Fit2Drive

Public report

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1 Sammanfattning

Rattfylla är ett stort trafiksäkerhetsproblem, eftersom även låga alkoholkoncentrationer ökar olycksrisken avsevärt och påverkar körningen negativt. Syftet med denna studie var att bedöma hur alkoholpåverkan interagerar med förarens uppmärksamhet och hur det påverkar lämpligheten att köra bil.

Trettiofem deltagare körde i en simulator och på en testbana medan de var nyktra och under påverkan av alkohol med ökande alkoholhalt i utandningsluften (BrAC). Deltagarna rekryterades baserat på flera kriterier, inklusive ålder, kön, språkkunskaper, körupplevelse, hälsotillstånd och giltigt körkort. Ytterligare en datainsamling med 35 deltagare gjordes i fält.

De insamlade data inkluderade videoupptagningar av förarens huvud- och ögonrörelser, inspelningar av insidan av kupén och förarens överkropp, hjärtaktivitet och körbeteende. Studien visade att uppmärksamhetsfördelning inte var tillräcklig för detektion av alkoholpåverkan, medan psykofysiologiska mått som fixeringstid och -hastighet samt saccad-amplituder var lämpliga kandidater för universell alkoholpåverkansdetektion. Blinkdynamiken visade också tydliga effekter av alkoholpåverkan. Placeringen av kameran bör beaktas för framtida algoritm-utveckling.

Studien visade att tre olika variabelgrupper - uppmärksamhet, utförande av extrauppgifter (NDRT) och körkvalitet – påverkades negativt efter alkoholkonsumtion. Deltagarna tenderade att titta bort från vägen längre, medan blickarna till speglarna minskade. Antalet utförda NDRT ökade med högre BrAC-nivåer, och medelblicklängden till NDRT-skärmen nästan fördubblades vid 1,0 ‰ jämfört med nykterhet. Dessutom försämrades körkvaliteten: Deltagarna körde snabbare, vinglade mer, och deras säkerhetsmarginaler gentemot andra minskade.

Kombinationen av minskad uppmärksamhet, ökat NDRT-engagemang och kompromissad körkvalitet skapar således en "farlig blandning". En diskriminant-analys genomfördes för att bedöma de kombinerade variablernas indikativa värde för BrAC-klassificering.

Sammanfattningsvis fann studien att alkohol försämrar uppmärksamheten, leder till minskade säkerhetsmarginaler vid körning och mindre restriktivt engagemang i icke-körrelaterade uppgifter. Ett kamerabaserat förarmonitorerings system (DMS) i bil kan hjälpa till att upptäcka minskad uppmärksamhet. Rekommenderad fortsatt forskning inkluderar att analysera befintliga data för att förstå uppmärksamhetsmekanismer som påverkas av alkoholkonsumtion och utvidga datamängden med en nykter kontrollgrupp och ett bredare spektrum av fysionomiska egenskaper för automatisk detektion av förarens tillstånd. Det rekommenderas även att använda sig av flera automatiseringsnivåer för att säkerställa att förartillståndsbedömningen fungerar på samtliga nivåer.

2 Executive summary in English

Drunk driving is a major road safety problem, with even low levels of alcohol concentration significantly increasing crash risk and negatively affecting driving. Studies have shown impairments in motor function, cognitive functioning, and impulsivity. The effect on visual sampling and attention is less well researched, though some studies suggest a negative impact on peripheral vision and attention-related processes. The goal of the project was to assess fitness to drive, and specifically how alcohol intoxication interacts with driver attention and drowsiness.

A test track and simulator study involved 35 participants driving in a simulator and on a test track while sober and under the influence of alcohol with increasing levels of breath alcohol content. The participants were recruited through word of mouth and a list of interested participants and underwent screening. The simulator consisted of a car seat and three screens, and the route involved driving through urban and suburban areas with other road users present. During the driving, participants were asked to perform a non-driving-related activity task. The test track was approximately 3.1 km long, and the vehicle used was equipped with three Smart Eye Driver Monitoring Systems and a Smart Eye Cabin Monitoring System.

The participants in the study were equipped with heart rate measuring electrodes and filled out a background questionnaire before practicing driving the simulator or instrumented vehicle on the track while sober. Participants then drove a sober baseline trial in both settings before receiving the first dose of alcohol based on the Hume-Weyers formula, targeting 0.2 ‰. The participants underwent the procedure for three additional target levels of intoxication (0.5 ‰, 0.8 ‰, 1.0 ‰).

In addition to the test track and simulator study, a field study with naturalistic driving in the city and outside of it was conducted. Participants were recruited based on several criteria, including age, gender, language proficiency, driving experience, health status and possession of a valid driving license. The driving session was conducted in real traffic in Sweden using a car with automatic transmission. During the session, participants were allowed to use cruise control and were observed by a test leader who monitored the measuring equipment and made notes on the driver's behaviour, sleepiness level, and any unexpected events or deviations from expected driving behaviour. The data collected included video recordings of the driver's head and eye movements, recordings of the inside of the cabin and the driver's upper body, heart activity measurements and driving behaviour. Thirty-five participants, 15 females and 20 males, completed the study, with an average age of 42.5 years for females and 36.9 years for males. The total recorded driving time was 92.3 hours.

The study aimed to evaluate how various behavioural and psychophysiological measures from a driver monitoring system are affected by intoxication levels and if a single camera system can still robustly measure them. It was also found that attention proportion measures were not suitable for intoxication detection due to data loss, while psychophysiological measures like fixation duration and rate and saccade amplitudes were good candidates for universal intoxication detection. Blink dynamics also showed a clear effect of intoxication. It was also found that camera placement should be taken into account for future algorithm development.

The data collected from the driving simulator was used to assess the impact of alcohol intoxication on attention and driving quality. The measured variables were categorized into three groups: attention, non-driving related task (NDRT) engagement, and driving quality. Most of these variables were not highly correlated. The study found that overall, all three variable groups were negatively affected after alcohol consumption. Participants tended to glance away from the forward roadway for longer periods of time, while glances to the mirrors decreased. The number of NDRTs executed increased with higher BrAC levels, and the mean glance duration to the NDRT screen almost doubled in the 1.0 ‰ condition compared to sober. Furthermore, the quality of driving deteriorated, with participants driving faster and weaving more, and their safety margins towards others were reduced. The study suggests that the combination of decreased attention, increased NDRT engagement, and compromised driving quality creates a "dangerous cocktail" of ingredients. A discriminant analysis was conducted to assess the combined variables' indicative value for BrAC classification. While a better-than-random result was achieved, some of the entered data may not be readily available to a driver monitoring system.

During the project, the drowsiness algorithm was improved with three new features and personalized data, and camera positions and frame rates were investigated for better results. A microsleep algorithm was also added to meet EuroNCAP requirements, and the drowsiness and attention algorithms are now available for personal vehicles and trucks.

