



# Alcohol impairs driver attention and prevents compensatory strategies

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## ABSTRACT

While the negative effects of alcohol on driving performance are undisputed, it is unclear how driver attention, eye movements and visual information sampling are affected by alcohol consumption. A simulator study with 35 participants was conducted to investigate whether and how a driver's level of attention is related to self-paced non-driving related task (NDRT)-engagement and tactical aspects of undesirable driver behaviour under increasing levels of breath alcohol concentration (BrAC) up to 1.0 ‰. Increasing BrAC levels lead to more frequent speeding, short time headways and weaving, and higher NDRT engagement. Instantaneous distraction events become more frequent, with more and longer glances to the NDRT, and a general decline in visual attention to the forward roadway. With alcohol, the compensatory behaviour that is typically seen when drivers engage in NDRTs did not appear. These findings support the theory that alcohol reduces the ability to shift attention between multiple tasks. To conclude, the independent reduction in safety margins in combination with impaired attention and an increased willingness to engage in NDRTs is likely the reason behind increased crash risk when driving under the influence of alcohol.

## 1. Introduction

Alcohol (ethanol)-induced impairment is causally linked to fatal crash involvement (Ahlner et al., 2014), leading to about 35% of all on-road deaths world-wide (World Health Organization, 2018). Compared to a sober (alcohol-free) driver, a drunk driver's relative crash risk is significantly elevated beginning at an alcohol concentration of about 0.4 ‰ (Compton et al., 2002). While the negative effects of alcohol on driving performance are undisputed, it is still difficult to study in which way alcohol actually impacts driving, as studies with high external validity cannot easily be conducted.

The behavioural effects of alcohol vary non-linearly in a dose- and time-dependent manner, ranging from sedation and induced anxiety relief to compromised motor function and cognition. Alcohol modifies the activity of neurons in the central nervous system (Abraham et al., 2017), thus affecting brain structures that govern motor control, motivation, and executive control, such as working memory and attention (Bjork & Gilman, 2014). As a result, alcohol affects visuo-motor control, focused attention, divided attention, reaction time, working memory, and response inhibition (Maurage et al., 2020; Zoethout et al., 2011). Response inhibition under the influence of alcohol has been shown to

lead to risky driving behaviour such as increased variability in lane positioning and more frequent line crossings, a higher mean speed and a decreased likelihood to stop at red traffic lights (Fillmore et al., 2008).

Since all the above-mentioned cognitive processes are an integral part of driving, it comes as no surprise that alcohol leads to higher crash risk (Garrisson et al., 2021; Moskowitz & Robinson, 1988; Yadav & Velaga, 2019). Compromised motor function manifests itself as less smooth steering and deteriorated lane-keeping (Gawron & Ranney, 1988; Helland et al., 2013; Ranney & Gawron, 1986). Similarly, since cognitive processing is hampered, complex reaction time (sometimes called compound/choice reaction time) becomes longer. The impact on more automated behaviours such as lane keeping and simple reaction time tasks is however limited, except for higher doses of alcohol. Impairments become more apparent with increasing complexity of the driving task, especially for tasks requiring information processing and decision making under conditions of divided attention (Martin et al., 2013; Mitchell, 1985; Ogden & Moskowitz, 2004).

An area that is not as well researched is how driver attention, eye movements and visual information sampling are affected by alcohol consumption (Shiferaw et al., 2014). Previous studies have found that alcohol impairs binocular visual function and vergence (Martino et al.,

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2021), worsens eye-hand coordination in steering (Marple-Horvat et al., 2008), and narrows drivers' visual perception (Belt, 1969; Moskowitz & Robinson, 1988; Tivesten et al., 2022). There are also studies showing an exacerbation of the damaging effect of alcohol when the drivers perform non-driving related tasks (NDRT). Examples of real-world NDRTs include reading a text message, changing playlists, or consulting a map. Tivesten et al. (2022) found that drivers with breath alcohol content (BrAC) exceeding 1.0 ‰ spent more time monitoring the forward roadway than alcohol-free drivers in manual driving without NDRT. However, when asked to perform various NDRTs, glances off the forward roadway were more frequent and longer after drinking alcohol. Freydl et al. (2014) found that alcohol impairs information processing accuracy in peripheral vision. These findings go hand in hand with the general result that alcohol intoxication places greater demands on visual spatial attention, disrupts the ability to shift attention between multiple spatial loci, and disturbs the ability to ignore distracting stimuli in order to focus attention on relevant information (Post et al., 1996; Weafer & Fillmore, 2012).

If alcohol consumption compromises attention in the sense that the driver's ability to sample information from multiple relevant targets is impaired, this may affect decision making and consequently the driver's actions, especially when NDRTs are performed while driving. An operationalisation of whether information has been sampled from all relevant targets can be based on the minimum required attention theory (Kircher & Ahlstrom, 2016), and implemented according to the AttenD2.0 framework (Ahlström et al., 2021). Relevant areas that need to be sampled visually are defined a-priori based on the infrastructure, the route and rules that apply. A maximum glance duration away from the forward roadway, a minimum glance frequency to the mirrors and visual sampling of crossing roads with priority are also required. In a simulator study with a fixed route, these requirements are the same for each participant. Since the concept is based on what the driver should do, NDRT engagement is not discouraged as long as all requirements are fulfilled. AttenD2.0 thus identifies instances of inattention as either too extensive glancing away from forward or as missing glances in the direction of required areas.

