding their demographic variables, driving styles and trust in automation. Takeover times after the first, second and third takeover do not show systematic differences, indicating that there were no training effects in the course of the experiment, $F < 1$. Kolmogorow-Smirnov-tests for normal distribution do not indicate significant deviation from normal distribution (an assumption of ANOVA) for time-to-collision and takeover times, $ps = 0.20$.

3.2. Main analysis

First, takeover times will be reported. Takeover times were measured in each condition. Next, the balloon car situation will be analyzed. The balloon car situation took place in each participant's last condition.[1]

3.2.1. Takeover time

Takeover times were logged for each condition, resulting in three takeover times per participant. Due to technical problems, several takeover times were not logged, leaving $n = 30$ takeover times for the first condition, $n = 34$ for the second and $n = 30$ for the third condition. This corresponds to $n = 31$ takeover times following watching a film, $n = 33$ following reading & typing and $n = 30$ following playing Tetris.

Out of 36 participants, five participants needed longer than 10 s (UN Regulation No. 157) for at least one takeover. In total eight takeover times exceeded 10 s, with four cases following watching a documentary film, two cases following reading & typing and two cases following playing Tetris. Table 3 shows descriptive statistics of takeover time.

A 3 × 2 repeated measures ANOVA on takeover times with non-driving related task as the within-subject factor and daytime/dark as the between-subjects factor reveals a main effect for non-driving related task, $F(2, 23) = 4.27$, $p = .013$, $\eta^2_{partial} = 0.314$, and a marginal significant main effect of daytime/dark, $F(1, 24) = 3.52$, $p = .073$, $\eta^2_{partial} = 0.128$, with longer takeover times in the dark than at daytime. There is no interaction between the factors daytime/dark and non-driving related task, $F(2, 48) < 1$ (see Fig. 7). Regarding the main effect of non-driving related task, Helmert contrasts show that takeover times following playing Tetris ($M = 5.66$, $SD = 1.94$) were shorter compared to the two other non-driving related tasks, $F(1, 24) = 10.56$, $p = .003$, $\eta^2_{partial} = 0.306$, and takeover times following watching a documentary film ($M = 6.76$, $SD = 2.64$) and reading & typing ($M = 6.84$, $SD = 2.58$) did not differ, $F < 1$.

3.2.2. Takeover quality

A 3 × 2 repeated measures ANOVA on minimum and maximum lateral acceleration and minimum and maximum longitudinal acceleration with non-driving related task as the within-subject factor and daytime/dark as the between-subjects factor reveals no significant main effects and no interactions, all $p > .05$. The main effect closest to reach significance was the effect of non-driving related tasks on maximum longitudinal acceleration, $F(2, 24) = 2.732$, $p = .085$, $\eta^2_{partial} = 0.185$ (see Fig. 8). Numerically, maximum longitudinal accelerations in the Tetris condition ($M = 0.65$, $SD = 0.32$) are lower than in the documentary film condition ($M = 0.81$, $SD = 0.48$) and the reading & typing condition ($M = 0.87$, $SD = 0.51$).

3.2.3. Time to collision

Time-to-collision data are related to the balloon car scenario that took place in each participant's last condition. For different reasons, data of several participants were not logged or had to be excluded from

[1] Following an anonymous reviewer's esteemed suggestion, we performed additional analyses including driving experience (annual mileage) as a covariate, otherwise analogous to the analyses reported in this section. Results are unchanged after including the covariate. Only for takeover time, the second Helmert contrast also becomes significant. Results on takeover time are therefore reported in Appendix B: Results on additional analyses including driving experience as covariate.