Obtaining a government waiver was necessary to conduct a test track study as Swedish law prohibits driving under the influence of alcohol anywhere. The waiver process took over half a year and required more resources than originally budgeted. The COVID-19 pandemic also caused delays in data collection, but the additional time for preparation and testing may have had benefits. A follow-up study is recommended to investigate how alcohol intoxication affects specific aspects of information sampling and attention. The field data collection was delayed, but there are plans to work on the collected data in future projects.

The study found that alcohol impairs attention, leads to decreased safety margins in driving and less restrictive engagement in NDRT. This is a dangerous combination, as no compensatory behaviour occurs, which is often found in sober driving. DMS systems in cars can help detect reduced attention and involvement in NDRT. Recommended further research includes analyzing existing data to understand attentional mechanisms affected by alcohol consumption and expanding the data set with a sober control group and a wider range of physiognomic features for automated driver state detection. Also, additional levels of automation should be included to make sure that the algorithms work agnostic of automation level.

3 Background

Drunk driving is a major road safety problem with around 35 percent of all lethal crashes worldwide being associated with it (World Health Organization, 2018). It is well established that already low levels of alcohol concentration (around 0.4 ‰; (Compton et al., 2002) significantly increase crash risk and negatively affect driving.

Previous studies have shown a number of driving impairments under the influence of alcohol. These fall under decreased smoothness of motor functions, which affect steering and lane keeping (Gawron & Ranney, 1988; Helland et al., 2013; Ranney & Gawron, 1986), impaired cognitive functioning (Martin et al., 2013; Mitchell, 1985; Ogden & Moskowitz, 2004), which may lead to increased reaction times and compromised decision-making, and an effect on impulsivity, leading to increased risk taking like higher means speeds and a reduced likelihood to stop at red lights (Fillmore, Blackburn, & Harrison, 2008).
(Åkerstedt & Gillberg, 1990)

The effect of alcohol on visual sampling and attention is less well researched. A test-track study indicated that drivers spent more time visually interacting with a non-driving related task (NDRT) after having consumed alcohol (Tivesten, Broo, & Ljung Aust, posted 2022). According to Freydier, Berthelon, Bastien-Toniazzo, and Gineyt (2014), peripheral vision was negatively affected, too. This fits with the finding that alcohol has a disruptive effect on the coordination of attention-related processes (Weafer & Fillmore, 2012).

4 Purpose, research questions and method

The goal of the project was to assess fitness to drive, and specifically how alcohol intoxication interacts with driver attention. An additional question was an assessment of driver state monitoring systems under realistic external conditions with varying illumination and actual vehicle and driver movements. Finally, the quality of assessment of driver state during manual driving and while in a passive role (resembling highly automated driving) was investigated.

Thus, a combined test-track and simulator study was conducted as described in Section 4.1. For a validation of the algorithm, additional data were planned to be collected in the field, though for sober drivers only. This study is described in Section 4.2.

4.1 Test track and simulator study

Thirty-five participants completed a route in a driving simulator starting from sober followed by under the influence of alcohol with increasing levels of breath alcohol content (BrAC). The simulator drive was alternated with a test track drive at the same level of intoxication. The study was approved by the Swedish Ethical Review Authority (Dnr 2020-03238). The Swedish government issued a waiver (I2021/00946), granting exemption from the Swedish law and thereby allowing the test track experiment with intoxicated drivers.

The participants were recruited by word of mouth and a list of interested participants. Screening was done via an extensive recruitment questionnaire that encompassed driving background, drinking habits and relevant physiological information. Participants were recruited pairwise to create a relaxed setting. Inclusion criteria were an age of 25-65 years, normal drinking habits and a minimum mileage of 5000 km in the previous year. Incompatible medical conditions or pregnancy belonged to the exclusion criteria, likewise self-reported aggressive behaviour under the influence. We had 20 male and 15 female participants averaging 41 years of age.

Simulator driving

The simulator consisted of a car seat and three screens with a visual angle of about 150 degrees, allowing driving in urban areas without making turns (see Figure 1). Smart Eye Pro with 4 cameras was used for recording the driver.

Figure 1. The simulator used in the study. Photo: Katja Kircher.

The route led through urban and suburban areas with other moving and stationary road users present in the form of pedestrians, cyclists and motor vehicles. Speed limits varied between 30 km/h and 70 km/h and there were bus stops, traffic lights and a road construction. The goal was to create a scene that required the driver to keep taking in visual information from several directions, but without encountering unpredictable critical events.

While driving, the participants were asked to perform a task that should resemble interaction with for example a mobile phone (a so-called non-driving-related task, NDRT). On a screen mounted at the centre console, a 5x5 matrix of arrows pointing in several directions was displayed. In half of the cases an arrow pointing upward was present. The driver should identify this arrow by touching it or otherwise press no. Each matrix was presented until the screen was pressed, such that the driver could choose when to perform the task. The goal was to assess how well drivers were able to integrate an additional task into driving.

Test track driving

A Volkswagen Passat 2013 with automatic transmission and left-hand driving was used for this study. The vehicle was equipped with one 1-camera Smart Eye Driver Monitoring System (DMS), one 5-camera Smart Eye Pro System, one 1-camera Smart Eye Pro System and 1 Smart Eye Cabin Monitoring System (CMS) (Figure 2). The first three were used to capture the driver's head and eyes up close and their movements and last one was used to capture the inside of the cabin, including the full upper body of the test participant. The DMS and multi-camera SEP were mounted on the driver's side to record the driver during manual driving. The single-camera SEP was mounted at the passenger side to record the driver during automated driving. The test vehicle was also equipped with CAN data recording module and the GPS unit for vehicle position estimation, both synchronized with camera recordings. The vehicle was equipped with a second set of pedals on the passenger side, where the test leader was seated. The experimenter also had gone through a "safety driver" education on how to intervene in case of the test driver displaying inappropriate and dangerous behaviour.

Figure 2. Partial view of the instrumented vehicle used in the project for two data collections. Photo: Katja Kircher.

The test track was the racing track in Mantorp Park (Figure 3). It was approximately 3.1 km long and contained straight stretches and curves. No other traffic was present. Speed limits varied between 50 km/h and 70 km/h. One narrow passage (Figure 4) and one chicane (Figure 5) were set out with cones.