A simulator study was conducted using an urban scenario to investigate whether and how a driver's level of attention is related to self-paced NDRT-engagement and tactical aspects of undesirable driver behaviour across a range of BrAC levels. An urban environment was selected to increase the complexity of visual information sampling requirements, and to better convey inappropriate law infringements like speeding in the vicinity of intersections, pedestrians and cyclists. By setting driver attention in relation to changes in behaviour it was possible to investigate whether risk taking or other potentially unsafe behaviours were linked to attentional deficiencies, or whether alcohol affected those behaviours more directly.

## 2. Method

As part of a study investigating alcohol and driving, 35 participants completed a route in a driving simulator first alcohol-free, then under the influence of alcohol with increasing levels of BrAC (0.2 ‰, 0.5 ‰, 0.8 ‰, and 1.0 ‰). The simulator drive was alternated with a test track drive at the same BrAC level. Here, only results from the simulator are reported, as this was the only condition where other traffic occurred. All drives were conducted on a single experiment day.

The study was approved by the Swedish Ethical Review Authority (Dnr 2020–03238). An exemption from Swedish law was granted by the Swedish government (I2021/00946), allowing the test track experiment with drunk drivers.

### 2.1. Participants

Recruitment was done via a list with interested participants and via word of mouth. For screening, prospective participants filled in a

recruitment questionnaire. Those who met the inclusion criteria received further information via a phone call. Participants were recruited in pairs as far as possible, preferably friends or couples, to create a relaxed atmosphere during the data collection. Both participants in the pair took part in the experiment.

Inclusion criteria: 25–65 years of age, normal drinking habits (as by the alcohol use disorders identification test, AUDIT, Saunders et al., 1993), valid driving licence and minimum mileage of 5000 km in the previous year, and understanding Swedish.

Exclusion criteria: pregnant or possibly pregnant, problematic drinking habits or absolutist (as by the AUDIT-scale), medication that should not be mixed with alcohol, self-reported aggressive behaviour under the influence of alcohol.

The study population consisted of 20 male and 15 female participants (mean age:  $40.6 \pm 12.4$  years; driving licence for  $21 \pm 12.8$  years on average). The sample size was a compromise between budget limitations and obtaining a representative dataset, where especially the availability and cost of the test track was a limiting factor. Given this, our aim was to maximise the number of participants that could realistically be run, prioritising the alcohol condition over a placebo/control group.

### 2.2. Apparatus

A fixed-base driving simulator consisting of a car seat, automatic transmission, and three screens with a visual angle of about  $150^\circ$  was used, Fig. 1. Gaze tracking was performed with a four-camera eye tracking system (Smart Eye Embedded Tracking SDK v12.0, Smart Eye AB, Gothenburg, Sweden). Eye tracking data were recorded at 60 Hz while additional driving simulator signals were recorded at 50 Hz.

### 2.3. Route

The route led through an urban environment and took about 10 min to complete. Other road users were present, including pedestrians and cyclists, both moving and stationary. Bus stops, one road construction, traffic lights, and various changes in the speed limit occurred (the main speed limit was 50 km/h, with 3 temporary changes to 30 km/h and 1 change to 70 km/h). The goal was to create a scenario that required the driver to attend to numerous targets in several directions, but without any unpredictable critical incidents. The participants had to drive straight on for the whole route and were instructed to drive as usual in a similar traffic situation. The route was constructed as a loop where the participants drove one lap, but with two different starting points. Conditions with 0.0 ‰, 0.5 ‰ and 1.0 ‰ used one starting point while 0.2 ‰



Fig. 1. The fixed-base driving simulator that was used in the experiments. Two of the four eye tracking cameras are visible above the steering wheel. The tablet running the NDRT is located to the right of the steering wheel close to the centre console.

and 0.8 ‰ used the other starting point. It was ensured that matching road segments were used in all analyses.

#### 2.4. Non-driving related task (NDRT)

The participants were asked to perform a NDRT consisting of finding an arrow pointing upwards in an array of 5x5 arrows pointing left, right and downwards (Östlund et al., 2004). In 50% of the cases an upwards-pointing arrow was present. The task was presented on a touchscreen mounted close to the centre console to the right of the steering wheel, Fig. 1. It was self-paced in that a new task appeared only when the participant had completed the previous one. The participant answered the task by touching the upwards-pointing arrow (if present) or selecting a “no”-button (if not present). The instruction was to engage frequently in the task, to the extent that felt reasonable in the present traffic situation. The idea was to assess the ability to integrate an NDRT with driving, and to direct the drivers’ possible spare visual capacity to the touchscreen.

#### 2.5. Procedure

After filling out a background questionnaire, one of the participants was instructed how to operate the simulator, practised the NDRT, and did a test drive on parts of the route. The eye tracking system was calibrated, whereupon the participant drove the route in an alcohol-free condition. Meanwhile, the other participant in the pair drove a car on the test track, after which they swapped places. Then the first alcohol dose was administered. The aim was to reach a breath alcohol level of 0.2 ‰. To this end, the alcohol doses were determined based on the Hume–Weyers formula (Hume & Weyers, 1971). Participants could choose from three different alcoholic beverages that could be mixed with a range of soft drinks. They had about 15 min to drink, followed by 5 min to let most of the mouth alcohol to wear off, after which they rinsed their mouth with water. The simulator and test track drives were then repeated at the current BrAC level, followed by the administration of the next dose, see Fig. 2. Note that the learning effects caused by repeatedly driving the same simulated route will likely confound the data, which may then lead to an underestimation of the actual impairment at higher BrAC levels.