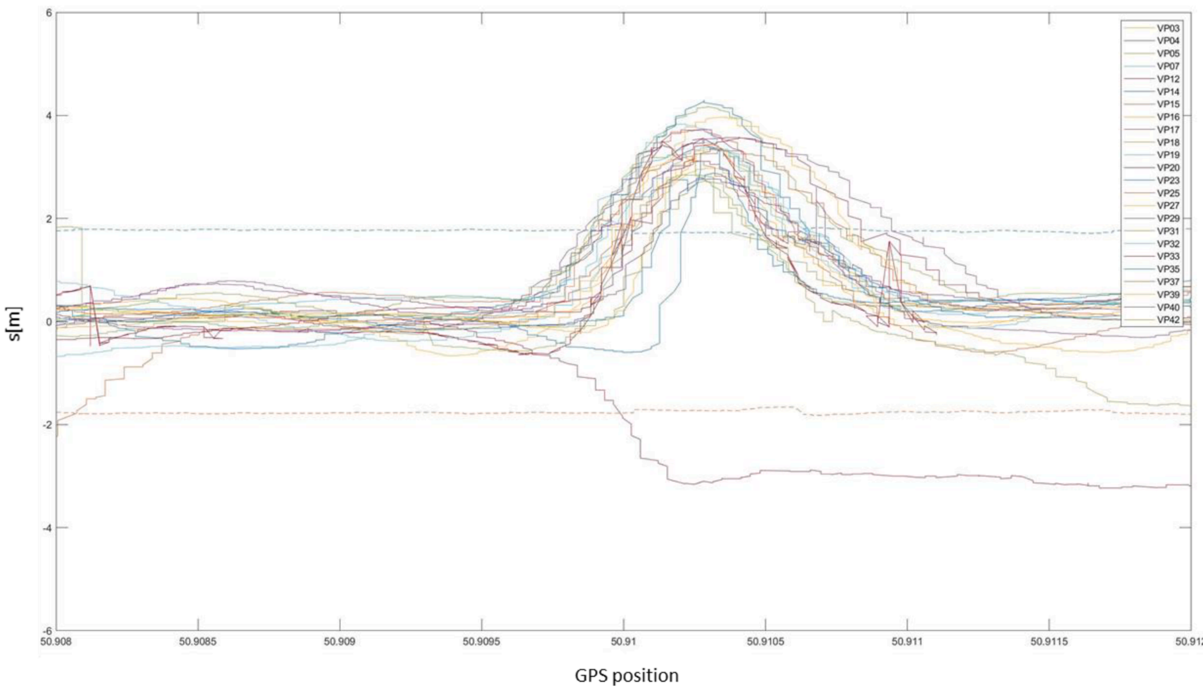

Fig. 10. Plotted trajectories of evading the balloon car.

Table 4
Results of univariate one-factorial ANOVAs for the evading maneuver.

dependent variable	daytime/dark	non-driving related task
min. acc. lat.	$F(1, 24) = 6.37$, $p = .019$	$F(2, 23) < 1$
max. acc. lat.	$F(1, 24) < 1$	$F(2, 23) = 1.43$, $p = .261$
min. acc. long	$F(1, 24) < 1$	$F(2, 23) = 1.40$, $p = .266$
max. acc. long.	$F(1, 24) < 1$	$F(2, 23) < 1$

Table 5
Results of univariate one-factorial ANOVAs for the manual driving behavior after passing the balloon car.

dependent variable	daytime/dark	non-driving related task
min. acc. lat.	$F(1, 19) < 1$	$F(2, 17) = 3.16$, $p = .068$
max. acc. lat.	$F(1, 19) = 1.46$, $p = .243$	$F(2, 17) = 2.78$, $p = .090$
min. acc. long.	$F(1, 19) < 1$	$F(2, 17) < 1$
max. acc. long.	$F(1, 19) = 1.20$, $p = .288$	$F(2, 17) < 1$

the analysis of the balloon car scenario, leaving a sample of $n = 24$. Two separate ANOVAs were performed because in case of a two-factorial ANOVA cell sizes would be too small (between $n = 3$ and $n = 6$). No main effect of non-driving related task, $F(2, 21) = 1.262$, $p = .304$, $\eta 2_{partial} = 0.107$, and no main effect for daytime/dark, $F < 1$, was found.

Numerically, time to collision values were greater after playing Tetris than after watching a documentary film or reading and writing (Fig. 9).

3.2.4. *Flow experience*

Due to missing values, for calculation purposes the mean was calculated instead of the sum as proposed by Rheinberg et al. (2003). For the total flow score, a 3 × 2 mixed design ANOVA shows a main effect for non-driving related tasks, $F(2, 34) = 9.542$, $p < .001$, $\eta 2_{partial} = 0.219$. There was no main effect for daytime/dark and no interaction, $Fs < 1$. To further examine the main effect for non-driving related tasks, post hoc tests were conducted. Alpha errors were corrected applying Bonferroni correction , yielding . Post hoc tests indicate that flow experience while reading and typing ($M = 4.65$, $SD = 1.21$) was significantly lower than while watching a documentary film ($M = 5.17$, $SD = 1.32$), $t(35) = 2.822$, $p = .008$, $d = 0.470$, or while playing Tetris ($M = 5.33$, $SD = 1.07$), $t(35) = 4.359$, $p < .001$, d = 0.727. No difference was found between Tetris and watching a film, $t(35) = 1.195$, $p = .240$, $d = 0.199$.

