Influence of non-driving-related tasks' motivational aspects and interruption effort on driver take-over performance in conditionally automated driving

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Abstract

Conditionally Automated Driving (CAD) as defined in SAE Level 3 (SAE, 2014) requires the driver as a fallback level in situations the car is unable to handle. The influence of non-driving-related tasks (NDRTs) on drivers' take-over performance is an issue of ongoing debate. The study at hand analyzed subjective and objective take-over measures as a function of drivers' task motivation achieved by the possibility to earn extra money and task interruption effort. A total of $N = 53$ participants (mean age = 32.3 years, SD = 9.7 years) took part in a driving simulator study with eight take-over situations. Higher task interruption effort through the instruction to store the task device in a box produced significantly longer reaction times to the Request to Intervene (RtI) with latencies between 1.5 s and 1.6 s - an equivalent of 50 meters at the implemented set speed. Although in a post-hoc rating participants considered performing the study task for incentive more critical than without external rewards, no differences between motivation conditions showed up in RtI reaction times. Results demonstrated a large impact of task interruption effort on drivers' reaction times in SAE Level 3 take-over scenarios. High task interruption effort is a typical characteristic of real-life NDRTs that requires increased attention in future research on automated driving.

Keywords: automated driving; automation; NDRT; take-over;

Introduction

Driving automation research is a field that has increasingly gained attention within the last decade. The expected benefits of automated driving functions include increased traffic safety (e.g., through the compensation of driver deficiencies and the prevention of so-called "human errors"), the saving of energy (e.g., economizing fuel through a more balanced way of driving) as well as temporal and mental resources (e.g., by releasing the driver from the driving task and allowing him/her to relax or deal with other activities). Conditionally Automated Driving (CAD) has the potential to fundamentally change driving experience as well as driving demands in the near future. It goes one step further than Partial Automation (which is already available on the market by several automobile manufacturers) by relieving the driver from the obligation to continuously monitor the driving environment and system status of the vehicle. Instead, it suffices if he/she is able to respond to a possible take-over request within an adequate period of time (Gasser et al., 2012; NHTSA, 2013; Pfleging, Rang, & Broy, 2016; SAE, 2014). At this level, take-over requests are expected to occur only when system limits are reached. Prominent examples being work zones, highway endings, missing lane markings or system failures. With the necessity of system monitoring being dropped, non-driving-related tasks (NDRTs) that had been distracting or even forbidden during partially automated driving are back on stage and require reassessment.

Comparative studies have shown that different NDRTs produce different take-over outcomes in terms of reaction times and take-over quality (Naujoks, Purucker, Wiedemann, & Marberger, submitted; Vogelpohl, Vollrath, Kühn, Hummel, & Gehlert, 2016). This raises the question if there are higher-level task characteristics that influence drivers' availability in take-over situations. Standardized NDRTs are widely used in automation research for their easy manipulation, reproducibility and adequacy to measure psychological constructs like cognitive workload or distraction. Studies using standardized NDRTs (like e.g., the Surrogate Reference Task or the n-Back-task) provided evidence that driver take-over behavior is influenced by modality of the NDRT (Gold, Berisha, & Bengler, 2015) and traffic situation (Radlmayr, Gold, Lorenz, Farid, & Bengler, 2014). The study at hand uses a different approach by using more naturalistic NDRTs that are closer to realistic driving situations and differ in the rather practical aspects of task motivation and interruption effort.

Public opinion studies indicate that future users of automated driving will engage in motivating tasks, such as texting, eating/drinking, surfing the internet or watching movies (Pfleging et al., 2016; Schoettle & Sivak, 2014). Evidence from real traffic research points into the same direction, showing that drivers who have experience with driving assistance functions show increased secondary task engagement during partially automated driving (Naujoks, Purucker, & Neukum, 2016). Since it is widely accepted that motivating tasks are preferably continued than monotonous ones, we assume that drivers with enhanced task motivation will show longer take-over reaction times and poorer take-over quality than those with lower motivation to continue the task.

Naturalistic NDRTs may also differ from standardized ones in terms of interruption effort, which refers to necessary motoric steps to interrupt the respective NDRT and lay related objects aside. Complex physical tasks like e.g., eating or reading a large newspaper may be hard to interrupt since related objects may have to be cleared away with effort. We therefore suppose that drivers who are engaged in tasks with high interruption effort will show longer take-over times and poorer take-over quality than those engaged in a task with low interruption effort.