Before and after each drive participants reported their perceived level of sleepiness via the Karolinska Sleepiness Scale (KSS, Åkerstedt & Gillberg, 1990), their BrAC was checked with a Dräger 6820 (Drägerwerk AG & Co, Lübeck, Germany), and the participants predicted and then assessed the quality of their driving (scale 0–10). Both the target BrAC level and the measured BrAC level was known to the participants.

After the last drive, the participants were picked up by an acquaintance as previously arranged, and who had confirmed by signature to take care of the participants while they were still under the influence of alcohol. The whole session took approximately 5:30 h per participant pair.

#### 2.6. Analysis

Three groups of variables were investigated, which reflected attention, NDRT engagement and driving quality. Four variables were included in each group. They are defined and described in Table 2. The eye tracking software calculated the intersection between the gaze

vector and a pre-defined world model, automatically determining which areas of interest the drivers were looking at. The areas of interest time series was filtered with an interpolating 200 ms median filter to reduce the impact of eye blinks and lost tracking. A glance was then defined as a consecutive sequence of gaze data points directed to one of these areas of interest, where the start/end points were refined based on the onset/offset of the first/last fixation towards the area. Fixations were calculated with a two-stage segmentation algorithm based on 2-D velocity and dispersion (Ahlstrom et al., 2011).

The data were analysed in three stages to learn more about how the different variables varied with BrAC. First, descriptive correlation analyses within and between the variable groups were computed for each BrAC level to find patterns of covariation between variables and potential changes depending on alcohol level. Second, separate analyses of variance were conducted for all 12 dependent variables with BrAC level as fixed factor and participant as random factor with subject-dependent intercept. The alpha-level was set at  $0.05/12 = 0.004$ , to adjust for multiple testing, with Bonferroni-correction for post-hoc testing. Exact p-values are reported. Third, a linear discriminant analysis was used to explore whether a combination of the investigated variables could differentiate between the different BrAC levels. Technical issues led to missing eye tracking data for eleven drives, distributed across three participants.

### 3. Results

The measured values for BrAC (from after each drive) and the reported KSS after the drive are reported in Table 1. While KSS-levels increased over time, the mean values remained on the “alert” side of the scale.

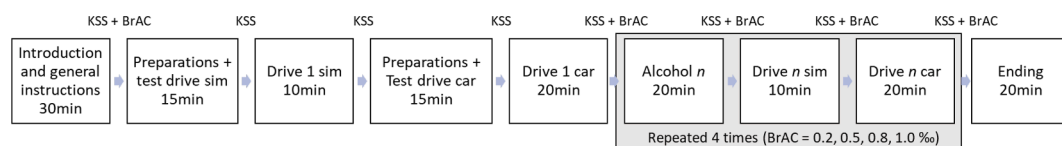
#### 3.1. Correlation analyses

Within each variable group (attention, NDRT engagement and driving quality), correlation coefficients did not generally change much with BrAC. Within the attention variables, the only significant association ( $p < .001$  on all alcohol levels,  $-0.98 < r < -0.73$ ) was found between *AttenD2.0 Forward* and the number of *AttenD2.0* warnings. Amongst the NDRT engagement variables, the *number of NDRT tasks* was highly related to *Glances to NDRT (%)*,  $p < .001$  on all alcohol levels ( $-0.25 < r < 0.21$ ). Within the driving quality variables, more *speeding* was associated with more frequent *THW < 1.5 s* ( $0.001 < p < .069$  for different alcohol levels,  $0.32 < r < 0.53$ ). In the alcohol-free condition, *THW < 1.5 s* ( $p = .025$ ,  $r = -0.39$ ) and *SWRR > 5°* ( $p = .020$ ,  $r = -0.40$ ) were associated with lower *self-reported driving quality*. *Speeding* ( $p$

**Table 1**

Actual mean breath alcohol levels and standard deviation per target level, along with reported mean KSS and standard deviation.

target breath alcohol level (‰)	breath alcohol level, mean (std), range of (‰)	KSS, mean (std) (range 1–9)
0.0	0.00 (0.00), 0.00 – 0.00	3.2 (0.97)
0.2	0.22 (0.11), 0.07 – 0.52	3.5 (1.05)
0.5	0.58 (0.15), 0.38 – 1.12	4.0 (1.19)
0.8	0.80 (0.13), 0.64 – 1.17	4.1 (1.26)
1.0	0.99 (0.09), 0.86 – 1.18	4.4 (1.56)



**Fig. 2.** Procedure outline. Two drivers participated in parallel, where one did the driving simulator sessions first and the other did the test track (car) driving sessions first.

**Table 2**

Definition and explanation of the dependent variables and their grouping into four categories.