There is no significant correlation between flow experience and takeover times (all $r < 0.40$, $p > .05$), and acceleration values (r between -0.34 and 0.28, all $p > .05$).

3.2.5. *Evading maneuver*

Most participants evaded the balloon car by changing to the left lane. One participant changed to the right lane. Another participant would have collided with the balloon car if the wizard driver had not intervened. Fig. 10 shows participants' trajectories when evading the balloon car. Due to small sample sizes separate one-factorial ANOVAs were calculated for each factor. Table 4 shows the results of the ANOVAs.

3.2.6. *Subsequent manual driving behavior*

Manual driving behavior after passing the balloon car was evaluated for a period of 30 s. Again two separate one-factorial ANOVAs were conducted due to small remaining sample size. Results are shown in Table 5.

3.2.7. *Video analysis of takeover behavior*

Some videos of rides in the dark were too dark to be coded, leaving a subset of $n = 28$. In at least one takeover situation, 46.4 % of those participants showed at least one of the following traffic safety relevant

Table 6
Examples of previous studies reporting takeover times after a request to intervene issued by a SAE Level 3 driving automation system.

publication	apparatus	mean takeover times	takeover time definition
present experiment	Wizard-of-Oz on test track	5.17 s – 7.72 s	deactivation by pressing button on steering wheel
Frey, 2021	Wizard-of-Oz on test track	approx. 6.1 s	deactivation by pressing button on steering wheel
Naujoks et al., 2019	Wizard-of-Oz in real traffic	2.77 s –5.50 s	deactivation by pulling levers on the steering wheel
Dogan et al., 2019	driving simulator	3.09 s – 5.21 s	deactivation via pedals, steering wheel or de-/activation handle
Klamroth et al., 2019	Wizard-of-Oz on test track	3.62 s	deactivation by pressing button on steering wheel
	Wizard-of-Oz in real traffic	3.58 s	
Zeeb et al., 2017	driving simulator	2.30 s – 3.15 s	first steering or braking
Feldhütter et al., 2018b	driving simulator	approx. 3 s	start of maneuver
Chen et al., 2021	driving simulator	1.83 s – 2–80 s	$>2^\circ$ steering wheel angle or $> 10^\circ$ brake pedal use
Radlmayr et al., 2018	driving simulator	approx 1.7 s – 2.8 s	$>2^\circ$ steering wheel angle or $> 10^\circ$ pedal use
Wintersberger et al., 2021	driving robot in real vehicle on test track	1.01 s – 1.29 s	first steering action $> 2^\circ$

behaviors after deactivation of the driving automation function: moving the driver's seat back to driving position, switching off the interior light in the dark, not looking at all to the adjacent lane when evading the balloon car.

These criteria's relevance for traffic safety shall be illustrated by the following case analysis:

3.2.7.1. Participant description. The participant is a 27 years old student of literary and linguistic studies. The participant states an annual mileage of 10,000 km with mostly private driving purposes (instead of professional). Regarding prior experience with driver assistance systems, the participant indicates the scale's minimum value. The participant states to have never experienced any motion sickness symptoms (MSSQ). On the multidimensional driving style inventory (MDSI), the participant scores high values on the factors "anxious driving style", "patient driving style" and "careful driving style". The participant indicates high trust (4.17) and low distrust (1.00) on the German version of the "Checklist of Trust between People and Automation" (Pöhler et al., 2016).

3.2.7.2. Video analysis: description of initial situation. The ride took place in the dark. It was raining, wipers were active, the roadway was wet. The driver's seat has been put back and the interior light is switched on. The participant works on the reading & writing task with the laptop placed on the lap. The participant has indicated a very low flow experience (< 2 SD below mean) while performing the task (total score = 31 with "absorption" subscale = 14 and "smooth automated progression" subscale = 17; *T*-value of total score = 37; Rheinberg et al., 2019). The participant is typing when the request to intervene is issued.

