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The influence of alcohol (0.5‰) on the control and manoeuvring level of driving behaviour, finding measures to assess driving impairment: A simulator study

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ABSTRACT

Objective: The influence of psychoactive substances on driving performance and traffic safety has been extensively studied. Research on the influence of alcohol at the control level of behaviour (i.e. automated processes) has been well established and has shown that the ability to operate a vehicle decreases with rising alcohol levels. However, results one level higher at the manoeuvring level (i.e. conscious processes), are inconsistent. The current study aimed to replicate findings on the influence of alcohol on the control level of behaviour and investigate effects on the manoeuvring level in order to find suitable measures to assess driving impairment.
Method: The study was double-blind, placebo-controlled with a counterbalanced treatment order and a two-way crossover design. Thirty participants performed tasks in a driving simulator under the influence of alcohol (0.5‰) and a placebo. In the driving tasks the control level of behaviour (swerving, average speed, and speed variation) was investigated, as well as the manoeuvring level of behaviour (distance to other traffic during an overtaking manoeuvre, reaction time to a traffic light turning amber, and response to a suddenly merging car).
Results: As expected, alcohol affected the control level of behaviour negatively. Participants swerved more and showed more speed variation after alcohol intake. The manoeuvring level of driving behaviour was also affected by alcohol. The distance to other drivers during an overtaking manoeuvre was smaller under the influence of alcohol. Results on reaction time were however less straightforward. Reaction time increased significantly under the influence of alcohol when reacting to a traffic light but not in reaction to a car unexpectedly merging into traffic. When analysing behaviour in reaction to these different events in more detail it became clear that they were responded to in varying manners, making it difficult to find an average impairment measure.
Conclusions: The deteriorating effect of alcohol at the control level of driving behaviour was replicated, confirming the suitability of the standard deviation of lateral position

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and the variation in speed as measures of impairment. At the manoeuvring level, the kept distance to the leading car during an overtaking manoeuvre appeared to be a suitable measure to assess impairment as well as reaction time to a traffic light. The current study also confirms the difficulties in evaluating complex driving behaviour and the need for more research on this subject.

1. Introduction

Both epidemiological and experimental studies show that the use of psychoactive substances increases the risk for traffic accidents (Dassanayake, Michie, Carter, & Jones, 2011). According to a European collaborative study between 18 countries on driving under the influence of psychoactive substances (DRUID), approximately 3.5% of European drivers use alcohol, 1.9% use illegal drugs and 1.36% use medication in traffic (Heissing & Albrecht, 2018). The use of psychoactive substances amongst road users is therefore a major issue of concern.

The golden standard for measuring driving performance (i.e. impairment) under the influence of psychoactive substances in experimental studies is the Road Tracking Test (O'Hanlon, Haak, Blaauw, & Riemersma, 1982; Ramaekers, 2017; Verster & Roth, 2011). During this on-the-road test, participants drive on a motorway in an instrumented car, accompanied by a driving instructor. In this test participants are typically instructed to drive 100 km in the centre of the lane, with a constant speed. From this Road Tracking Test, the standard deviation of lateral position (SDLP) is obtained, which represents the weaving behaviour of a driver. Drug-induced impairment is measured by comparing the performance of the driver under the influence of a substance to performance after a placebo. Over the years, the Road Tracking Test has proven to be a very robust measure of substance related driving impairment (Irwin, Iudakhina, Desbrow, & McCartney, 2017). Moreover, it has been shown to predict actual drug-induced crash risk (Ramaekers, 2017).

Although the Road Tracking Test has proven to be very sensitive to pick up impairments at the control level of driving behaviour, i.e. automated processes, it may be questioned whether the effects are indicative of more conscious i.e. higher level driving behaviour. Generally, driving is divided in three levels of behaviour, the control level, the manoeuvring level, and the strategic level (Michon, 1985). The control level contains automatic action patterns. This entails a set of basic skills that are needed to operate a vehicle, such as steering and braking. The manoeuvring and strategic levels entail conscious behaviour, with at the manoeuvring level controlled action patterns that involve anticipation to acute circumstances such as overtaking, obstacle avoidance, and gap acceptance, and at the strategic level more general planning, such as which route to take.