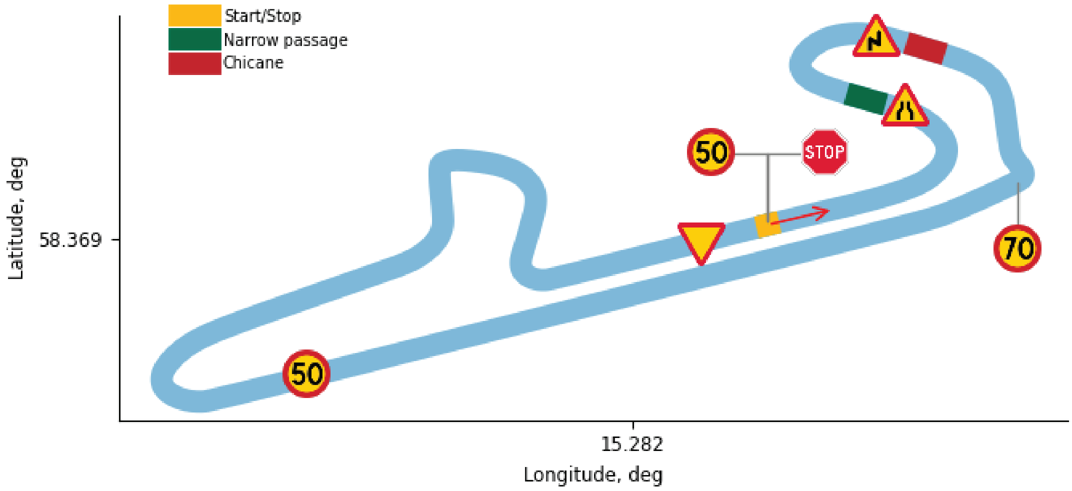


Figure 3. Schematic layout of the test track. Speed limits and other signs were placed in the indicated locations. The narrow passage is indicated in green and the chicane is indicated in red.

Figure 4. The narrow passage from the driver's point of view. Photo: Katja Kircher.

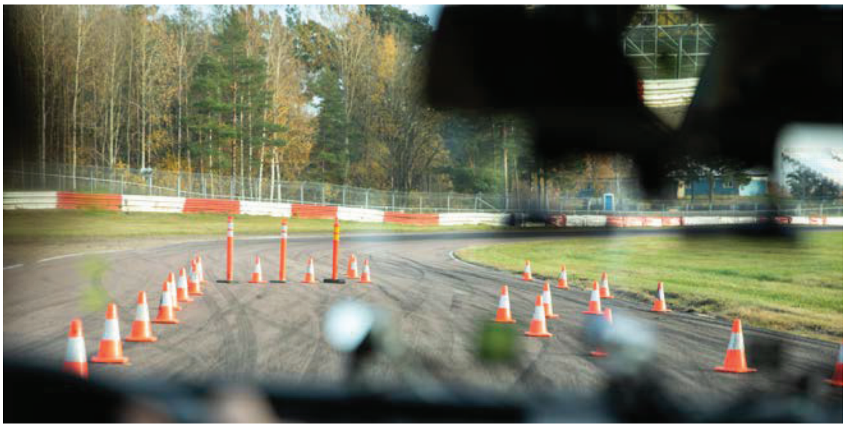


Figure 5. The chicane from the driver's point of view. Photo: Katja Kircher.

Procedure

After having completed all formalities including obtaining informed consent, each participant filled out a background questionnaire and was equipped with three electrodes measuring heart rate. As mentioned, participants were run in pairs. One practiced driving the simulator and executing the NDRT (Figure 6 right), the other practiced driving the instrumented vehicle on the track. After this, both drove a baseline trial while sober. In the simulator, this constituted a trip of ca. ten minutes, on the test track this meant driving one lap in the driver's seat, then swapping places with the experimenter and sitting in the passenger seat while being driven around the track another lap (ca. 4 mins for each lap). This condition was meant to simulate high-level automation. When this was done, the participants changed places with each other and repeated the procedure in the other setting – vehicle or simulator. Before the baseline drive, both in the car and the simulator, the participants were asked to report their level of sleepiness according to the Karolinska Sleepiness Scale (KSS, Åkerstedt & Gillberg, 1990) and how good on a scale from 0 to 10 they expected to be driving. Afterwards, they were asked to rate how good they actually had driven.

Figure 6. The breath alcohol measurement equipment (left) and the NDRT performed while driving in the simulator. Photos: Katja Kircher.

- measure breath alcohol level
- report sleepiness
- report expected driving quality
- drive either in the simulator or on the test track (one lap in the driver's seat and one in the passenger seat)
- report sleepiness
- report experienced quality of driving
- measure breath alcohol level
- swap places with the other test participant
- report expected driving quality (for the other setting)
- drive either the test track or the simulator
- report sleepiness
- report experienced quality of driving
- measure breath alcohol level
- intake of next dosage of alcohol

The next step was to administer the first dose of alcohol. Based on the Hume-Weyers formula (Hume & Weyers, 1971) considering sex, length and body weight, a dosage targeting 0.2 ‰ was provided. The participants could choose from three different alcoholic beverages which would be mixed with one out of a range of soft drinks. They then underwent the procedure described in the following for altogether four different target levels of intoxication. Table 1 shows the target levels, the mean measured level with the associated standard deviation and the mean self-reported level of sleepiness and standard deviation. Figure 7 shows the BrAC values for before and after each part of the trial at a given level of intoxication.

Table 1. Actual mean breath alcohol levels and standard deviation per target level with reported mean KSS and standard deviation.

target breath alcohol level ‰	mean breath alcohol level ‰	std	mean (std) KSS (range 1-9)
0.0	0.00	0.00	3.2 (0.97)
0.2	0.20	0.10	3.5 (1.05)
0.5	0.56	0.10	4.0 (1.19)
0.8	0.79	0.12	4.1 (1.26)
1.0	1.00	0.11	4.4 (1.56)

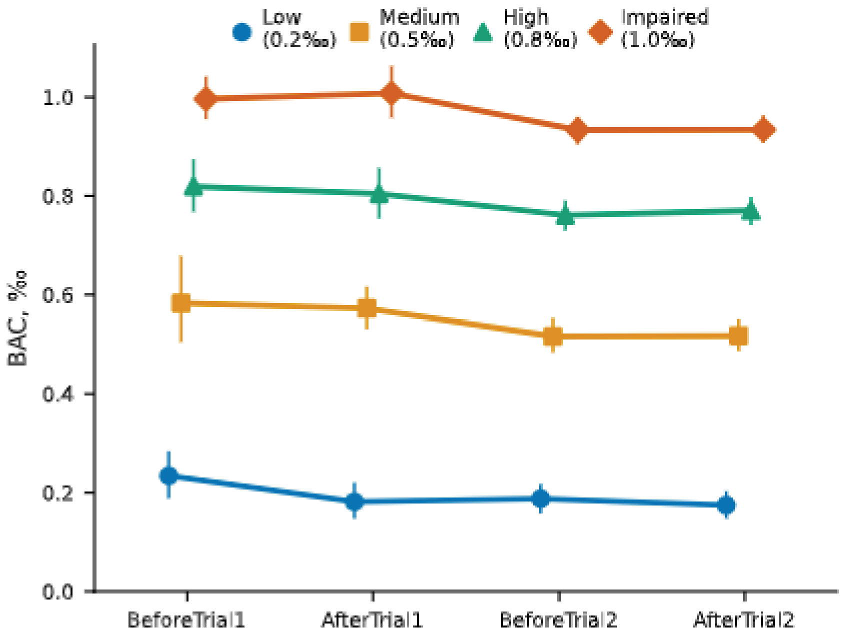


Figure 7. Average BrAC and error bars (90% confidence interval) across all participants for the four intoxication levels before and after the first trial (simulator or test track) and before and after the second trial (test track or simulator) within each alcohol level condition.