The present study compares two different motivational driver states regarding the NDRTs, as well as two differently effortful interruption conditions of these tasks. The impact of these manipulations on drivers’ take-over behavior will be investigated at the example of a broken-down vehicle on the ego-lane.

Method

Driving simulation

The study was conducted in the static high-end driving simulator (Figure 1) of WIVW GmbH. The driving simulation software SILAB was used for environment visualization as well as for simulation of the ADAS for cooperative driving, traffic and vehicle dynamics. An Opel Insignia Sports Tourer is used as mockup of the driving simulator. The simulator had a 300° horizontal and 47° vertical field of vision, with five image channels, each one with a resolution of 1400x1050 pixels. The update frequency was 60 Hz. In addition, there were two LCD displays representing the right and left outside mirror. The interior mirror reflects a LCD display positioned in the trunk of the mockup showing the scenery behind the vehicle. During the experimental drives, the experimenter was able to observe the driver and to communicate with the participant via intercom.

Figure 1. The static WIVW driving simulator.

Conditional automation specifics

Vehicle automation included lateral and longitudinal guidance (SAE Level 3) with a set speed of 120 km/h. Set speed was reached whenever there was no slower vehicle ahead. Within automated driving sections, no lane changes were executed, neither by the system nor by the driver. In case there were slower vehicles ahead, they were followed with a pre-set time-headway of 2 s. The system was activated and deactivated via pressing two steering wheel buttons simultaneously that could easily be reached with the driver's thumbs when holding the wheel at "ten and two". Steering against the counterforce of the automation at a steering wheel angle larger than 2° also deactivated the automation. Lane changes were not necessary during CAD sections.

Scenario Layout

In the study at hand, an emergency take-over request on a highway was examined. The ego-vehicle was driving autonomously on the right lane following a lead vehicle at 120 km/h. At a predefined point, the lead vehicle pulled out to the left and gave view to a broken-down vehicle on the ego-lane. At the same moment, a visual-auditory Request to Intervene (RtI) was issued and longitudinal guidance was shut off, leading to drag torque related deceleration. Time to collision (TTC) at the moment of RtI output was approx. 9 s. An absence of driver reaction would have resulted in a collision with the standing car.

Human Machine Interface

The RtI was visualized in the vehicle's central infotainment display (Figure 2). It disappeared when the driver deactivated the system by braking or pressing the buttons (as described above). The visual display was accompanied by two consecutive high frequency warning tones to prompt immediate driver intervention.

Study Design

A complete within-design was used in the study. Every participant completed two blocks in randomized order: A block with the NDRT for external incentive and a block with the NDRT as a simple pastime. Both blocks further split up into two consecutive take-over situations with high and two consecutive take-over situations with low interruption effort. As a result, every participant encountered eight takeover situations.

Figure 2. The visual RtI from the vehicle's central infotainment display.

Independent Variables

The video game Tetris® was chosen as NDRT because it could hardly be neglected by the driver without score loss, thereby requiring continuous task attention. However, the game could be paused with a "Pause"-button on the tablet screen. The game was provided on two identical eight inch hand held Samsung tablets which for better discriminability of the motivation conditions were color coded. Driver motivation was manipulated by external rewards: When playing with the yellow tablet, drivers could monitor their high score and were instructed to give their best to earn extra money depending on their performance (performance condition). For every Euro earned, a cash register sound was presented, and the actual profit was reported verbally by the experimenter via intercom. When playing with the red tablet, drivers could neither see their high score, nor could they win any money, and the experimenter described the task as a simple pastime without any performance measurement (pastime condition).

Task interruption effort was manipulated by two different interruption instructions: To create high interruption effort, drivers were instructed to pause their task on the tablet, put the device into a plastic box on the co-driver's seat and place a lid on top of the box before taking over vehicle control (Figure 3). For low task interruption effort, it sufficed to pause the tablet task and lay the device aside, but not into the box. Continuous task processing and correct interruption were monitored by the experimenter.

Figure 3. Box for high task interruption effort (with lid and tablet).