3.2.7.3. Video analysis: description of takeover behavior. When the request to intervene is issued, the participant quickly interrupts typing and places the laptop in the box on the passenger's seat, then moves both hands to the steering wheel and presses the button to deactivate the driving automation system (takeover time = 6.21 s). The participant tries to reach the gas pedal with the right foot, however, cannot reach it. The participant moves the right hand below the driver's seat and pulls the seat forward. The left hand remains on the steering wheel. In this position, while the driver's seat is sliding forward, the participant changes to the left lane in order to evade the balloon car (max. lateral acceleration = 3.69 m/s2). After passing the balloon car, the participant returns to the middle lane (min. lateral acceleration = -2.04 m/s^2).

The gaze behavior is parallel to the actions, that is, when the request-to-intervene is issued, the participant immediately looks up and briefly looks to the HMI and to the front. Then the gaze moves to the passenger's seat where the laptop is placed. After placing the laptop, the gaze moves to the steering wheel, then the HMI and front. When the participant pulls the driver's seat forward, the gaze moves down to the seat briefly, then quickly returns to the front again. The participant does not show gazes to any side mirrors neither when changing to the left lane nor when changing back to the middle lane.

The participant does not switch off the interior light until the end of the ride.

TTC value cannot be reported because distances to lane markings and distance to the balloon car were not reliably detected.

4. Discussion

First, we address our experiment's central assumptions and our three research questions. Second, we compare our results to previous literature. Third, we discuss the theoretical and practical implications of our experiment, including possible future research. Finally, we provide a conclusion of our study.

4.1. Answering the research questions

Our experiment contributes to research on differentiation of non-driving related tasks in terms of their effects on takeover. Specifically, we propose and investigate a theoretical basis that covers the characteristics of both the non-driving related task and the Level 3 driving automation context: Considering task switching theory (Rubinstein et al., 2001), we assume that non-driving related tasks that are similar to the subsequent driving task will be followed by shorter takeover times and higher takeover quality compared to non-driving related tasks that are dissimilar to the driving task (Spence et al., 2001). Based on this theoretical basis, our research questions read as follows:

4.1.1. RQ1: Do task switching and modality shifting effects cause differences in takeover behavior and following manual driving behavior in a real driving setting?

To answer this question, we selected three non-driving related tasks with different similarity to the driving task (playing Tetris, reading &

writing, watching a documentary film) and investigated their effects on takeover performance and manual driving behavior. Tetris has a higher similarity to the driving task (both visual and spatial tasks requiring adaptive output depending on the visual and spatial input) compared to watching a documentary film (visual, yet not spatial, no reaction needed) and reading & typing a summary of the text (visual, yet not spatial, motoric reaction needed).

Our results are in accordance with our hypothesis: **Takeover** times following an automated driving phase during which participants played Tetris are lower compared to takeover times following the two other non-driving related tasks. Regarding accelerations as indicators for takeover quality, no significant effects were found between non-driving related tasks. The maximum longitudinal acceleration was closest to reach significance. Numerically, maximum longitudinal accelerations following playing Tetris were lower than following the two other non-driving related tasks. This pattern is in accordance with our assumptions.

Time-to-collision data indicate that the **subsequent manual driving behavior** in the balloon car scenario was descriptively less critical following an automated driving period where participants played Tetris compared to the other two non-driving related tasks. In this context, the small remaining sample sizes need to be considered that might counteract statistical significance. Further research is needed to support these descriptive effects.

4.1.2. RQ 2: Does takeover behavior in the dark differ from takeover behavior at daytime?

To answer this question, experimental rides took place at daytime and in the dark. Takeovers in the dark took longer than takeovers at daytime (prolongation after playing Tetris: +0.92 s, watching a documentary film: +1.53 s, reading & typing: +1.90 s). Prolonged takeover times may be due to several reasons: Darkness itself hampers seeing the driving environment, which might lead to a decrease in perceived urgency of takeover. Moreover, circadian rhythm may lead to higher fatigue compared to rides at daytime. Another reason could be that participants took part in our study after work, which might cause additional fatigue compared to participants taking part at daytime. Darkness did not change effects of non-driving related tasks on takeover time. Lateral and longitudinal acceleration after takeover, as indicators for takeover quality, do not differ between rides at daytime and rides in the dark.

4.1.3. RQ 3: Does flow experience while performing non-driving related tasks have an impact on takeover performance?

Flow experience during non-driving related task engagement did not correlate with following takeover time or acceleration parameters. Hence, we cannot conclude that flow experience influences takeover time and takeover quality.