After the last testing round, the electrodes were removed. The participants were picked up by an acquaintance who had signed a paper that they would take care of the participant while sobering up.

None of the participants quit prematurely. The whole session took about five hours and a half for each pair of participants. On each day, two pairs were run, one starting in the morning and one starting in the early afternoon.

4.2 Field study

Within the Fit2Drive project Smart Eye AB conducted a field driving study in the city of Gothenburg and on the highway outside of it. The study was approved by the Swedish Ethical Review Authority (Dnr 2022-03796-01). It was carried out during December 2022 and January-February 2023.

The aim was to collect data from at least 30 participants. Each participant was supposed to participate in one driving session, driving two identical 15-minute-loops in the city (Figure 7) followed by one of the two 2-2.5 hours highway loops (Figure 8 and Figure 9). The total time of the driving session was planned to be approximately 2-3 hours.

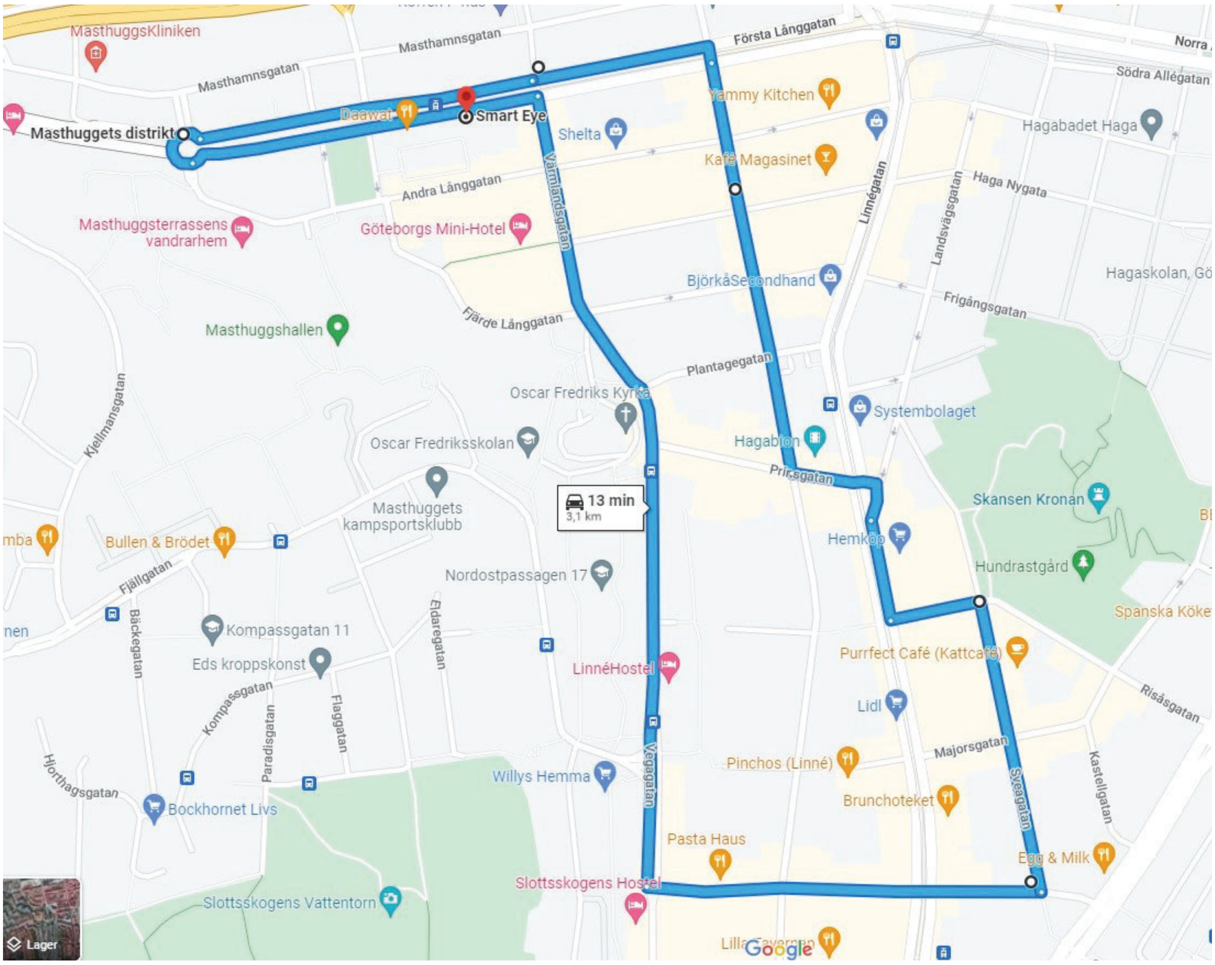


Figure 8. An outline of the city loop driven in the field study. Google Maps. Retrieved 20230324, from https://www.google.com/maps/dir/Egg+%26+Milk,+%C3%96vre+Husargatan+23,+413+19+G%C3%B6teborg/57.6952141,11.953362/57.6992137,11.9493679/57.6926425,11.9499768/Gyllene+Prag/@57.6962894,11.9435212,16z/data=!4m29!4m28!1m10!1m1!1s0x464ff31707240617:0x35e17aa8c9fcbe7d!2m2!1d11.9555499!2d57.6927873!3m4!1m2!1d11.9544095!2d57.6928689!3s0x464ff36ad191d829:0x44b5be7c10672bfc!1m1!4e1!1m6!3m4!1m2!1d11.9451956!2d57.6996299!3s0x464ff343fdd26021:0xd0d7f53c9d9f583!4e1!1m0!1m5!1m1!1s0x464ff315291ea38b:0xd780cfb5dbedb742!2m2!1d11.9545055!2d57.6924167!3e0.

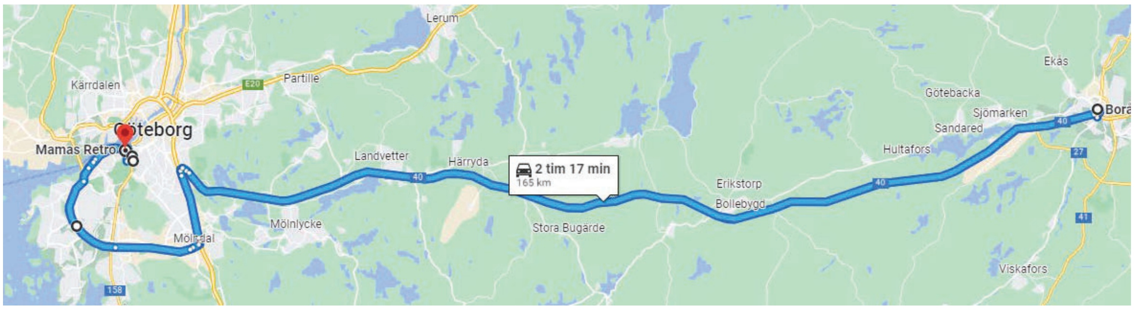


Figure 9. Motorway stretch A driven in the field study. Google Maps. Retrieved 20230323, from https://www.google.com/maps/dir/57.6996068,11.9450268/57.7172836,12.9322153/@57.738917,12.3122224,11.14z/data=!4m9!4m8!1m5!3m4!1m2!1d11.8942312!2d57.6731612!3s0x464f8d29044c3c67:0x7f36f5355536de3b!1m0!3e0.