Group/name (unit)	Definition	Comment
Attention		
Mean forward buffer AttenD2.0 (s)	mean forward AttenD2.0 value over the drive; possible range 0–1; higher values indicate higher level of attention (excluding speed < 3 km/h)	used to assess the driver's level of attention to the forward roadway
AttenD2.0 warnings (#)	number of distraction occurrences as per AttenD (excluding speed < 3 km/h)	the buffer used to assess the level of attention reaches 0
Glance away 95th percentile (s), no NDRT	the 95th percentile of the glance duration outside of the front screen and also not towards the NDRT (excluding speed < 3 km/h)	looking away from forward can be necessary for information sampling, but very long glances are typically detrimental
Glances to mirrors (%)	share of dwell time on any of the three mirrors	indicates awareness of traffic behind and on sides
NDRT-engagement NDRT tasks (#)	the number of NDRT answered	
Correct NDRT (%)	the percentage of correctly answered NDRT per drive	indicates whether quality or quantity is preferred
Mean glance duration to NDRT (s)	the mean duration of all glances directed at the NDRT screen	long durations can indicate getting "caught" in the task
Glances to NDRT (%)	share of dwell time on the NDRT screen	
driving quality		
Speeding Ix	proportion of the drive exceeding the speed limit, weighted by the amount of speeding	superior to mean speed, as speed exceedance cannot be compensated for
THW < 1.5 s (#)	number of occurrences where the time headway to the vehicle in front was below 1.5 s	
SWRR > 5 deg (#)	number of occurrences where the steering wheel reversal rate exceeded five degrees	rather than SDLP as our scenario contained situations which could confound SDLP
Self-reported driving quality	self-report of driving quality after each drive	

$=.008$ ,  $r = -0.45$ ) and  $SWRR > 5^\circ$  ( $p = .012$ ,  $r = -0.43$ ) were associated with *self-reported driving quality* at BrAC level 1.0 ‰.

Between variables from different variable groups the correlations are in the range of  $-0.5 < r < 0.5$  and not significant, with a few exceptions. The number of *AttenD2.0 warnings* is highly correlated with the number of *NDRT tasks* performed ( $p < .001$  on all levels,  $0.65 < r < 0.83$ ) and thus, also to *Glances to NDRT* ( $p < .001$  on all levels,  $-0.09 < r < 0.46$ ). Similarly, *AttenD2.0 forward* was also correlated with *NDRT tasks* performed ( $p < .001$  on all levels,  $-0.83 < r < -0.73$ ) and *Glances to NDRT* ( $p < .001$  on all levels,  $-0.35 < r < 0.17$ ). Most other correlation values were lower than  $r = \pm 0.4$ , reaching significance in a few spurious cases.

There were no clear trends in increasing or decreasing associations with increasing BrAC levels. In Fig. 3, the mean correlation coefficient between all pairs of variables, across the five alcohol levels, are plotted against the slope of the correlation coefficients across alcohol levels. The slope was calculated using a first order polynomial fitted to the five correlation coefficient values obtained between two variables per alcohol level. None of the variable pairs showed an association that varied with BrAC, as evidenced by the small slopes in the Figure.

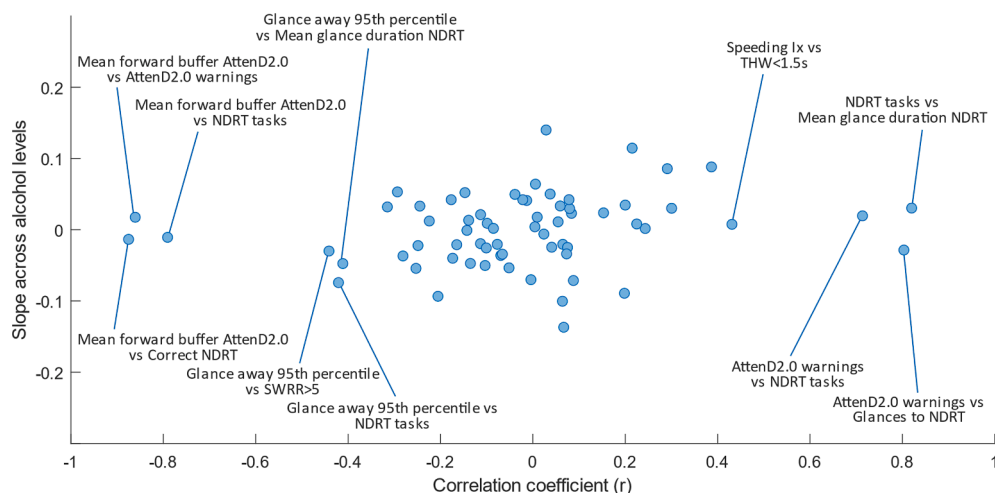
### 3.2. Attention

With increasing BrAC, up to level 0.8 ‰, the general attention level decreases, more instances of inattention occur, and the 95th percentile glance away from the forward roadway become longer (Table 3). The share of dwell time to the mirrors decreases. Fig. 4 shows that the variance within BrAC levels is large, with a tendency to increase with increasing BrAC. The variance of the value for *AttenD2.0 Forward* is increasing already at 0.2 ‰, with the percentage of drivers obtaining a

**Table 3**

Anova-results for the attention-related variables.

	F	df	p	post-hoc (Bonferroni-corrected)
AttenD2.0 Forward	17.8	(4, 123)	<0.001	0.0 ‰ differs from all levels but 0.2 ‰; 0.2 ‰ differs from 0.8 ‰ and 1.0 ‰
AttenD2.0 warnings	7.4	(4, 123)	<0.001	0.0 ‰ differs from all levels but 0.2 ‰; 0.2 ‰ differs from 0.8 ‰ and 1.0 ‰
Glance away 95th percentile, no NDRT	23.2	(4, 123)	<0.001	all levels differ except between 0.0 ‰ and 0.2 ‰, and between 0.8 ‰ and 1.0 ‰
Glances to mirrors	5.7	(4, 123)	<0.001	0.0 ‰ and 0.2 ‰ differ from 1.0 ‰



**Fig. 3.** Mean correlation coefficient between variables within an alcohol level versus slope of the correlation coefficients across alcohol levels. Only significant correlation coefficients with  $r > 0.4$  have been labelled.