Dependent Variables

On an objective level, the time from RtI onset to the first driver reaction was of particular interest. It was defined as the first of the following driver reactions: (1) System deactivation with the steering wheel buttons, (2) braking, or (3) steering with more than 2° steering wheel angle.

On a subjective level, drivers were asked to rate the criticality of the take-over situations directly after they had completed them using the 'scale of criticality assessment of driving and traffic situations' (Figure 4). The scale was originally developed in order to assess the controllability of erroneous interventions of driver assistance systems (Neukum & Krüger, 2003) and later extended to the assessment of the criticality of driving situations (Neukum, Lübbeke, Krüger, Mayser, & Steinle, 2008). The advantage of the scale is the definition of a threshold value that defines critical situations from the driver's perspective (rating as 'dangerous' or 'uncontrollable').

Figure 4. Scale of criticality assessment of driving and traffic situations.

In addition, directly after each take-over, drivers rated helpfulness of the TOR as well as their own take-over performance on Likert scales ranging from 0 to 15. At the end of the study, subjects filled out a questionnaire related to task involvement which contained similar Likert scales. The questionnaire also served as a manipulation check. Items were:

- *"How pronounced was your motivation to play Tetris?"* (subsequently referred to as 'task motivation')
- *"How hard was it for you to interrupt the game*?" (referred to as 'hardness to interrupt')
- *"How critical do you consider playing Tetris during a real, highly automated freeway drive?"* (referred to as 'task criticality')

Items had to be answered separately for conditions with and without monetary reward.

Procedure

Upon arrival, subjects were welcomed and gave informed consent. The experimenter explained that the goal of the study was the evaluation of a visual display under different distraction conditions. In a next step, the functionality of the conditional automation was explained. Participants were instructed that they did not have to monitor driving when the automated system was active and should fully apply themselves to the NDRTs. They were told that whenever they had to take back vehicle control, they system would inform them in time. The different motivation and interruption conditions were explained as well. The training was rounded off with a short drive in which participants practiced system (de)activation and the two interruption conditions without encountering take-over requests. It was finished when participants had fully understood system operation as well as motivation and interruption procedures.

The following main drive consisted of eight highly automated driving sections that each lasted approx. 3 min and were followed by the previously explained take-over situations. The test course was designed in a way that take-over situations were hardly predictable for the drivers. The experimenter instructed which tablet was to be used before the respective takeover situations, and how the task had to be interrupted in case of a possible take-over request. When subjects started a "performance task" section, they were also verbally motivated by the experimenter (*"Now try to give your best and become high score leader!"* etc.). When they started a "pastime task" section, verbal instructions were kept explicitly discouraging (*"Now you can start playing as a pastime, but your performance doesn't matter."* etc.). After the main drive, participants completed questionnaires, received monetary compensation for their participation, and were discharged. The entire procedure took approx. 40 min.

Participants

A total of *N* = 58 participants took part in the study. 28 participants were female and 30 male. The mean age was 32.3 years (*SD* = 9.7 years). The oldest driver was 54 and the youngest driver 19 years old. Participants were recruited from the WIVW test driver panel and had taken part in an extensive driving simulator training (Buld, Krüger, Hoffmann, & Totzke, 2003) prior to the study.

Data exclusion

Driving data results revealed training effects between the first two take-over situations across participants, so the first of the eight take-over situation of every subject was excluded from the analysis. Of the 406 take-over situations analyzed, 36 had to be reclassified because participants confused the instructed interruption conditions. For example, when participants in a condition with “high interruption effort” only laid the tablet on the seat although they were instructed to put it into the box before taking over, the situation was reclassified into “low interruption effort”. In addition, 14 take-over situation had to be excluded because participants did not play Tetris at the moment of take-over (e.g., because they had gone game over right before).

Statistical procedure

Statistical tests were conducted using IBM SPSS Statistics Version 25. The obtained data was analyzed descriptively before applying inferential statistics. Comparisons between the manipulation conditions were realized using univariate analyses of variance. Although the present study had a *within* design, repeated-measures analyses of variance would not have been an adequate procedure because of missing data (see above). For that reason, two-factorial univariate analyses of variance without repeated measures were calculated. These analyses can be considered conservative since they do not take individual differences between participants into account.