4.2. Comparison to previous studies

Compared to previous studies, mean takeover times resulting from our study are rather high (see Table 6). Since a takeover situation's urgency and the provided time budget for takeover influence participants' takeover time (Gold et al., 2013; Zhang et al., 2019), these might have influenced the generally higher takeover times in our experiment. Takeover situations in our experiment took place on a straight section of the test track. From participants' perspective, the request to intervene was caused by the lead vehicle accelerating beyond 60kph which constitutes a system limit. It can be assumed that participants perceived the takeover situation as rather uncritical and not urgent since they did not expect an obstacle. Future research might investigate further circumstances under which participants will need more time.

4.3. Implications for theory

Current research on effects of non-driving related tasks on takeover behavior in Level 3 automated driving tends to describe non-driving related tasks in terms of one (primary) characteristic (e.g. Lee et al., 2021; Radlmayr et al., 2018). Based on this notion, tasks are described as a "visual task", "cognitive task" or "motoric task" (Radlmayr et al., 2018). A recent meta-analysis follows this approach and indicates that takeover time is prolonged after engaging in a visual task compared to an auditory or a cognitive task (Zhang et al., 2019). Furthermore, handheld non-driving related activities compared to not handheld activities extend takeover time (Zhang et al., 2019). The perspective of looking at s single main characteristic of a non-driving related task not only reduces the respective task to this single characteristic, but also isolates the engagement in a non-driving related task from its context in Level 3 automated driving.

In addition, non-driving related tasks in experimental settings are usually instructed by experimenters and clearly defined. This might contrast with the natural automated driving setting where participants might engage in an activity that is not clearly defined or instructed. Furthermore, in a natural context, users might engage in more than one task at a time or might change from one task to another during the automated driving period. These aspects are commonly not reflected in experimental setups which is why we apply the term *non-driving related activity* when referring to the natural automated driving context. We distinguish the non-driving related activity from the *non-driving related task* because the non-driving related task is the experimental tool needed and used to simplify and abstract the natural context for the purpose of estimating effects of non-driving related activities.

Looking at the "single characteristic" approach to describe and differentiate non-driving related tasks, this might be applicable at the task-level in experimental settings, especially for standardized tasks such as SuRT and *n*-back. However, when moving towards non-driving related activities in the natural automated driving setting, it becomes increasingly difficult to identify the one characteristic.

Our approach of comparing similarity between a previously performed non-driving related task and the subsequent driving task contributes to resolving this issue. Instead of identifying and focusing on one characteristic, our approach pictures the psychological demands of a task. This approach is applicable to both tasks used in experimental settings and activities in natural automated driving settings. Our experiment provides first support for the application on natural activities as well as for the potential to differentiate subsequent effects on takeover behavior. The experimental character of our study indicates that the approach might be even suitable for explaining and predicting such effects.

Since this is a first study, its reliability needs to be tested in future studies. For instance, we focused on providing a natural automated driving setting and, therefore, selected natural non-driving related activities as experimental tasks. However, these activities may differ in aspects other than cognitive demands (which are the focus of our study). Replication with standardized tasks could underline our theoretical claim in terms of similarity in cognitive demands. Furthermore, our study raises the question under which conditions multiple task performance theories and task switching theories are more suitable to explain and predict effects of non-driving related tasks performed during an active Level 3 automated driving phase on following takeover and manual driving behavior. For example, from the perspective of multiple task performance theories, it could be argued that fallback-ready users do not disengage from the driving task mentally after activation of the Level 3 driving automation system, which leads to multiple task performance situations when users engage in non-driving related activities, even during Level 3 automated driving phases. In the context of which theory is valid under which conditions, futures studies could, for example, address the assumption of not disengaging from the driving task mentally during Level 3 automated driving.

4.4. Implications for practice

The takeover times of our study mostly fall into the time span stated in UN Regulation No. 157. It demands to provide the user 10 s time for taking over the driving task. In our study, five of 36 participants (13.89 %) did not take over within 10 s. Regarding traffic safety, it is highly advantageous that the above regulation does consider a minimum risk maneuver in case the user did not take over the driving task, even though the technical definition by SAE J3016 (2021) does not require so.