There are no standardized methods for testing higher level driving behaviour, therefore no straightforward conclusion about the effects of psychoactive substances on higher level driving behaviour can be drawn (Irwin et al., 2017; Iwata, 2018; Jongen, Vuurman, Ramaekers, & Vermeeren, 2016). Since the use of psychoactive substances has a high impact on traffic safety (Dassanayake et al., 2011) it is essential to close this gap in knowledge and to find suitable measures that reflect higher level driving behaviour. Therefore, the current study aimed to replicate the influence of psychoactive substances at the control level of driving behaviour and investigate the influence of psychoactive substances at the manoeuvring level of driving behaviour in a driving simulator. Herewith, suitable measures to assess driving impairment under the influence of psychoactive substances in a driving simulator can be identified. As the use of alcohol as a benchmark for effects on driving performance is recommended (Walsh, Verstraete, Huestis, & Mørland, 2008), 0.5‰ alcohol, which is the legal alcohol level limit in traffic in the Netherlands, is the investigated substance in the current study.

Recent studies that used the Road Tracking Test to investigate the effects of alcohol on driving performance, showed that SDLP increased under the influence of alcohol both on the road (Jongen et al., 2017) and in the simulator (Freydier, Berthelon, Bastien-Toniazzo, & Gineyt, 2014; Veldstra et al., 2012). This means that a higher level of alcohol induces larger weaving patterns. This is a constant finding and has to date not been falsified. Effects of alcohol on the manoeuvring level of driving however, show a less clear pattern.

For example, the outcomes on the influence of alcohol on time headway (THW) in literature differ. Kenntner-Malabia, Kaussner, Jagiellowicz-Kaufmann, Hoffman, and Krüger (2015) found that the percentage of time that participants adopted a THW below 1 s during a car following task, was higher under the influence of alcohol (0.5‰ and 0.8‰) compared to the placebo condition. Moreover, Freydier et al. (2014) conducted a study amongst novice (<2 months) and experienced (3 years) drivers. They found that novice drivers adopted a smaller THW to other drivers under the influence of alcohol (0.5‰) compared to placebo, while no difference was found between the alcohol and placebo conditions in experienced drivers. Contradictory, Leung and Starmer (2005) found no difference in adopted THW during an overtaking manoeuvre between the alcohol (0.6‰) and placebo condition of participants.

According to a literature review by Jongen et al. (2016), the scientific literature on the influence of alcohol on reaction time (RT) in traffic is also inconsistent. This seems to be the case for both simple RT tests and RT tasks in driving simulators. The influence of alcohol intoxication on RT appears to be dependent on the complexity of the task, with alcohol having no influence on the performance on simple RT tasks, while it does seem to deteriorate RT in more complex tasks (Martin et al., 2013; Ogden & Moskowitz, 2004).

There are studies that suggest that persons who drive under the influence of alcohol apply compensatory strategies by lowering their speed in complex situations (Vollrath & Fischer, 2017), while others have observed an increase in speed under the influence of alcohol (Fillmore, Blackburn, & Harrison, 2008), or no influence of alcohol on speed at all (Veldstra et al., 2012). There is however consensus that the ability to maintain a constant speed (i.e. standard deviation of speed) is impaired under the influence of alcohol (Irwin et al., 2017).

The information described above illustrates that effects of psychoactive substances on the control level of driving behaviour are relatively straightforward. With regard to effects of psychoactive substances on the manoeuvring level however, more insight is needed, and the current study contributes to knowledge on this subject.

In the current study it was expected that both the control and manoeuvring level of driving behaviour are affected by alcohol. Deterioration at the control level was expected to be demonstrated by more variation in speed and lateral position in the alcohol condition as compared to the placebo condition. Because of the contradicting outcomes between studies on the maintained average speed under the influence of alcohol, this measure was exploratively investigated in the current study. Impairments at the manoeuvring level were expected to be demonstrated by a smaller THW and a larger RT in the alcohol condition as compared to the placebo condition.