Results

Subjective Data

Figure 5 shows mean situation criticality ratings of the take-over situations. In take-over situations with high interruption effort criticality ratings were significantly higher (M = 5.08, SD = 2.49) than in situations with low interruption effort (M = 3.75, SD = 2.12; F (3,404) =

17.30, $p < .001$). There were no significant differences between motivation conditions nor any interactions.

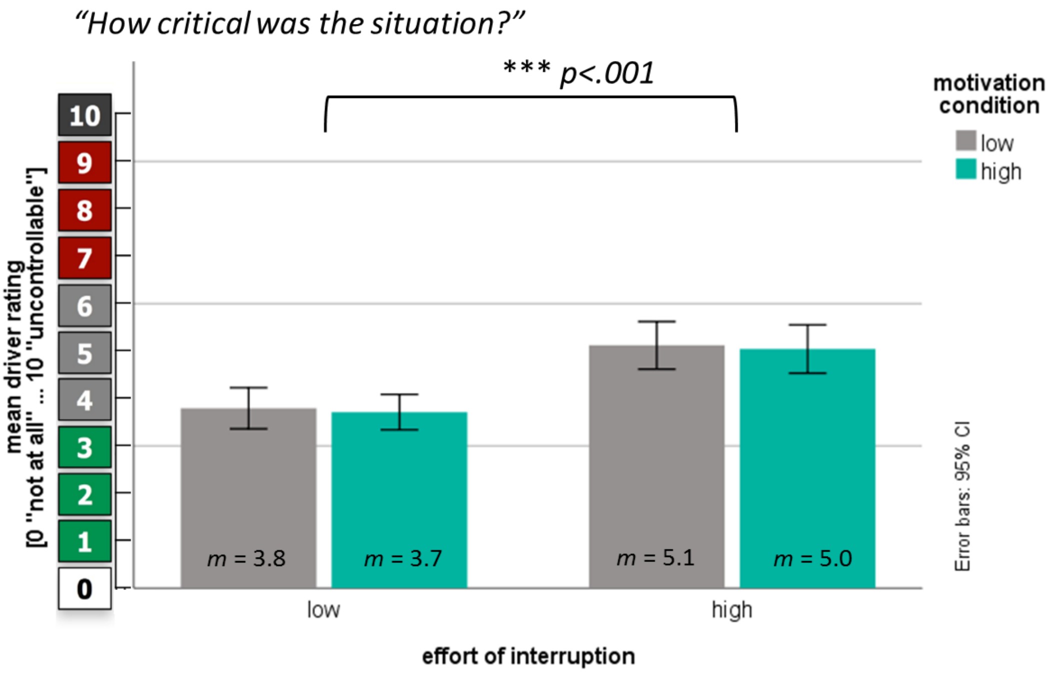

Figure 5. Mean criticality ratings gathered directly after the take-over situation, as a function of motivation condition and effort of interrruption.

The interruption effort also influenced drivers' self-rated take-over performance (Figure 6). Although all ratings were in the range from 10 to 12 (*"good"*), drivers rated their take-over performance significantly lower in situations with high interruption effort (M = 10.6, SD = 2.8) than in situations with low interruption effort (M = 11.9, SD = 2.0; $F(1,406) = 31.59$, $p < .001$). There were no significant differences between motivation conditions nor any interactions.