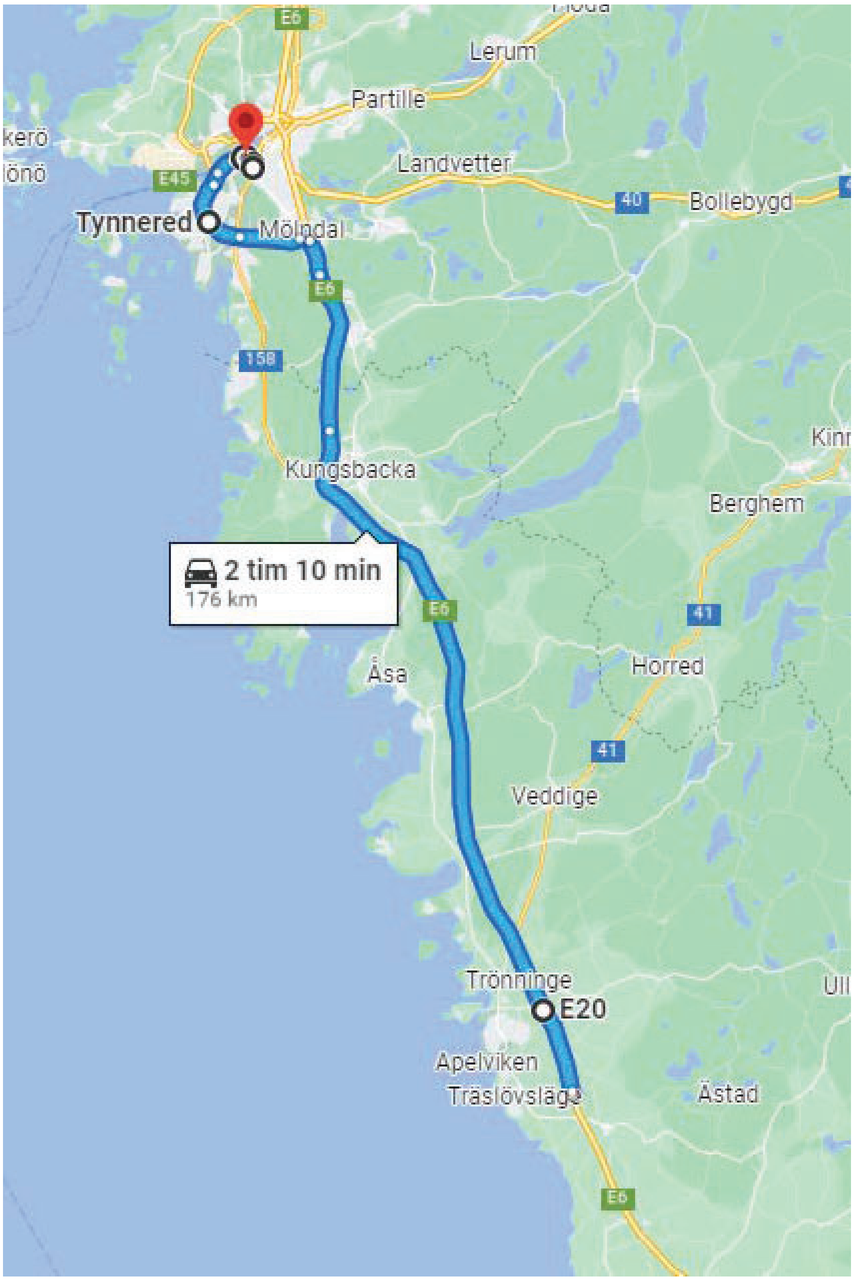


Figure 10. Motorway stretch B driven in the field study. Google Maps. Retrieved 20230323, from https://www.google.com/maps/dir/57.6996068,11.9450268/57.1283082,12.3126896/@57.3984335,11.858053

7,10.4z/data=!4m9!4m8!1m5!3m4!1m2!1d11.9219825!2d57.6467593!3s0x464ff2bed5182f55:0x962c13b04a96a9af!1m0!3e0.

Recruitment and Inclusion criteria
For the recruitment of the participants the Smart Eye recruitment process was used. The study was advertised in different media and those interested in participating were referred to the link with the recruitment questionnaire. Once they answered the questions, their answers were evaluated and if they matched the criteria, they received an email for the interview call. During the course of that call, they received some follow up questions and were booked for the study.

For the participant selection several criteria were used. The age range was planned to be within 24-70 years. The lower limit was to ensure enough driving experience. The upper limit was to ensure that age-dependent variation was limited. The goal was to balance gender. To understand instructions, questions, consent forms, etc. test participant should be able to communicate in either English or Swedish. Participants had to be healthy enough to participate in the study. They had to have a valid driving license as the study was conducted on real roads in Sweden, and they had to comply with the traffic regulation. As the car had automatic transmission, it was important that participants were comfortable driving with that type of transmission, so that their driving behavior was natural. People who had driven less than 2500 km in total in the last twelve months were excluded because they did not have enough driving experience to participate in the trial.

Procedure
Upon arrival at the test site (Smart Eye headquarters) the participant received an oral recapitulation of the procedures (including the driving route) and had the possibility to ask questions about the study. The participant was then asked to sign the informed consent form and the form for monetary reimbursement, as well as the background questionnaire. Once this was completed, the participant was offered a selection of snacks and drinks to eat/drink if they wish to do so anytime during the study. After that the measuring equipment was turned on and calibrated for the driving session. All these preparations were planned to take about 30 min.

After these preparations the driving session began. During the driving session participants were allowed to use cruise control. A test leader (TL) was sitting in the backseat during the whole time observing the participant, as well as monitoring measuring equipment. If the driver for any reason had to deviate from the pre-defined route, the test leader made a note of it together with the reason why and guided the participant back to the route, either to the same point the deviation occurred or to the closest possible point back on the pre-defined route, depending on the situation and available time. Both the participant and the test leader had the possibility to stop the driving session at any time if needed, for example, if the participant was feeling unwell for any reason or too tired to drive, or if the recording equipment malfunctioned. If the situation could be mitigated after a short pause, the study would be resumed, if not, the study would be terminated. The test leader was able to take over driving of the car if needed . The finishing point of the driving session was the same as the starting point.