The necessity and importance of users' fallback-readiness needs to be communicated sufficiently, not only regarding the provided time for takeover, but also when considering that 46.4 % of our participants showed some kind of poor behavior at least once during the three takeover situations of our experiment. A case analysis shows the relevance of these minor misbehaviors, especially when they accumulate. It might be argued that participants of our study might be prone to such misbehaviors due to lack of experience. In this context, it needs to be noted that (1) participants showed misbehavior in the third experimental takeover, too, (2) the experimental ride lasted one hour and included three experimental takeovers and at least two prior takeovers for training and familiarization purposes. In a natural automated driving setting using a traffic jam pilot, participants might not experience as many takeovers within a one hour ride. (3) Each participant was informed on his or her role as a fallback-ready user as well as on safe takeover behavior before the experimental ride one-on-one. This intensive instruction and information are likely to be artificial when compared to real driving settings.

Hence, we see the need to raise users' awareness for both being the fallback-ready user while using Level 3 driving automation, and for safe takeover upon a system's request to intervene.

Whether the traffic safety effect of information and instruction provided before the ride has been diluted in the course of experiencing Level 3 automated driving, is another open question for future research.

4.5. Conclusion

Characteristics of a non-driving related task influence takeover behavior and following manual driving behavior depending on the compatibility of demand profiles of the respective non-driving related task and the following driving task. A low extent of compatibility between demand profiles incurs longer takeover times and might lead to more critical subsequent manual driving behavior compared to a high degree of compatibility. Takeovers in the dark take longer than takeovers at daytime. Darkness does not alter the effects of non-driving related tasks on takeover behavior. Future research might investigate demand compatibility effects in further activities and using other Level 3 driving automation functionality.

CRediT authorship contribution statement

Elisabeth Shi: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition. **Klaus Bengler:** Conceptualization, Methodology, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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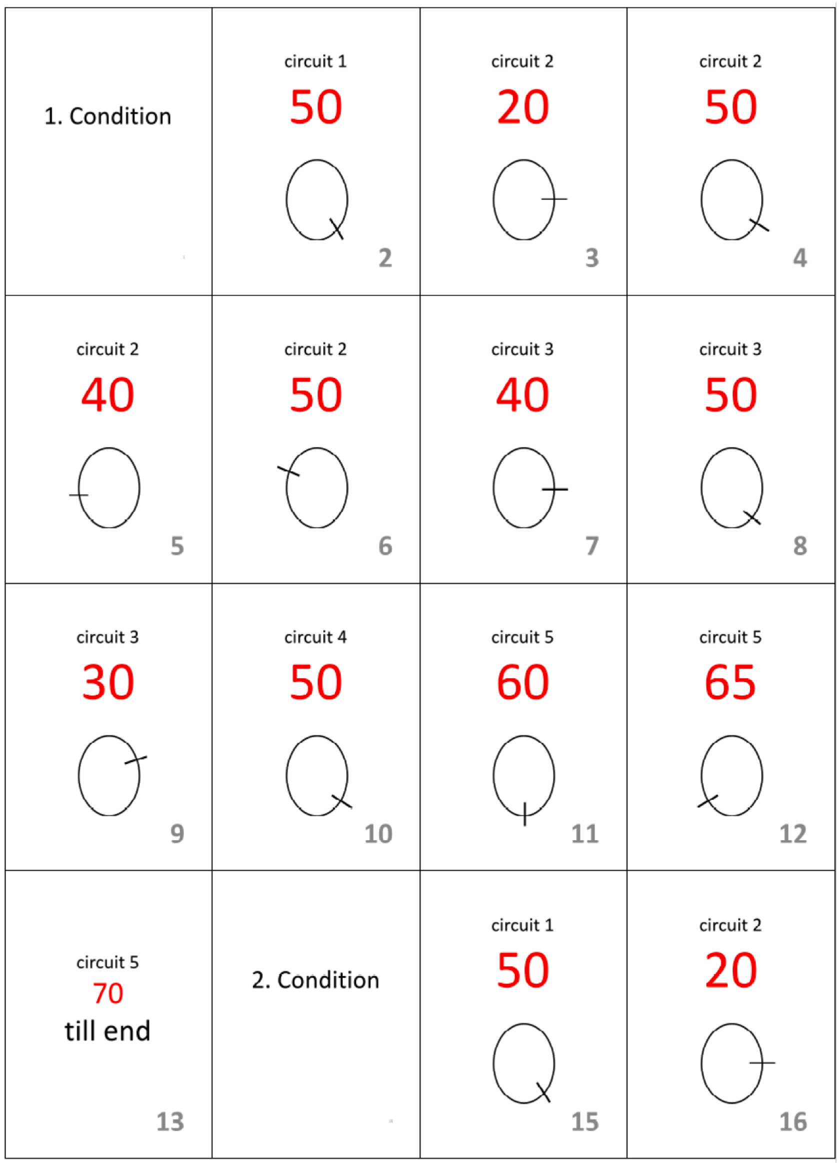
Appendix A:. Standardized traffic jam for all conditions