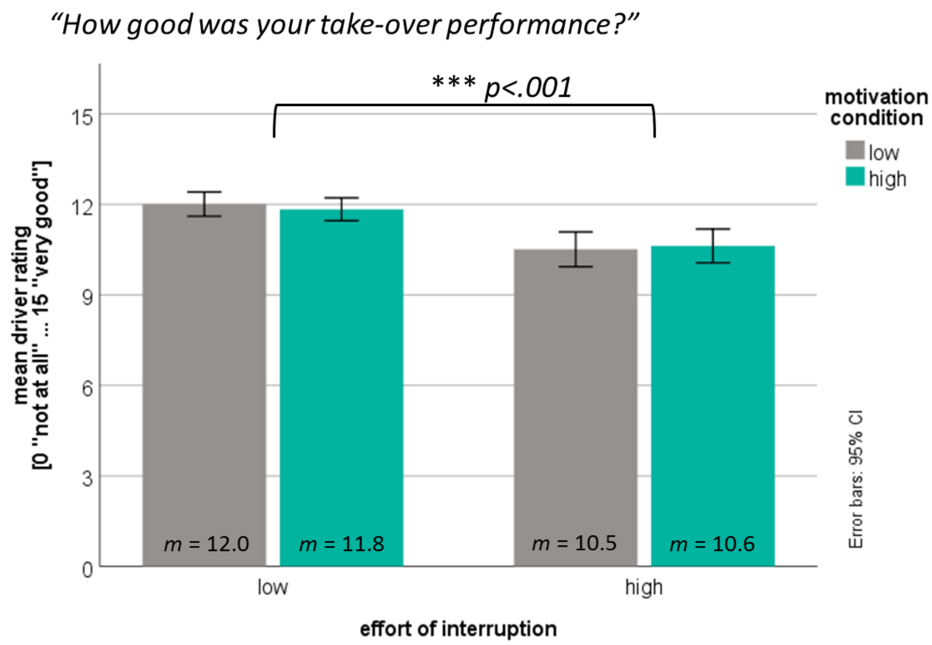

Figure 6. Mean self-reported driver performance ratings gathered directly after the take-over situation, as a function of motivation condition and effort of interruption.

In an inquiry after the test drive, drivers had to give their degree of agreement to the statement "How dangerous do you consider playing Tetris during real, highly automated highway drives?" on a 15-point Likert scale. The performance condition (with high score and money) was considered significantly more dangerous (M = 11.2, SD = 3.0) than the pastime condition (M = 9.8, SD = 3.3; $F(1,128)$ = 6.13, p = .015). When drivers had to rate their task motivation and how hard it was to interrupt the playing, only minor differences between conditions occurred on a descriptive level (Figure 7).

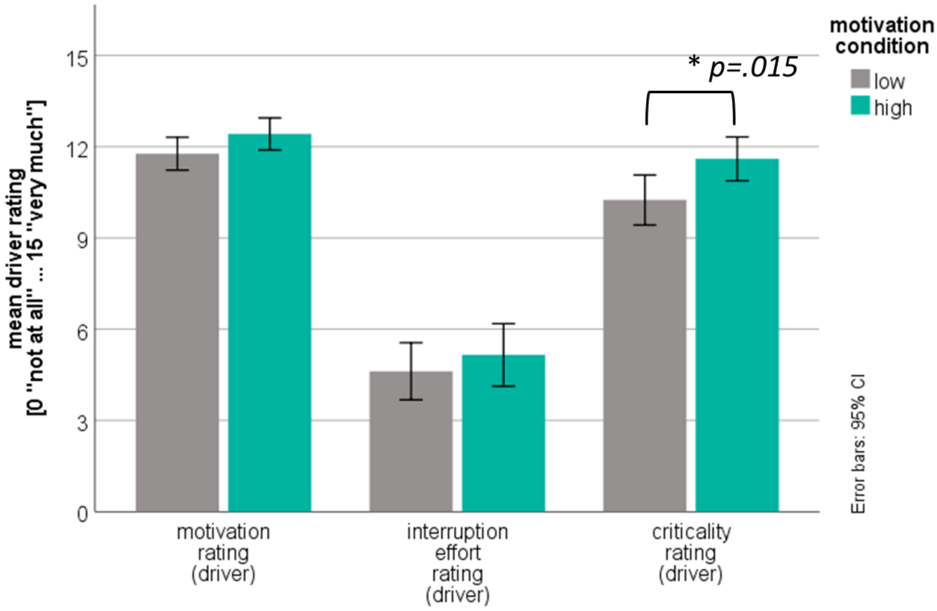

Figure 7. Subjective driver rating of task motivation, hardness to interrupt and task criticality depending on motivation condition.

Objective Data

Figure 8 shows the time to first driver reaction after the RtI (defined as previously described). In situations with high interruption effort, drivers reacted significantly slower (M = 5.3 s, SD = 1.3) than in those with low interruption effort (M = 6.9 s, SD = 1.1; $F(1,383) = 158.93$, $p < .001$). For situations with low manipulated driver motivation, mean reaction times were 5.3 s in the low interruption effort condition (SD = 1.4) and 6.8 s in the high interruption effort condition (SD = 1.0). For situations with high manipulated driver motivation, mean reaction times were 5.4 s in the low interruption effort condition (SD = 1.3) and 7.0 s in the high interruption effort condition (SD = 1.2). There were no significant differences between motivation conditions nor any interactions. The most prominent first driver reaction was button press (47.1% of all take-over situations), followed by braking (46.9%) and steering (6.0%), with very little variation within participants.