1.1. Method

1.1.1. Participants

Thirty-nine healthy men and women participated in this study. Nine participants had to terminate their participation after the training day due to simulator sickness. Consequently, 30 participants (10 female, 20 male) completed the study. Participants were between 21 and 75 years old (M = 45.4; SD = 18.4 years), possessed a driver's licence for at least 3 years (M = 26.9; SD = 18.9 years), drove on a regular basis (M = 14900; SD = 18250 km/year), and had a visual acuity of at least 0.5 on the Snellen chart. The average blood alcohol concentration (BAC) before participants drove in the simulator was 0.49‰ (SD = 0.03), after the rides the level was 0.35‰ (SD = 0.07). Participants provided written informed consents. The current study was performed according to the ethical principles for medical research involving human participants established by the declaration of Helsinki (amended by the 64th WMA General Assembly, at Fortzaleza, Brazil, October 2013) and in agreement with the Medical Research Involving Human Subjects Act (WMO). Ethical approval was provided by the Medical Ethics Committee of Maastricht University. Participants received a monetary compensation for their participation.

2. Research design

The study was placebo-controlled, double blind, with a 2-way crossover design and counter-balanced treatment order.

2.1. Measures

Driving simulator The driving simulator was a Jentig50 cockpit simulator developed and produced by ST Software©. It consisted of a fixed-base mock-up with a safety belt, three pedals, a steering wheel, a handbrake, a gear box, and indicators. The simulator environment was depicted on three 50-inch LED screens that surrounded the simulator, which created a view of 200°. Additionally, the rear view mirror, side mirrors, dashboard, car windows, and front of the car were shown on the screens (see Fig. 1). Simulated vehicles were able to respond to the environment in an intelligent way as developed by Van Winsum and Van Wolffelaar (1993).

Driving tasks The order of the driving tasks was fixed to minimise simulator sickness and to prevent transfer effects of fatigue. Experimenters provided participants with instructions before each ride according to a fixed protocol. During the

Fig. 1. The driving simulator.

rides synthetic speech instructions were given. The first ride in the simulator consisted of driving a winding road without traffic signs and other traffic, this took approximately 10 min. Participants were instructed to drive as they would normally do on such a road. The purpose of the ride was to familiarise participants with the simulator. No data were collected during this ride.

The second ride (see also Piersma et al., 2016) lasted approximately 10 min, and consisted of driving a rural road with traffic signs and other traffic. Participants encountered six intersections with different traffic regulations. The participants were instructed to drive straight on each intersection and to comply with the traffic regulations. Additionally, at a certain point between two intersections a parked car suddenly drove onto the road, close in front of the participant (with a THW of 3 s). In the ride RT was assessed by the following measures: the RT to an upcoming traffic light (turning amber at a distance of 111 m from the participant), the RT in response to the suddenly merging car, and the minimum time to collision (TTC) to the suddenly merging car. Furthermore, the average speed on road sections with different speed limits were measured. There were four road sections with a length of approximately 700 m each, two with a speed limit of 60 km/h and two with a speed limit of 80 km/h.

During the third ride, that took approximately five minutes, participants started on an acceleration lane. They were instructed to merge into traffic on the motorway, and later to overtake a car and to return to the right hand lane again. Traffic in the left hand lane adopted a preferred distance to the car in front of them. This distance increased for each consecutive car, making overtaking easier over time. Finally, participants were instructed to leave the motorway and stop the car. Distance to other road users was assessed by using the following measures during the overtaking manoeuvre: the THW between the participant and the car in front of them, the THW that was adopted by the car behind the participant, and the degree of deceleration of the car behind the participant.

The last ride was a simulated version of the Road Tracking Test in which participants drove on a single carriageway without traffic signs and other traffic. They were instructed to drive in the centre of the right hand lane to the best of their ability with a constant speed of 100 km/h for 30 min. Sustained vehicle control was assessed by using the following measures: the SDLP, the standard deviation of speed, and the average speed.

2.2. Procedure

Participants were recruited by advertisements in newspapers. Volunteers could sign up on a website and were subsequently screened for inclusion and exclusion criteria via a telephone interview. Volunteers were excluded from participation if they suffered from a neurological condition, used recreational drugs, abused alcohol (>21 units/week), smoked over 10 cigarettes a day, or used medicines that interact with alcohol. Furthermore, participants were excluded if they showed signs of simulator sickness during the training day. Inclusion criteria were an age between 21 and 75 years, a body mass index between 19 and 29 kg /m^2, possession of a driver's licence for at least 3 years, driving experience of at least 3000 km/year, consumption of at least 3 alcoholic beverages per week, and a minimal visual acuity of 0.5.

Eligible volunteers received additional information about the study, along with a medical questionnaire and a form on which participants could confirm their informed consent. The medical questionnaire was evaluated by a physician, who decided whether or not volunteers were allowed to participate. Participants visited the lab on three different occasions, the time of day at which participants visited the lab was the same for all three visits, each consecutive visit took place within approximately one week from the previous visit.