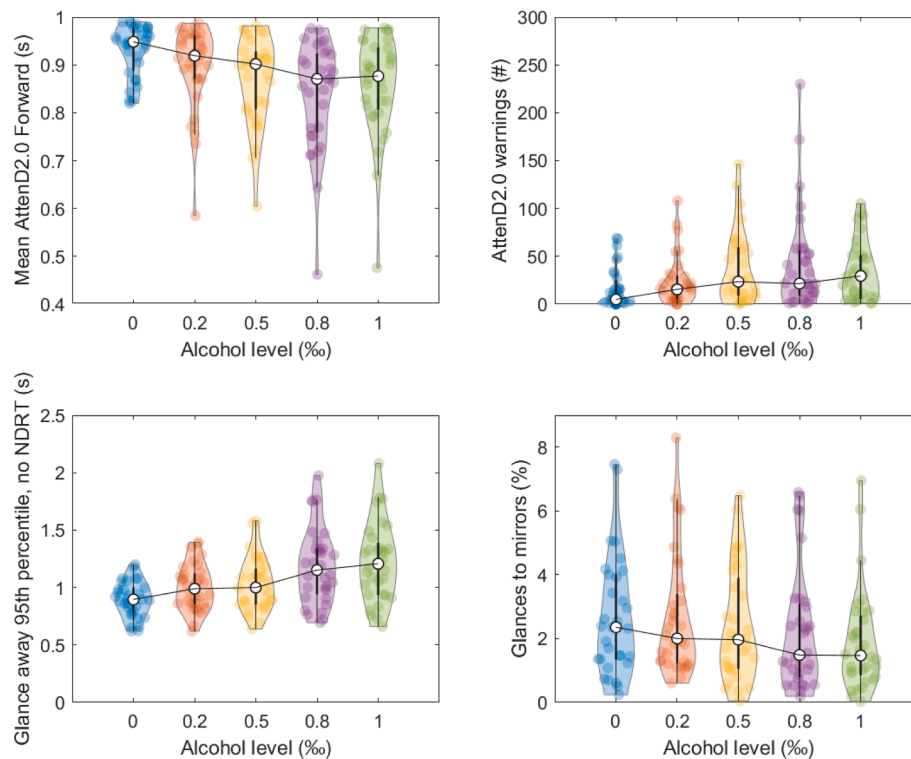


Fig. 4. Violin-plots for the attention-related variables per BrAC level, showing the distribution and median values.

lower number than the lowest in the alcohol-free condition being 16% at 0.2 ‰, 28% at 0.5 ‰, and 31% at 0.8 ‰ and 1.0 ‰. The highest value measured for the 95th percentile of glance duration away from forward in the alcohol-free condition was 1.2 s, which was exceeded by 16% of the participants at level 0.2 ‰ and by 50% of the participants at level 1.0 ‰. The overall mean value for glancing away from forward screen, except to the NDRT, was 0.41 s and did not differ between alcohol levels ( $F(4, 123) = 1.7, p = .158$ ).

### 3.3. Ndrt

The NDRT is performed more frequently with increasing BrAC levels (Table 4). Additional analyses showed that almost all participants increased their NDRT-engagement with increasing BrAC. At 0.2 ‰, 80% of the participants increased their NDRT-engagement compared to at 0.0 ‰, and at 0.5, 0.8 and 1.0 ‰, the corresponding percentage was 92%. The participants did not get better at the task itself, but performance is generally high with a median accuracy of > 90% for all BrAC

levels (Fig. 5). The participants spent more time looking at the NDRT to be able to solve more NDRTs, which is at least partially due to longer single glances. While the highest measured mean single glance duration in the alcohol-free condition was 1.7 s, a quarter of the participants exceeded this value at level 0.4 ‰. Mean glance durations to the NDRT above 2 s occurred from 0.5 ‰ upwards for 10%, 16% and 20% of the participants, respectively. Around 15% of the participants glanced at the NDRT for more than one third of the time in the two highest BrAC levels.

### 3.4. Driving quality

The participants reported a decreased quality of driving with increasing BrAC (Table 5). Still, the percentage of participants who judged their driving performance to be six or higher was 82% (0.0 ‰), 91% (0.2 ‰), 71% (0.5 ‰), 56% (0.8 ‰) and 48% (1.0 ‰) respectively. In this context, it can be noted that all participants exceeded the speed limit to some extent, with some outliers at level 0.0 ‰ and increased speeding at higher levels of BrAC. In only 12 of 170 drives, no occasion with a time headway of below 1.5 s was registered. Large steering wheel movements became frequent for more participants at higher BrAC levels.

### 3.5. Discriminant analysis

An exploratory discriminant analysis was used to investigate how the variables together were related to the different BrAC levels. The variable *correct NDRT* was excluded since it did not change significantly across BrAC. The variable *NDRT tasks* was also excluded since an analysis of collinearity showed that it was highly correlated with the *glances to NDRT* and *Attend2.0 warnings* variables. All remaining variables were used in the linear discriminant analysis.

The resulting discriminant functions (accuracy = 48.4%) were significantly better than chance (accuracy = 20%) at differentiating the BrAC levels ( $\chi^2(40) = 118.7, p < .001$ ). Misclassifications were mainly made with direct neighbours, see Fig. 7. The variables with the highest explanatory power were *Mean glance duration towards NDRT*,

Table 4  
Anova-results for the NDRT-related variables.