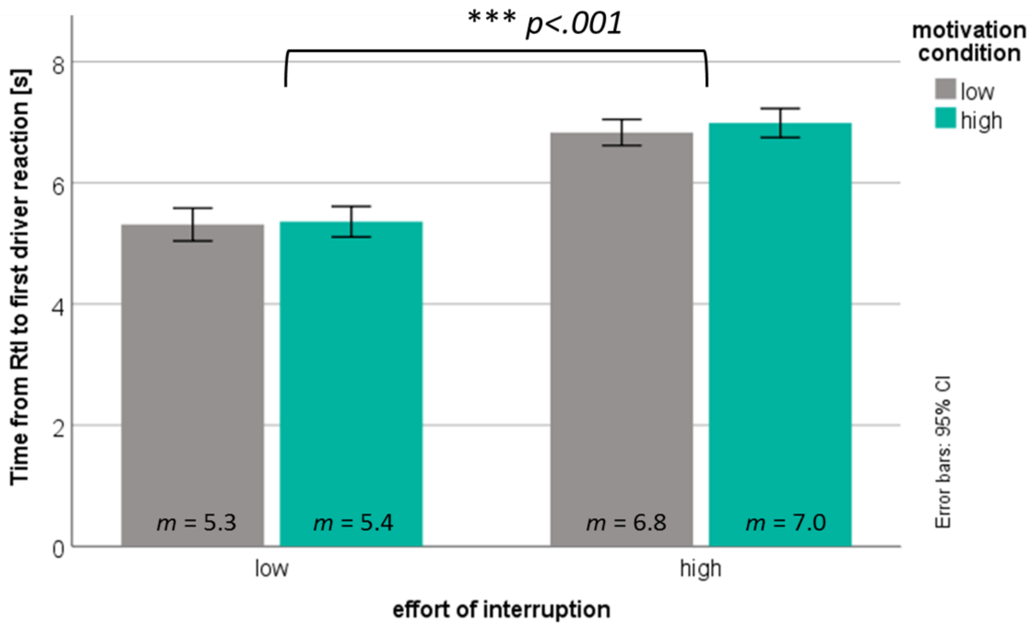

Figure 8. Mean driver reaction times following take-over requests, depending on motivation condition and interruption effort condition.

Discussion

With a large body of research focusing on easily interruptible standardized NDRTs, motoric interruption steps which are rather typical for naturalistic NDRTs have largely been disregarded. The study at hand analyzed subjective and objective take-over measures as a function of driver task motivation and task interruption effort. It could be demonstrated that task interruption effort has a considerable influence on driver take-over reaction times. Storing the task device in a box came along with significantly longer reaction times to the RtI in a range between 1.5 s and 1.6 s, an equivalent of roughly 50 meters at the implemented set speed of 120 km/h.

Considering the finding that drivers of conditionally automated vehicles are likely to engage in complex natural tasks (Pfleging et al., 2016), task interruption effort requires increased attention in future research on automated driving. Different approaches could be taken to address the issue: For example, tasks with excessive interruption effort may in part be *prevented* by limiting media use to in-vehicle screens and touch pads which do not have to be cleared away as it is the case with brought-in media devices. Additionally, these in-vehicle devices offer the opportunity to stop any visual presentation in case of RtIs (often called “lock-out”). Storage aids for NDRT devices may also help to reduce interruption effort. A second approach would be to *manage* interruption effort issues by detecting potentially critical tasks with eye tracking and posture detection, allowing to adjust RtI timing to the particular situation. However, in conditionally automated driving there will always be sudden time-critical take-over situations like in the study at hand that leave virtually no room for RtI timing adjustment.

Regarding task motivation, playing the tablet game for points and money was considered more critical by participants than playing without external rewards in the post-hoc rating. However, no differences between motivation conditions showed up in RtI reaction times. A possible explanation for this finding is provided by the manipulation check: Driver-reported motivation to play Tetris was high – almost independently from monetary incentives.

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