The first occasion was a training day on which participants were made familiar with the driving tests and the driving simulator. Furthermore a drug test and a pregnancy test were conducted (both via urine) and the BAC was determined using a breathalyser. Finally, the visual acuity of the participants was determined with the Snellen chart. The second and third occasions were testing days. After again testing for drugs, alcohol, and pregnancy, participants were administered either alcohol (up to 0.5‰) or placebo (counter-balanced), through a beverage. They performed the same tests as during the training day.

The alcoholic beverage was prepared by mixing ethanol (96%) with orange juice. To determine the amount of ethanol that was necessary to obtain a BAC of 0.5‰ for each individual participant, the Widmark formula (Widmark, 1932) was used. The placebo beverage consisted of orange juice with a spray of ethanol on top. Participants consumed the drink followed by a 15 min break after which their BAC was determined. After this participants performed the simulator rides, which took about 60 min, and subsequently their BAC was measured again.

2.3. Statistical analyses

Statistical analyses were performed using IBM SPSS Statistics 25. Initial analysis indicated that the data were not normally distributed. Therefore, the Wilcoxon signed ranks test and Chi-square test were performed to compare performance between participants in the alcohol and the placebo condition. Missing values were left out of the analyses. Average speed was tested two-sided because no clear expectations existed on the direction of possible differences. All other measures were tested one-sided, p-values < 0.05 were considered significant.

2.4. Results

2.4.1. Control level of driving behaviour

Participants showed a significantly larger average SDLP during the Road Tracking Test in the alcohol condition compared the placebo condition (Table 1, Fig. 2). Because the found SDLP values were quite large, the lateral position of a subsample of the participants was inspected visually. Other than high variation in lateral position, no abnormalities were found. In the alcohol condition participants drove significantly faster compared to the placebo condition on roads with a posted speed limit of 80 km/h (Table 1), in both conditions the maintained speed was below the posted speed limit. No differences in speed were found between the two conditions at road sections with posted speed limits of respectively 60 or 100 km/h (Table 1). In the alcohol condition participants displayed significantly more variation in speed during the Road Tracking Test compared to the placebo condition (Table 1).

2.4.2. Manoeuvring level of driving behaviour

All participants in the placebo condition braked for the amber traffic light, while in the alcohol condition, one participant failed to brake. The brake RT of participants braking for the traffic light was significantly larger in the alcohol condition as compared to the placebo condition (Table 1). Participants on average travelled 5.6 m further before they responded to the traffic light in the alcohol condition, compared to the placebo condition.

During the unexpected event, in which a car suddenly merged in front of the vehicle, two of the participants in the placebo condition responded by swerving around that car, compared to four participants in the alcohol condition. One participant in the alcohol condition did not brake for or swerve around the car, and collided. The remaining participants (28 in the placebo condition and 25 in the alcohol condition) responded by braking successfully for the suddenly merging car. Alcohol intoxication had no significant influence on the chosen response (χ^2 (2) = 2.52, p = .28). For the participants who responded by braking, no differences were found between the alcohol and placebo conditions in brake RT and minimum TTC during the unexpected event (Table 1).

One participant in the placebo condition was involved in a collision during the simulator tasks, compared to two participants in the alcohol condition. The THW between participants and the car in front of them during the overtaking manoeuvre was significantly larger (i.e. safer) in the placebo condition as compared to the alcohol condition. On average the distance to the leading car was 0.83 m smaller in the alcohol condition (Table 1). The THW that was adopted by the driver behind the participant during the overtaking manoeuvre did not differ between the alcohol and placebo condition (Table 1). In both the placebo and alcohol condition the car behind the participant did not have to decelerate during the overtaking manoeuvre on only two occasions. This means that most participants hindered the other drivers while filtering into traffic. For these participants no difference was found for the degree of deceleration of the car behind them between the alcohol and the placebo condition (Table 1).

2.5. Discussion

The first objective of the current study was to replicate earlier findings on the influence of 0.5‰ alcohol at the control level of driving behaviour. Similar to previous studies (e.g. Freydier et al., 2014; Jongen et al., 2017; Veldstra et al., 2012), both on the road and in driving simulators, the current study found an increase in swerving behaviour (measured with SDLP)

Table 1
Average, standard deviation, 95% CI, Wilcoxon sign rank test and effect size for the differences in driving performance measures between participants under the influence of placebo and alcohol.