	F	df	p	post-hoc (Bonferroni-corrected)
NDRT tasks	20.7	(4, 132)	<0.001	0.0 ‰ differs from all but 0.2 ‰; 0.2 ‰ and 0.5 ‰ differ from 0.8 ‰
Correct NDRT	0.80	(4, 128)	0.530	
Mean glance duration to NDRT	22.8	(4, 119)	<0.001	0.0 ‰ differs from all but 0.2 ‰; 0.2 ‰ differs from all other levels
Glances to NDRT	24.8	(4, 132)	<0.001	0.0 ‰ differs from all but 0.2 ‰; 0.2 ‰ differs from all other levels

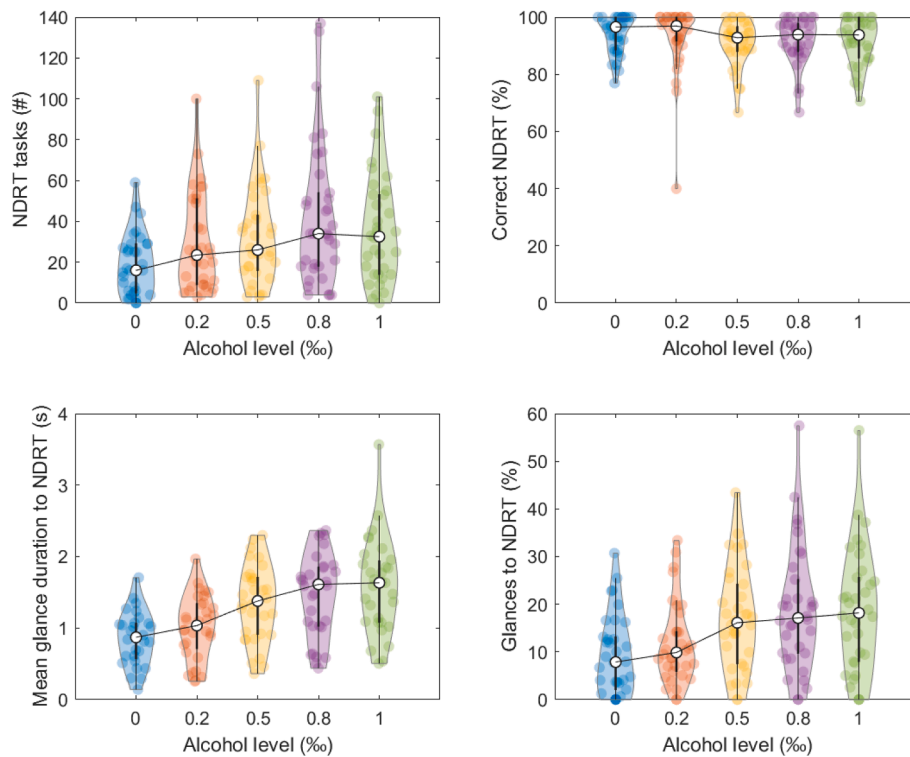


Fig. 5. Violin-plots for the NDRT-related variables per BrAC level, showing the distribution and median values.

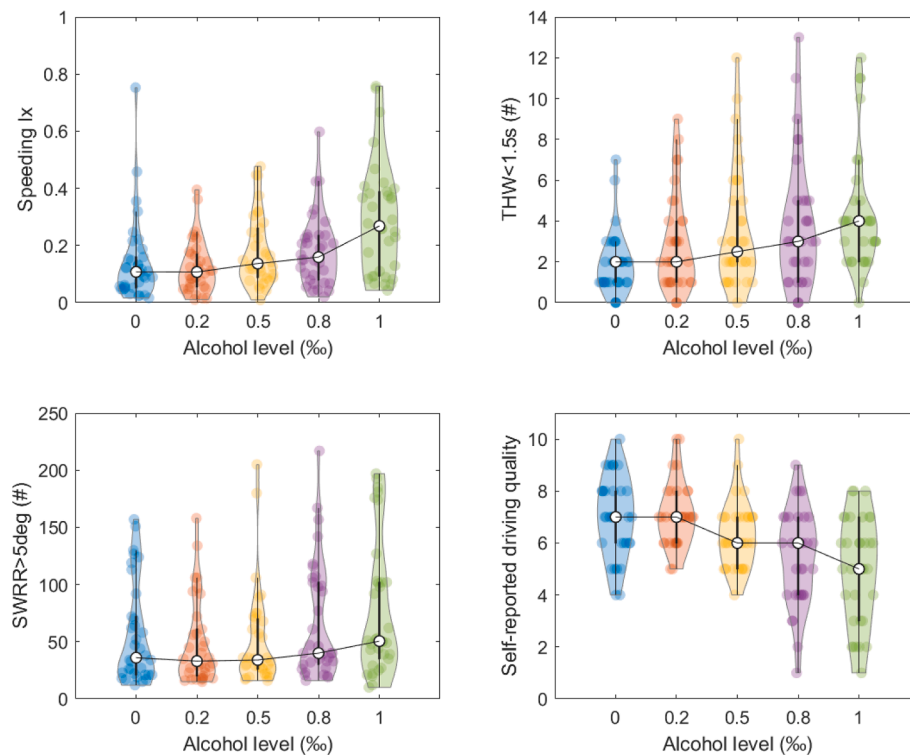


Fig. 6. Violin-plots for the driving quality-related variables per BrAC level, showing the distribution and median values.

