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Effect of different alcohol levels on take-over performance in conditionally automated driving

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ABSTRACT

Automated driving systems are getting pushed into the consumer market, with varying degrees of automation. Most often the driver's task will consist of being available as a fall-back level when the automation reaches its limits. These so-called take-over situations have attracted a great body of research, focusing on various human factors aspects (e.g., sleepiness) that could undermine the safety of control transitions between automated and manual driving. However, a major source of accidents in manual driving, alcohol consumption, has been a non-issue so far, although a false understanding of the driver's responsibility (i.e., being available as a fallback level) might promote driving under its influence. In this experiment, $N = 36$ drivers were exposed to different levels of blood alcohol concentrations (BACs: placebo vs. 0.05% vs. 0.08%) in a high fidelity driving simulator, and the effect on take-over time and quality was assessed. The results point out that a 0.08% BAC increases the time needed to re-engage in the driving task and impairs several aspects of longitudinal and lateral vehicle control, whereas 0.05% BAC did only go along with descriptive impairments in fewer parameters.

1. Introduction

Several vehicle manufacturers have announced automated driving features in their current or upcoming production vehicles (e.g., the "traffic jam pilot" in the Audi A8; Audi, 2017). These driving functions will still require the driver as a fallback level (so-called "conditionally automated driving", SAE L3, SAE, 2014) to intervene in case of system limits or malfunctions (Gold et al., 2017). Thus, the driver's role will change from manually operating the vehicle to intervening occasionally (Naujoks et al., 2017b). Concerns have been expressed that the switch from automated to manual driving might not be handled safely as a disengagement from driving related tasks can go along with decreased situation awareness (Feldhütter et al., 2018; Strand et al., 2014), drowsiness (Jarosch et al., 2017; Neubauer et al., 2014) and increased engagement in non-driving related tasks (NDRTs, see Merat et al., 2012; Naujoks et al., 2016b). Those psychological conditions might impair the driver's ability to re-engage in the driving task when a system limit is reached (Marberger et al., 2017; Naujoks et al., 2018).

During conditionally automated driving, the automated driving system will indicate the need for manual control by a so-called "take-over request" (TOR). Thereby, the driver will have to notice and interpret the TOR, possibly interrupt an ongoing NDRT (Large et al., 2017; Pfleging et al., 2016), interact with the vehicle controls and perform the required driving maneuver (Naujoks et al., 2018). This re-engagement process will afford cognitive and motoric re-configurations of the driver's state to meet the demands of the driving situation (Marberger et al., 2017). Typically, such task switches have been shown to go along with increased reaction times, mental effort and error rates in cognitive psychology (so-called "switch costs", Altmann and Trafton, 2004; Salvucci and Bogunovich, 2010; Trafton et al., 2003), which can be reflected in worsened vehicle control directly after a transfer of control event (Merat et al., 2014; Naujoks et al., 2017a).

There is a growing body of research that investigates the circumstances that lead to prolonged take-over times, such as unobtrusive take-over requests (e.g., Naujoks et al., 2014; Petermeijer et al., 2017) or engagement in NDRTs (Dogan et al., 2017; Ko and Ji, 2018; Payre et al., 2017). However, one major cause of accidents in manual driving, alcohol consumption (Krüger and Vollrath, 2004; Taylor et al., 2010), has been a non-issue in the context of automated driving so far. A false understanding of the driver's responsibilities when using conditionally automated vehicles (i.e., not knowing that the drivers is still the fall-back level) might promote driving under the influence of alcohol. While it is not yet known whether drivers will be more willing to drive under the influence of alcohol when using automated vehicles, its well-known impact on skills related to driving, such as reaction time, tracking and psychomotor performance (Hindmarch et al., 1991; Moskowitz and

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Robinson, 1988; Schnabel, 2011) is undisputed and will likely worsen problems associated with transfer of control from automated vehicles.

In this first-of-its-kind study, a sample of drivers completed three drives in a high fidelity driving simulator with different blood alcohol concentrations (BACs: placebo vs. 0.05% vs. 0.08%). Kenntner-Mabiala et al. (2015) used the same alcohol levels to investigate alcohol related impairments of manual driving in the same driving simulator. The test course involved typical take-over situations that have already been used to study take-over performance in the context of automated driving (see Gold et al., 2017, for a review). The aim of the study was to investigate, whether these dosages – as in manual driving conditions – would go along with impairments of the participants' reactions to the take-over request and their driving performance in the subsequent period of manual driving. The investigated BACs were chosen as benchmarks as a limit of 0.05% is the legal limit in most European countries and up to 0.08% is the limit in several states in the US. We also expected to find alcohol-related impairments of take-over performance as epidemiological research on accident risks suggests a linear increase from BACs between 0.04–0.10% and an exponential increase above 0.1% (Borkenstein et al., 1974; Krüger and Vollrath, 2004).