	Alc 0.5‰	Pla	Alc – Pla (95% CI)	Z	p	r
Control level						
Road tracking						
SDLP (cm)[1]	36.88 ± 11.79	31.06 ± 6.83	5.81 (2.52, 9.10)	−2.85	<0.01	0.37
Speed						
60 km/h[2]	64.33 ± 5.22	62.97 ± 3.85	1.36 (-0.47, 3.18)	−0.87	0.38	0.11
80 km/h[2]	78.08 ± 6.12	75.96 ± 5.57	2.13 (0.69, 3.57)	−2.83	<0.01	0.37
100 km/h[2]	99.75 ± 2.27	99.47 ± 2.10	0.28 (−0.47, 1.03)	−0.75	0.45	0.10
SD speed (at 100 km/h, km/h)[1]	1.89 ± 1.12	1.51 ± 0.95	0.38 (0.03, 0.73)	−1.99	0.02	0.26
Manoeuvring level						
Reaction time						
RT unexpected event (s)[1]	1.71 ± 0.43	1.66 ± 0.36	0.04 (−0.14, 0.21)	−0.51	0.30	0.07
Minimum TTC unexpected event (s)[1]	1.26 ± 0.29	1.31 ± 0.30	−0.04 (−0.17, 0.10)	−0.60	0.28	0.09
RT traffic light (s)[1]	1.87 ± 0.60	1.61 ± 0.49	0.25 (0.05, 0.45)	−2.25	0.01	0.30
Distance to other road users						
Rear deceleration (m/s^2)[1]	−5.13 ± 1.75	−5.12 ± 1.84	0.02 (-0.89, 0.93)	−0.01	0.50	0.00
Rear THW (s)[1]	0.66 ± 0.28	0.70 ± 0.44	−0.04 (−0.19, 0.11)	−0.18	0.43	0.02
THW (s)[1]	0.26 ± 0.18	0.29 ± 0.13	−0.03 (−0.11, 0.05)	−2.08	0.02	0.27

[1] Tested one-sided; [2] Tested two-sided; Alc = Alcohol; Pla = Placebo.

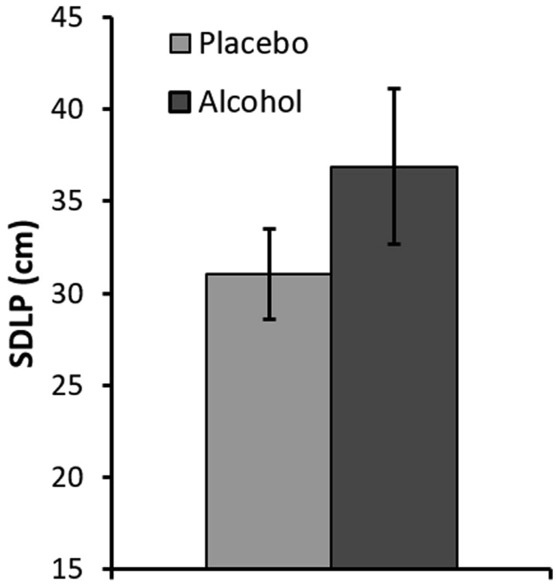

Fig. 2. SDLP and 95% CI for participants in the placebo and alcohol condition.

under the influence of alcohol. The average found increase of SDLP in the driving simulator under the influence of 0.5‰ alcohol is about 4 cm (Irwin et al., 2017). The current study however found an average increase of 5.8 cm. This might be due to the characteristics of the driving simulator, as many factors (e.g. type of scenario, number of screens, duration of the task) influence the outcomes of driving simulator studies (Irwin et al., 2017). Nevertheless, it can be concluded that, as expected, alcohol increased swerving behaviour in the current study.

The variation in speed in a simulated version of the Road Tracking Test (posted speed limit 100 km/h) was also elevated under the influence of alcohol in the current study. The increase that was found was 0.38 km/h, the same increase that was found in a *meta*-analysis on 22 trials (Irwin et al., 2017). Although one can question if this relatively small elevated variance in speed is a threat to traffic safety, participants had significantly more difficulty to adhere to the research instructions under the influence of alcohol as compared to placebo. Because the instructions were to adopt a constant speed of 100 km/h, it can be argued that alcohol intoxication deteriorated the control that participants had over the vehicle.