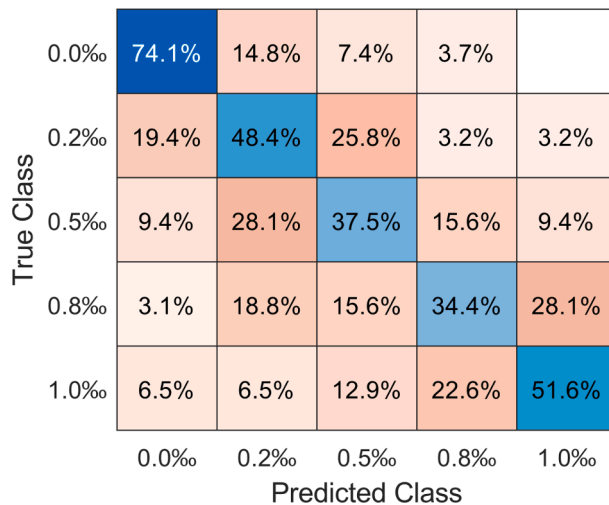
*Self-reported driving quality* and *Glance away 95th percentile*, in that order. The *Glances to mirrors* did not contribute to the classification, and the contribution of *Attend2.0 warnings* was also low.

The three variables mentioned above were correlated with the first discriminant function with  $r > 0.4$ . This discriminant function had a

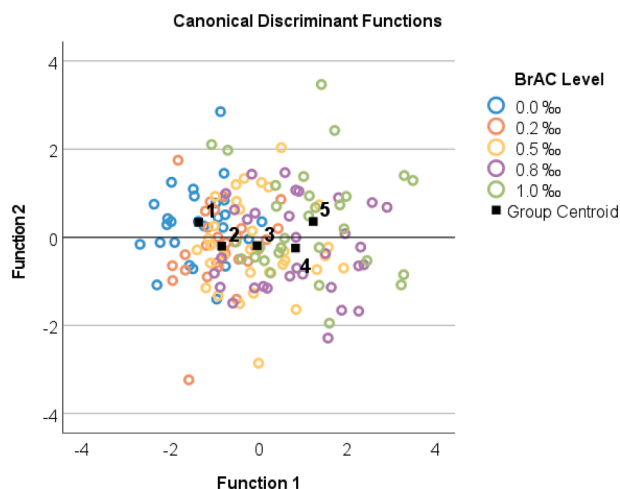
share of 85.9% of the variance explained by the analysis. The second discriminant function was mainly related to *speeding index* and *SWRR > 5°* from the driving quality block. As shown by Fig. 8, the group centroid order for the first discriminant function reflected the order of the BrAC levels. The second function explained 6.9% of the variance but was not

**Table 5**  
Anova-results for the driving quality-related variables.

	F	df	p	post-hoc (Bonferroni-corrected)
Speeding Ix	12.4	(4, 132)	<0.001	1.0 ‰ differs from all other levels
THW < 1.5 s	6.0	(4, 132)	<0.001	0.0 ‰ differs from all but 0.2 ‰
SWRR > 5 deg	9.1	(4, 132)	<0.001	1.0 ‰ differs from all but 0.8 ‰;
				0.2 ‰ differs from 0.8 ‰
Self-reported driving quality	15.6	(4, 130)	<0.001	1.0 ‰ differs from all but 0.8 ‰;
				0.2 ‰ differs from 0.8 ‰



**Fig. 7.** Confusion matrix from the linear discriminant analysis.



**Fig. 8.** Scatter plot for drives and group centroids for both training and test set data for Discriminant Function 1 and Discriminant Function 2.

significant.

#### 4. Discussion

The simulated driving scenario was designed to be busy but did not contain any unpredictable events. None of the participants ended up in a crash or a near-crash, something which would have provided uncontested proof of excessive driver impairment. Still, there are indications

that alcohol hampers performance in several areas independently of each other. In line with previous research (Fillmore et al., 2008; Gawron & Ranney, 1988; Helland et al., 2013; Ranney & Gawron, 1986), we found driving quality degradations like increased speeding, more frequent occurrences of short time headways, and reduced lateral control. Engagement in risky behaviour seems to be a conscious personal choice, as more frequent speeding and short time headways co-occur without being linked to the measured level of attention. People who behave in a riskier manner show a tendency to judge their driving performance as less good, which suggests at least a certain degree of awareness of their behaviour. Overall, the variance in the measured variables increased with increasing BrAC-levels, indicating individual differences in how alcohol affects performance, which is in line with previous findings (Gawron & Ranney, 1988).

Glances away from the forward roadway can be separated into those that are likely relevant for driving and those that are directed towards the NDRT. The mean duration of the former does not increase with BrAC level, even though the longest 5% become longer. The mean glance duration to the NDRT in the alcohol-free condition is comparable to what is found in the literature, which shows that drivers are generally not willing to look away from the forward field of view for more than about 1.5 s (e.g. Wierwille, 1993). NDRT-engagement with longer total task durations are generally split into multiple short glances away from the forward roadway, so-called visual time sharing (VTS; Wikman et al., 1998; Zwahlen et al., 1988). Here, however, increasing BrAC levels led to an increase in mean glance duration to the NDRT, which was also found by Tivesten et al. (2022). A possible explanation can be that the NDRT has a high potential to capture attention, and with increasing BrAC, drivers fall victim to this, with prolonged single glances and with spending more time engaging in the NDRT overall. This finding aligns well with the theory that alcohol disturbs the ability to shift attention between multiple tasks (Post et al., 1996; Weafer & Fillmore, 2012).