Collected data
The vehicle used in this study was the same as the one used for the intoxication study at the test track. During the driving session each participant was video recorded for further processing and algorithm development. Participants were recorded with two kinds of systems, one that captured head and eyes up close and their movements and another that captured the inside of the cabin including the full upper body of the test participant. Heart activity was measured and recorded. Participants' driving behavior was registered through the systems available in the car. In addition to that, the test leader made notes during each driving session. They included but were not limited to driver's sleepiness level according to the Karolinska Sleepiness Scale (KSS) every five minutes of the driving session, the driver's secondary actions not related to driving (for example, drinking and eating), presence of any unexpected events that required the driver's

attention or deviation from the expected driving (like an encounter of a responding emergency vehicle or a traffic jam, etc.). Test leader made also notes on the weather that could influence driving behavior.

Thirty-five participants (15 females and 20 males) completed this study. All but one completed the full planned session. One session was terminated due to the recording equipment malfunction. Average ages of the participants were for females 42.5 (24-69) years and for males 36.9 (22-70) years. The average driving experience was 18 (1-51) years. The total recorded driving time was 92.3 hours. The average driving time per participant was 2.64 hours. The recorded KSS range was 3-8, with the majority being 4-6.

5 Goals

The implementation of a real-time fitness to drive assessment would be a next step in road safety in an ever more automated world. The long-term goal is to interlink advanced contact-free intoxication assessment with the AttenD-algorithm and the MiRA theory (Kircher & Ahlstrom, 2013, 2017). The idea was to merge cutting-edge technology with innovative thinking to advance road safety.

By combining independent research with strong industry, as was the case with Smart Eye AB as the SME technological partner and VTI as independent research institute, it is guaranteed that the theoretical knowledge will not be locked to a single car manufacturer only, but that a much higher penetration can be reached.

The concrete goals of the project are listed below.

Goal 1: Collect data with intoxicated drivers driving and data with sober drivers driving under different levels of automation.

Goal 2: Investigate whether intoxication can be detected unobtrusively in the car/simulator.

Goal 3: Investigate relation between attention and intoxication.

Goal 4: Investigate relation between drowsiness and intoxication.

Goal 5: Improve drowsiness algorithm making it more robust and stable.

Goal 6: Create fitness to drive model based on combination of signals.

Goal 7: Disseminate knowledge gained in this project and initiate more discussions and more cooperations on this topic.

Goal 8: Implement into the Smart Eye products and make a difference on the global automotive market. Contribute to strengthening Swedish competitiveness within automotive industry.

6 Results, discussion and achievement of goals

6.1 Alcohol intoxication detection

For robust remote intoxication detection, first robust measures are needed. In this study we aimed to evaluate how, compared to sober driving, various behavioral and psychophysiological measures available from a conventional driver monitoring system are affected by the level of intoxication. In addition, we aimed at evaluating if effects of intoxication can be still robustly detected using a single camera DMS, mounted on the steering column.

Video recordings of the driver were processed by the Smart Eye Pro v10.1.3 software resulting in various head and eye tracking features. To assess how drivers' gaze behavior changes when they are intoxicated, we first performed a glance analysis. Glances (events that start with the onset of the first fixation on the area-of-interest (AOI) and end with the offset of the last fixation on that same AOI) provide indication of where, how and for how long participants look and therefore are often used as a substitute for measuring attention. We found that in manual drives glance rate decreased, while glance duration increased with increasing intoxication level. This effect could be robustly measured using both the multi-camera system and the single-camera system and did not differ between the two. In the simulated automated driving mode, however, these glance metrics did not change with intoxication level, meaning that they cannot be used when developing algorithms that work independent of driving mode.

Attention proportion analysis showed that participants tended to increase their attention proportion to the road when intoxicated at the expense of reduced attention to the instrument cluster and environment around them. We also found indications that drivers become more easily distracted from driving task – they tended to engage more in conversations with the test leader, especially in automatic driving mode, while they significantly less frequently glanced to areas relevant for the driving task – the instrument cluster and surrounding environment. Attention proportion measures appeared to be very sensitive to data loss – something that happens if using a DMS camera position behind the steering wheel; this indicates that attention proportion measures are less suitable candidates to be used in an intoxication detection algorithm.

Psychophysiological measures – fixation duration and rate, and saccade amplitudes were also affected by intoxication level – drivers made fewer but longer fixations and smaller saccades. Moreover, these measures did not differ significantly between the manual and automatic driving modes, making them good candidates for universal intoxication detection. However, they were significantly affected by the noise in the eye tracking data (i.e. precision), which signals that future algorithms need to take data precision into account.

Not surprisingly, blink dynamics also showed a clear effect of intoxication – blinks became longer, with slower closing and opening speeds. While we observed some differences between driving modes and camera systems, we believe these can be attributed to camera placement, warranting future algorithm to account for that also (or improve blink estimation of blink dynamics signals).

6.2 Effects on attention from alcohol intoxication

The data collected from simulator driving were the main source for assessing the effect of alcohol intoxication on attention, as this setting allowed the presence of other road users and more complex environments than the test track. Video recordings of the driver were processed by the Smart Eye Embedded Tracking SDK v12.0 software resulting in various head and eye tracking features.

We grouped the measured variables into mainly pertaining to attention, to NDRT engagement, and to driving quality. Most of the variables were not highly correlated, except a few. Examples are that the AttenD2.0-algorithm (Ahlström, Georgoulas, & Kircher, 2021) indicated decreased attention with increased NDRT engagement, that more speeding was associated with a higher likelihood of small headways (< 1.5 s), and that the number of NDRTs executed was higher when the mean glance duration to NDRTs was higher. None of these correlations changed much with increasing BrAC levels. This means that the relationship between different variables was not influenced by alcohol impairment.

All three variable groups were negatively affected after alcohol consumption. An overall pattern was that performance decreased already at 0.2 ‰ with a continuing decrease to 0.8 ‰, where it tended to level out. Another general pattern was that the variance between participants increased for increasing intoxication levels.

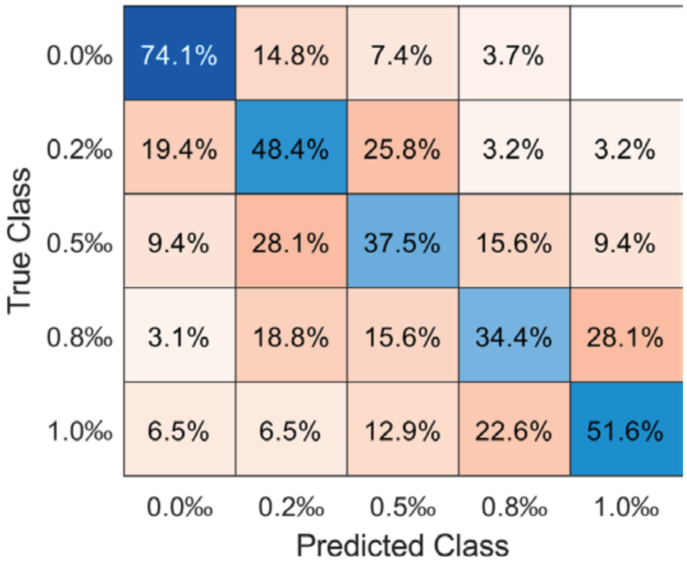
Related to attention, participants glanced away from the forward roadway for longer. The highest 95th percentile value (excluding glances to the NDRT) measured for any participant was 1.2 seconds in the sober condition. This was exceeded by half of the participants in the 1.0 ‰ condition. Glances to the mirrors decreased instead. The AttenD2.0-buffer for glances to the forward roadway decreased, with a third of the participants reaching levels below the lowest level measured for sober when having a BrAC of 0.8 ‰ or 1.0 ‰. The algorithm would have issued significantly more warnings for attention deficits when BrAC levels were higher.