Adopted average speed under the influence of alcohol has been investigated in multiple studies that show contradicting outcomes (Fillmore et al., 2008; Irwin et al., 2017; Veldstra et al., 2012; Vollrath & Fischer, 2017). Therefore, the maintained average speed was investigated exploratively in the current study. No difference in average speed was found between the alcohol and placebo conditions on road segments with a posted speed limit of respectively 60 and 100 km/h. However, participants drove 2 km/h faster in the alcohol condition compared to the placebo condition on road segments with a posted speed limit of 80 km/h. In both the placebo and the alcohol condition a speed below the posted speed limit was adopted (respectively 76 and 78 km/h).

Comparing the literature on the influence of alcohol intoxication on average driving speed comes with some challenges. Studies differ for example in posted speed limit, type of scenario, given instructions, study population, and complexity of the task. Vollrath and Fischer (2017) for instance compared male participants who were under the influence of alcohol, a placebo, and participants who were consciously sober. They presented participants with a seemingly easy and a complex driving scenario, and in both scenarios, drivers encountered a situation in which they had to prevent an accident. In the easy scenario no significant differences in average speed were found between the three groups. In the complex scenario however, consciously sober participants drove significantly faster compared to participants under the influence of alcohol or a placebo. Vollrath and Fischer (2017) suggest that participants might compensate their expected impairment if they expect a difficult situation, by lowering their speed. In the current study this might have been the case as well, as participants adopted a speed below the posted speed limit in both the alcohol and placebo condition on road sections with a posted speed limit of 80 km/h. However in the current study there was not a condition in which participants were consciously sober, therefore no comparisons to this group were possible. On the other hand, participants drove faster in the alcohol condition compared to the placebo condition in the current study, which might argue against a compensation for expected intoxication. Also, the difference was only found on road sections with a posted speed limit of 80 km/h, while no differences in speed were found between the alcohol and placebo condition on road sections with posted speed limits of respectively 60 and 100 km/h.

Aarts and Van Schagen (2006) reviewed the influence of adopted speed on crash risk. They found that although the magnitude is influenced by many factors (e.g. traffic flow, road type, lane width), an increase in speed increases crash risk. Therefore, it can be concluded that participants accepted a higher risk in the alcohol condition compared to the placebo condition on road segments with a posted speed limit of 80 km/h. This effect was however not found on road segments with posted speeds limits of respectively 60 and 100 km/h. The different findings on the influence of alcohol intoxication on average speed within the current study reflect the differences on this topic in literature. Some standardization of the methods to measure average driving speed might be needed to be able to compare findings between different studies.

The second objective of the current study was to investigate the influence of 0.5‰ alcohol at the manoeuvring level of driving behaviour. It was expected that alcohol would deteriorate RT to a traffic light and a suddenly merging car. An increased reaction time was indeed found in the event that participants were confronted with a traffic light turning amber, but not during an unexpected event in which they had to respond to a car that suddenly merged into traffic. These different outcomes on seemingly similar measures resemble the inconsistencies in the current literature on the influence of alcohol on RT (Jongen et al., 2016). Differences in the type of actions participants showed in reaction to the two different events may explain the contradicting findings in the current study as well as in the literature.

For example, in the condition whereat the traffic light suddenly turned amber, the only safe action was to brake, while in the case of the car unexpectedly merging onto the road participants had the choice between two responses: brake or steer around the car via the opposite lane. The traffic in the used scenario was generated randomly in order to create a driving experience that was as naturalistic as possible. However, this meant that some participants had the opportunity to move around the suddenly merging car, while others could not do this because of oncoming traffic. Additionally, it can be argued that the required responses to the amber traffic light and the unexpectedly merging car differ. In case of the traffic light participants had the time to anticipate to a situation that could be expected, while in case of the merging car a fast response to an exceptional situation was required. Multiple response possibilities and different types of responses are required for different types of tasks that reflect RT, it is therefore difficult to show systematic differences between the alcohol and placebo conditions. On the other hand it is more realistic to have multiple options in driving behaviour, since the choices in real life are often also not dichotomous (Lipshitz, Klein, Orasanu, & Salas, 2001), especially when it comes to higher order driving behaviour such as at a manoeuvring level.