There is evidence that drivers compensate for NDRT engagement by slowing down (Oviedo-Trespalacios et al., 2017), by increasing their headway (Saifuzzaman et al., 2015) or by choosing to engage with NDRTs in situations with low complexity (Tivesten & Dozza, 2015). With increasing BrAC, this protective strategy seems to break down. Drivers engage in the NDRT to a higher extent while they also increase their speeding, accumulate more short time headways, and show reduced lateral control. In this context it is interesting to note that bad driving quality is not in itself correlated with high NDRT engagement, but rather that both develop negatively with increasing BrAC levels.

Similarly, the degree of NDRT-engagement in the alcohol-free condition was not associated with the level of attention to the forward roadway (*Attend2.0 Forward*), even though the number of instances of distraction (*Attend2.0 warning*) was higher for those drivers who performed more NDRTs. A possible interpretation of this can be that drivers have varying capability of integrating the NDRT in their driving, but that they are aware of this and therefore stay within their personal limits, such that overall attention levels are not affected. Still, the captive nature of the task tends to lead to occurrences of distraction. With increasing BrAC-levels, more tasks are executed, such that not only instantaneous distraction events become more frequent, but also overall attention is affected. The decline in overall attention does not only result from increasing NDRT-engagement. It can also be connected to a decreasing ability in adaptation to task complexity, such that the NDRT is executed at inopportune moments. Furthermore, the decrease in glances to the mirrors can be an indication for visual and/or cognitive tunnelling known to occur when driving under the influence of alcohol (Belt, 1969; Moskowitz & Robinson, 1988; Tivesten et al., 2022).

Results from the linear discriminant analysis are promising in several ways. First, the confusion matrix reveals that misclassifications mainly occur between neighbouring levels of BrAC. Second, it is interesting that the alcohol levels show up in order in the first discriminant function. This is a clear indication that the linear combination of the variables included in the first discriminant function is related to the BrAC level. A

linear discriminant analysis maximizes differences between groups without taking order into account, so this is not a self-evident outcome. Considering the large overlap between classes (Fig. 8), and the increase in variance with increasing levels of BrAC for many of the variables (Fig. 4 – Fig. 6), it is clear that the classification task is difficult. More descriptive features or more advanced classifiers may help, but given the interindividual variability in the data, personalised algorithms are probably a more feasible approach. A larger dataset is needed to pursue this further. A first step would then be to test the generalisability on an independent dataset.

A major drawback of the setup was that no placebo group was used to control for familiarity. This was due to budget constraints in the project, where a larger number of participants in the alcohol group was prioritised over a placebo/control group. There is a chance that increased familiarity may have contributed to a more intensive NDRT engagement and thereby to reduced attention levels, but it is unlikely that it would lead to increased speeding, small THWs and increased SWRR. Also, the increased mean glance duration to the NDRT is unlikely to be due to more familiarity with the situation and corresponds well with the findings of Tivesten et al. (2022). However, a follow-up study with a placebo control group is recommended.

## 5. Conclusions

The observed effects could be seen at BrACs as low as 0.2 ‰ but typically set in at about 0.5 ‰. The impairments found at BrAC levels 0.8–1.0 ‰ are likely to underestimate the true impact of alcohol, because of the learning effect arising from the repeated simulator drives. In the alcohol-free condition, the level of NDRT-engagement was not directly related to attention in general, but local distraction instances occurred, potentially due to the capturing effect of the task. Increasing BrACs lead to increased NDRT-engagement without compensatory behaviour. Instead, safety margins were reduced, indicating that drivers lose their ability to plan and make up for a temporary impairment. This also implies that the popular comparisons of mobile phone use to a certain BrAC level (Burns et al., 2002; Leung et al., 2012; White et al., 2004) can be misleading. There are, however, major differences between alcohol and mobile phone use. Drivers use strategies to manage NDRTs by shedding, delaying, and resuming task-engagement depending on the traffic situation, and distracted drivers can quickly become attentive by turning their attention back to the driving task. In contrast, a drunk driver remains drunk until the effects of alcohol wear off, and as this study shows, alcohol prevents compensatory strategies and self-regulation. The most dangerous consequence of comparisons between phone use and alcohol might be that drivers who exhibit good compensatory strategies when engaging in NDRTs could be led to believe that they would be equally successful in handling driving under the influence of alcohol. The results from this study provide further evidence of the extensive detrimental effects of alcohol on driving and the importance of keeping drunk drivers away from the roads. The insight that alcohol effectively prevents compensatory behaviour motivates a lowering of the legal limit in many countries, and should also be taken into account when designing public health and safety awareness campaigns, as well as technical prevention measures.

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## CRediT authorship contribution statement

**Christer Ahlström:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization. **Raimondas Zemblis:** Resources, Data curation, Writing – review & editing. **Svitlana Finér:** Funding acquisition, Resources, Project

administration. **Katja Kircher:** Funding acquisition, Project administration, Methodology, Formal analysis, Writing – original draft.

## Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Raimondas Zemblis and Svitlana Finér are employed by the eye tracking company Smart Eye AB, Gothenburg, Sweden. All authors declare that there are no additional conflicts of interest.

## Data availability

The authors do not have permission to share data.

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