NDRT-engagement became more frequent and more intensive in the sense that more tasks were performed and the number and mean duration of glances to the NDRT screen increased with higher BrAC levels. At 1.0 % the mean glance duration to the NDRT was around 1.5 s, which is almost twice as long as in the sober condition. At 0.8 ‰ and above, around 15 % of the participants glanced at the NDRT screen for more than a third of the time.

At the same time, the quality of driving was compromised. Higher BrAC-levels led to the participants' driving faster with smaller margins and more weaving. While the self-assessed driving quality decreased as well, still about half of the participants estimated their driving to be on the higher half of the scale (down from 82 % when sober).

Thus overall, the participants reduced their safety margins towards others while increasing their engagement in their own tasks (in this case the NDRT). This, in combination with the decreased level of attention leads to a "dangerous cocktail" of ingredients which all on their own are detrimental to safe performance. The combination that we find here shows that the otherwise often found compensation strategies are not employed. Typically, drivers can increase their safety margins when choosing to engage in NDRTs (Oviedo-Trespalacios, Haque, King, & Washington, 2017; Saifuzzaman, Haque, Zheng, & Washington, 2015), while here, the opposite was the case. Our results also indicate that drivers' capacity to integrate the NDRT in their driving seems to degrade with higher BrAC levels.

To assess how indicative the combined variables are for the BrAC classification, we conducted a discriminant analysis (Figure 6), as some of the variables have potential to be used in classification algorithms. It turned out that most misclassifications occurred between nearest neighbours. While no sober person was predicted to lie at level 1.0 ‰, one in ten was classified as at 0.5 ‰ or above when sober, and 13 % of the cases at 1.0 ‰ were classified as 0.2 ‰ and sober. Some of the data are probably not readily available to a driver monitoring system.



True Class \ Predicted Class	0.0‰	0.2‰	0.5‰	0.8‰	1.0‰
0.0‰	74.1%	14.8%	7.4%	3.7%	
0.2‰	19.4%	48.4%	25.8%	3.2%	3.2%
0.5‰	9.4%	28.1%	37.5%	15.6%	9.4%
0.8‰	3.1%	18.8%	15.6%	34.4%	28.1%
1.0‰	6.5%	6.5%	12.9%	22.6%	51.6%

Figure 11. The results of the discriminant analysis. Blue fields indicate correctly classified cases. Darker fields indicate a higher frequency of the field.

6.3 Drowsiness

During the course of this project, new drowsiness features were researched. Some were adapted to real-time and were added to the drowsiness algorithm, making algorithm more accurate and more robust. Others turned out to be too costly for the real-time algorithm and were not added to the drowsiness algorithm at this time, but there is a plan to continue working on them in the future potentially in the follow up project. Data that was used for their development was collected in an external study as in-kind contribution. Updated drowsiness algorithm was added to the Smart Eye product family and already being used for personal vehicles and trucks, performing equally well for both types of these vehicles. In the nearest future it is planned to supply even other types of vehicles as well.

When it comes to drowsiness under alcohol intoxication, the results in our study show that self-assessed drowsiness using KSS increased by approximately one KSS level on average (see Table 1). This may be attributed to a confusion in between drowsiness and intoxication that need to be further studied.

6.4 Fitness to drive

Within the project we developed a theoretical model that could be used to assess drivers' fitness to drive. As input, it uses different indicators such as drowsiness level, microsleep, intoxication level, repeated short distraction from the road, long distraction from the road, eating, drinking, using the phone, and more. As output, it gives a fitness to drive score between 0 and 1. As our experiments on the test track, simulator and real road covered only some of the model's cases, more data are needed before we can fully test this model. Data collected in this project did help us evaluate some of the theorised weights of different input indicators, but not all.

6.5 Impact on FFI programme

An overarching project goal was the contribution to strengthening Swedish competitiveness within automotive industry and improving the world's leading Driver Monitoring System software, selected by 19 OEMs for 217 car models. Smart Eye's Driver Monitoring System software has been installed in more than 1,000,000 cars on roads globally, such that improvements to the system reach far and can have a substantial impact. Equipping more vehicles on the road with these safety systems than any other vendor, Smart Eye has established itself as a definitive market leader[1].

The cooperation between research and industry worked very well in the project. We successfully designed and executed two data collections which needed government permissions, test leaders, equipment, test participants. We disseminated and promoted project and project results among research community and industry.

Increased knowledge about driver state and how various detrimental aspects are interrelated are important for well-functioning driver monitoring systems, which can uphold and improve road safety especially in an increasingly automated traffic system. Continuous monitoring and early detection are crucial under these circumstances. (Area A)

An improved interaction with modern technology and low false alarm rates has potential to lead to higher acceptance rates amongst customers. While this still needs to be investigated further (see also Section 6.6), detailed knowledge of how intoxication affects attention can improve today's algorithms. Additional data analyses could help reach that goal. (Area D)

The driver monitoring system is developed by an independent first-tier supplier, such that the technology is available to a wide range of manufacturers. The option to integrate the system with sensors on the vehicle improves performance, and a feature of the used attention monitoring algorithm consists of a possibility to refine its output by taking situational factors into account. (Area F)

6.6 Deviations from plan

In the planning phase of the project, it turned out that Swedish law prohibits driving under the influence of alcohol not only on public roads, but anywhere, regardless of whether it is done on private property or a fenced-in test track. This had not been considered during the application phase. It entailed that the project had to apply for a government waiver, exempting us from the law for the specific purpose of running the study. The process included a detailed documentation of the planned procedure, a description of the safety precautions and preparations for dealing with potentially occurring incidents. The government then awaited responses and comments from other authorities ("remisssvar"), which also meant that we had several meetings with representatives of these authorities, who inquired about details in the planned procedure. In all, the process of obtaining the waiver took more than half a year and an amount of financial resources that we had not budgeted for.

The Covid pandemic prevented conduction of the test track study directly after having obtained the waiver, such that the whole data collection was delayed by one year. This also meant that personnel that had already been prepared and trained for the data collection procedure had to be replaced and trained again. Luckily, the situation allowed us to conduct the study before new restrictions were in place, and the additional time for preparation and testing was probably beneficial for the successful conduction of the study with minimal loss of data.