circuit 2 50 17	circuit 2 40 18	circuit 2 50 19	circuit 3 40 20
circuit 3 50 21	circuit 3 30 22	circuit 4 50 23	circuit 5 60 24
circuit 5 65 25	circuit 5 70 till end 26	3. Condition	circuit 1 50 28
circuit 2 20 29	circuit 2 50 30	circuit 2 40 31	circuit 2 50 32

circuit 3 40 33	circuit 3 50 34	circuit 3 30 35	circuit 4 50 36
circuit 5 60 37	circuit 5 65 38	circuit 5 65 CUT OUT Balloon Car! 39	

Note. The oval represents the oval circuit of the Aldenhoven Testing Center of RWTH Aachen University GmbH (cf. Fig. 6). The access to the oval circuit is on the left side of the depicted oval. The slides were used by the experimenter who drove the lead vehicle and simulated a traffic jam. The red numbers indicate driving speeds in kph. A line marks the position on the oval circuit from where the experimenter starts to adapt vehicle speed to the driving speed indicated in red font color.

Appendix B:. Results on additional analyses including driving experience as covariate

In this appendix, results of the analyses with annual mileage as a covariate are reported. The covariate does not alter effects reported in section 3.2. Only for takeover time, there is a slight difference with the second Helmert contrast reaching significance (see B.2).

B.1 No differences in annual mileage between groups

Annual mileage in kilometers serves as the indicator for driving experience. Table 7 shows the descriptive statistics for the total sample and for the groups by daytime/dark and non-driving related task in the third round. A 3 × 2 ANOVA on annual mileage reveals no significant differences between the groups (for non-driving related task in the third round: $F(2, 30) = 1.922$, $p = .164$, for daylight/dark: $F(1, 30) = 1.304$, $p = .262$.

Table 7
Mean annual mileage by day/night group and by non-driving related task in the third round.

	overall	by daylight / dark group		by non-driving related task in the third round		
		daylight	dark	Film	Reading & typing	Tetris
N	36	18	18	11	12	13
Mean	20319.44	23722.22	16916.67	29272.73	14125.00	18461.54
SD	18432.95	25381.92	5547.26	31559.76	3451.78	5871.76

Note. mean and standard deviation reported in kilometers.

B.2 Effects on takeover time

A 3 × 2 repeated measures ANCOVA on takeover times was conducted with non-driving related task as the within-subject factor, daytime/dark as the between-subjects factor and annual mileage as a covariate. The covariate shows a significant main effect, $F(1, 23) = 9.611$, $p = .005$, $\eta^2_{partial} = 0.295$, and a significant interaction with non-driving related task, $F(2, 46) = 4.07$, $p = .024$, $\eta^2_{partial} = 0.150$, but not with daytime/dark, $F(2, 46) = 1.422$, $p = .252$. After controlling for participants' annual mileage, the results remain widely unchanged: There is a main effect for non-driving related task, $F(2, 46) = 3.371$, $p = .043$, $\eta^2_{partial} = 0.128$, and a main effect of daytime/dark, $F(1, 23) = 8.22$, $p = .009$, $\eta^2_{partial} = 0.263$. There is no interaction between the factors daytime/dark and non-driving related task, $F(2, 46) = 1.422$, $p = .252$. Regarding the main effect of non-driving related task, Helmert contrasts show that takeover times following playing Tetris ($M = 5.66$, $SD = 1.94$) were shorter compared to the two other non-driving related tasks, $F(1, 23) = 3.015$, $p = .096$ $\eta^2_{partial} = 0.116$. Different from the analysis reported in 3.2.1, the Helmert contrast comparing takeover times following watching a documentary film ($M = 6.76$, $SD = 2.64$) and reading & typing ($M = 6.84$, $SD = 2.58$) is significant after controlling for paricipants' annual mileage, $F(1,23) = 3.722$, $p = .066$, $\eta^2_{partial} = 0.139$.

For all other dependent variables, after controlling for participants' annual mileage, the results show the same pattern as the results reported in the main analysis (section 3.2).

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