2. Method

2.1. Driving simulator

The study was conducted using the moving-based driving simulator at the Würzburg Institute for Traffic Sciences (WIVW GmbH, see Fig. 1) and the driving simulation software SILAB. The integrated vehicle's console is identical with a production type BMW 520i with automatic transmission. To simulate a realistic steering torque, a servo motor based on a steering model is used. The motion system uses six degrees of freedom and can briefly display a linear acceleration up to 5 m/s^2 or 100°/s^2 on a rotary scale. It consists of 6 electro-pneumatic actuators (stroke ± 60 cm; inclination ± 10°). Three LCD projectors are installed in the dome of the simulator and provide a projection of a 240° screen image. LCD displays serve as exterior and interior mirrors.

2.2. Study design and sample

The study was carried out in a within-subject design with the experimental variables BAC-level (BACs: placebo vs. 0.05% vs. 0.08%) and driving situation (five levels, see Section 2.4). Each driver completed the five test situations with all BAC-levels in three different test sessions. The order of the BAC-levels was balanced within the sample.

The study was approved by the ethics committee of the Bavarian State Medical Association (Bayerische Landesärztekammer, Munich). Prior to the study, all participants had a counselling meeting with a psychologist in which they were informed about the procedure and gave informed consent. For their complete participation, subjects received 120 Euro.

Participants did not know that there was a 0.00% condition. They were only informed that they will be driving under the influence of different blood alcohol concentrations and that their maximum blood alcohol concentration would be 0.08%. To make the placebo condition more compelling, odours of alcohol were diffused in the room where the drinks were applied. Participants were randomly assigned to one of six possible treatment sequences, which were recorded in a randomization scheme. They remained blinded to the treatment sequence until database lock.

The participants were recruited from the WIVW test driver panel. In accordance with the ethical requirements, invitations containing all relevant information about the study were sent to all panellists between the age of 23 and 50 years who had passed a standardized simulator familiarization training. This training is aimed at improving handling of the simulated vehicle (e.g., accelerating, braking, keeping the vehicle in the lane and overtaking) and avoiding symptoms of simulator sickness (Hoffmann and Buld, 2006). It consists of two training sessions (duration: about two hours per session) in the same simulator used in this study. 41 drivers were screened to check if they meet the following inclusion criteria:

- Holding of a valid driving license
- Having no acute or chronic disease
- No medication intake during the study (except for oral contraceptives)
- Moderate alcohol use as defined by the criteria by Dawson et al. (1995): consumption of a minimum of one alcoholic beverage per month and a maximum of 14 alcoholic beverages per week
- No more than six points on a screening questionnaire for the risk of alcohol abuse (Feuerlein et al., 1976)
- For females: reliable birth control during the study, negative pregnancy test at each driving session

In total, N = 36 (n = 17 female) participants took part in the study. All but five participants had taken part in previous simulator studies. They had a mean age of 33 years (SD = 9.22).

2.3. System description and non-driving related task

The automated driving system used in the study took over the longitudinal and lateral control and kept a set speed of 130 km/h. Thus, the drivers could take their hands off the steering wheel and their feet off the pedals. The system had a visual-auditory HMI that was developed and used in prior studies (Naujoks et al., 2016a). The visual interface was presented in a simulated Head-Up Display (HUD) and contained status indicators to support the drivers' awareness of the system mode (i.e., system available, system active, take-over request). Take-over requests were accompanied by a generic warning tone and a speech output ("take-over driving", see Forster et al., 2017). The visual part of the take-over requests showed a picture of hands grasping a steering wheel and a message box ("Take over!"). System activation required pushing two buttons on the steering wheel simultaneously;

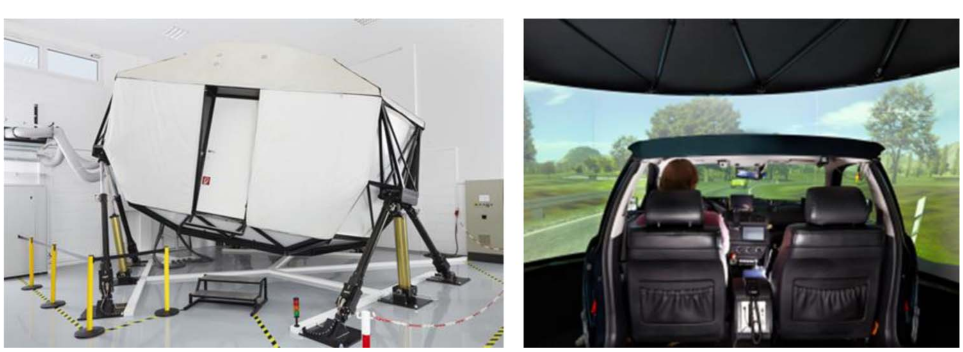

Fig. 1. The WIVW moving-based driving simulator. Hexapod movement system (left) and simulator interior with vehicle mock-up and image projection (right).