Another expectation concerning the manoeuvring level of driving behaviour was that alcohol would influence the distance that drivers keep to other traffic. As was expected, participants kept less distance to the traffic in front of them (i.e. lower THW) during an overtaking manoeuvre in the alcohol condition compared to the placebo condition. This is in line with a study by Kenntner-Malabia et al. (2015), but in disagreement with the findings of Freydier et al. (2014), and Leung and Starmer (2005). According to Brookhuis, De Waard, and Fairclough (2003) a THW below 0.7 s is considered as following too closely. The found THW within the current study was however 0.29 in the placebo condition and 0.26 in the alcohol condition. Both considered unsafe in case of the need for an emergency stop. However, relatively, in the alcohol condition participants accepted a greater risk compared to the placebo condition.

Contrary to the expectation there was no effect of alcohol on the degree of deceleration and the THW of the car behind the participant while overtaking in the fast lane. Almost all participants hindered the traffic behind them during the overtaking manoeuvre irrespective of alcohol intoxication. Although it was the aim to measure the manoeuvre in busy traffic, the characteristics of the scenario made it almost impossible for participants not to hinder the other traffic. The obtained results from the overtaking manoeuvre might indicate that strategies that drivers apply during such a manoeuvre focus more on the car in front of them than behind them during this manoeuvre. Because not much is known on hindrance during overtaking, it would be interesting to further investigate this in future studies.

A limitation of the current study is the heterogeneity of the research sample. Participants showed a broad range in age and driving experience, which might have influenced the outcomes. Therefore, the results reflect overall effects on a broad group of drivers and it would be interesting to investigate different age groups in future research on the influence of psychoactive substances on the manoeuvring level of driving behaviour. Furthermore, it would have been interesting to also include a group of participants that was consciously sober. As hypothesized by Vollrath and Fischer (2017), the expectation of impairment might influence driving behaviour as well. Moreover, it is more natural that a person knows whether they used psychoactive substances or not. Another difficulty in the current study was the design of the driving simulator scenarios. The scenarios were developed to measure driving behaviour in a way that was as naturalistic as possible. This however comes with the drawback that participants have freedom in their responses, which makes it more difficult to analyse behaviour in a structural manner. On the other hand, strictly structured scenarios with only two possible response options would be less naturalistic and more difficult to translate to real life driving.

In conclusion, the current study aimed to investigate the influence of alcohol on both the control and manoeuvring level of driving behaviour, in order to identify measures to assess driving impairment under the influence of psychoactive substances. At the control level of behaviour, alcohol impaired both SDLP and variation in speed. This confirms the findings of previous studies that identify SDLP and variation in speed as suitable measures for driving impairment. In the current study, maintained average speed differed between the alcohol and placebo condition at a posted speed limit of 80 km/h, but no effects of alcohol intoxication on maintained average speed were found at road sections with posted speed limits of 60 or 100 km/h. This reflects the differences that were found in literature. With the current knowledge it is questionable whether average speed is suitable as a measure for driving impairment and this topic deserves further study. The influence of alcohol on driving behaviour at the manoeuvring level is less straightforward compared to the effect on the control level. RT in a predictable task with rigid response options increased under influence of alcohol, and THW to the lead car during an overtaking manoeuvre decreased under the influence of alcohol, indicating that both were sensitive to the alcohol manipulation. Measures such as these (with restricted behavioural options) are good candidates for measuring driving impairment at the manoeuvring level of behaviour. Tasks that entail more freedom of choice in behavioural options and hindrance during overtaking were not clearly affected in the alcohol condition and future research should shed light on this. There is a need for studies on driving behaviour with both freedom of choice as well as more restricted response options. Future endeavours could go beyond the normal performance measures and look into patterns of behavioural reactions in more complex driving scenarios, scenarios that one encounters in everyday driving.

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CRediT authorship contribution statement

J.H. van Dijken: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Project administration. **J.L. Veldstra:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Supervision. **A.J.A.E. van de Loo:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Project administration. **J.C. Verster:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Supervision, Resources, Funding acquisition. **N.N.J.J.M. van der Sluiszen:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Project administration. **A. Vermeeren:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Supervision. **J.G. Ramaekers:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Supervision, Resources, Funding acquisition. **K.A. Brookhuis:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Supervision, Resources, Funding acquisition. **D. de Waard:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Supervision.

Declaration of Competing Interest

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