Due to the contingencies above, we could not conduct the planned in-depth analysis of how alcohol intoxication may affect certain aspects of information sampling and attention more than other aspects. We assume that not all processes are affected similarly, and the data from the simulator study have the potential to shed light on this issue. A follow-up study looking into this aspect is recommended, as it would deepen our understanding of which processes relevant for driving are affected most in drunk driving.

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[1] *https://smarteye.se/news/smart-eye-announces-its-automotive-driver-monitoring-technology-has-been-installed-in-more-than-1000000-cars-on-roads-globally/)*

Not strictly a deviation, but rather to state a positive experience – we had expected that more participants would have to quit prematurely, and that targeting the goal BrAC values would be more complicated than it proved to be eventually. Thus, in spite of the tight schedule we achieved and went beyond the targeted number of participants with only a small amount of data loss.

The field data collection was done later in the project than planned due to the COVID pandemic. Project partners managed to acquire and use other data for the planned purposes saving data analysis and algorithm development. However, it was not enough time to look at heart and breathing related data. That research is still considered valuable and in high demand both for algorithms and automotive industry, so there is a plan to work on this in the future, perhaps in a follow-up study.

7 Dissemination and publication

Dissemination was done in the scientific field, to interested stakeholders and to the general public via regular publications, seminars and a youtube-clip.

7.1 Dissemination of knowledge and results

Hur har/planeras projektresultatet att användas och spridas?	Mark with X	Notes
Öka kunskapen inom området		
Increased knowledge in the research area	X	Advancements in the effects of alcohol on the interaction of attention, driving quality and NDRT engagement.
Föras vidare till andra avancerade tekniska utvecklingsprojekt		
Transfer to other advanced, technical development projects	X	Future Intoxication detection projects.
Föras vidare till produktutvecklingsprojekt		
Transfer to product development projects	X	Smart Eye transferred part of the project results to product development. However, the intoxication requires more research with a plan for product integration 2026+.
Introduceras på marknaden		
Introduction to the market	X	Smart Eye updated products on the market including some of the project results.
Användas i utredningar/regelverk/ tillståndsärenden/ politiska beslut		
For use in assessments/regulations/ certifications/political decisions	X	Part of the results are communicated to EuroNCAP and will be disseminated to EUCOM.

7.2 Dissemination and publications

More information about the background and the project can be found here: https://smarteye.se/blog/fit-to-drive-5-key-insights-into-the-state-of-intoxicated-driving-research/https://smarteye.se/blog/fit-to-drive-5-key-insights-into-the-state-of-intoxicated-driving-research/

To spread awareness about Fit2Drive research in intoxicated driving, a video that documents the data collection in the simulator and on the test track was created and distributed through

Smart Eye's social media channels and website. This video demonstrates the importance of collecting intoxicated driver data, the challenges in collecting it and more. That video can be found here:
https://www.youtube.com/watch?v=RF5mYGfazh0

Two scientific articles are accepted and published:
Ahlström, C., Kircher, K., Nyström, M., & Wolfe, B. (2021). Eye Tracking in Driver Attention Research—How Gaze Data Interpretations Influence What We Learn [Perspective]. *Frontiers in Neuroergonomics*, *2*(34). https://doi.org/10.3389/fnrgo.2021.778043

Ahlström, C., Zemblys, R., Finér, S., & Kircher, K. (2023). Alcohol impairs driver attention and prevents compensatory strategies. Accident Analysis & Prevention, 184, 107010. https://doi.org/10.1016/j.aap.2023.107010

A third scientific article is under preparation (the preliminary title is "Predictors for intoxication in manual and automated driving") and will be submitted in May 2023.

The project was associated with SAFER and Road User Behavior group at SAFER. It was presented at the SAFER lunch seminar on 2022-10-27. (https://www.saferresearch.com/events/safer-thursday-lunch-seminar-hosted-anna-sjors-dahlman-alcohol-driving)

In addition to that project and some of the results were presented at the conference InCabin Phoenix 2023 in USA on 2023-03-17. (https://auto-sens.com/incabin/phoenix/agenda/jsf/jet-engine/meta/session-start-date:Friday%2017th%20March/)

Project was also promoted at the CES2023 (Consumer Technology Association) annual conference in Las Vegas, NV, USA, 5-8 January 2023 (https://smarteye.se/ces-2023-vip/). CES is one of the most influential tech event in the world — the proving ground for breakthrough technologies and global innovators (https://www.ces.tech/). This year CES was attended by 118 000 people, representing 151 countries and regions. Around 4815 media representatives attended this event (https://www.ces.tech/about-ces/global-impact-of-ces-2023.aspx).

Smart Eye products (that included updated software from the project) were demonstrated at the The 8th International Conference on Driver Distraction and Inattention (DDI2022) in Gothenburg, Sweden 19-20 October 2022 (https://ddi2022.org/) (https://www.youtube.com/watch?v=WBmLk5lYmyk). In addition to that, project and research results were promoted and discussed at the networking dinner before the conference 18 October 2022 organised by Smart Eye AB (https://www.saferresearch.com/events/study-tour-and-networking-dinner-smart-eye).

This webpage also includes a link to a webinar where driving under the influence of alcohol was discussed by experts from the industry and research:
https://smarteye.se/webinars/advancing-road-safety-the-state-of-alcohol-intoxication-research/

8 Conclusions and future research

Adding to existing knowledge, we found that alcohol affects attention in driving in combination with a lowering of safety margins and a less restrictive engagement in additional tasks. While drivers in a sober state typically compensate for their engagement in other tasks than driving, this mechanism does not seem to function when drunk. The combination of less margin for error in driving, a compromised attentional capacity and a greater willingness to conduct other activities, also at inopportune moments, is a recipe for disaster.

Having DMS system in the car, even if not detecting intoxication directly, could detect reduced attention to the road and/or involvement in NDRT and either warn driver or increase sensitivity of ADAS systems. We have also found number of indicators that could be used to directly estimate alcohol intoxication.

Still, several aspects of the topic require additional research. We propose both a further analysis of the already collected data, but also an expansion of the data set to include a sober control group, but also to increase the number of data sets for increased statistical power and to include a wider range of physiognomic features, which is important for automated driver state detection.

Existing data could be used to dive further into the attentional mechanisms relevant for driving that are affected by alcohol consumption. A more fine-grained analysis would enable an assessment of whether certain attentional requirements are more prone to be neglected than others, which is important knowledge to improve the detection of intoxication.

Additional data from a sober control group can help in de-confounding intoxication and learning/habituation, as participants get to know the situation over time.

In the course of the project, we found systematic changes based on intoxication level, such that an offline classification is possible to some extent. The increasing variance between people with increasing intoxication levels complicates the picture, though. Also, the question remains whether it is possible to distinguish between different driver states in real time, using the same features measured here.

9 Participating parts and contact persons

This project was a collaboration of VTI and Smart Eye AB.

vti

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smart eye

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