Evaluation of a fragrance system to counter sleepiness at the wheel

Publik rapport

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Innehållsförteckning

1 Summary

Driver fatigue is a major cause of car accidents, and the prevention of fatigue is a major goal in the automotive industry. To reach the goal of zero traffic-accident fatalities, developing innovative solutions to prevent fatigue is a key objective. Solutions for fatigue countermeasures during driving have not yet reached a satisfactory level for effectiveness and safety. The most effective ones, such as taking a break and napping, are highly intrusive in the sense that they require you to stop the vehicle or shift drivers. In the current study, the possibility of using odors to counter driver fatigue has been explored.

In this proof-of-concept study, the aim was to investigate if a fragrance system incorporating trigeminal components can have an alerting effect on sleepy drivers. The goal of the project was to provide enough evidence to determine whether the alerting fragrance is effective enough to justify further development and integration of the product into vehicles. The fragrance was tested on 21 healthy but sleep-deprived individuals while they performed a driving task in a simulator. We investigated whether the fragrance system had a measurable effect on subjective sleepiness, objective signs of fatigue and driving performance and attention.

Each participant performed a monotonous driving task twice. An alerting fragrance or an inactive substance was administered during these driving tasks using a cross-over single-blind design. Hence, each participant performed one drive with active fragrance and the other with an inactive treatment. The order of active/inactive fragrance was randomized between participants, and the participants were not informed about the type of fragrance they received. Self-reported sleepiness was assessed using the Karolinska Sleepiness Scale (KSS) every 5 min during the driving task. Speed variability, lateral position variability and line crossing frequency (the vehicle crossing the lane demarcation line) were logged for each drive to measure driving performance. For the analyses, data were aggregated in one-minute segments around the point in time when the fragrance was administrated (five segments before and ten after). Physiological assessments; heart rate measurements (ECG), eye blinks (EOG), and brain activity (EEG) were performed during each drive to investigate potential arousing effects of the fragrance and to track objective signs of sleepiness. A Psychomotor Vigilance Test (PVT) was used to capture attention and cognitive performance before and after the drives.

Subjective sleepiness decreased after fragrance administration, irrespective of whether the fragrance had the active alerting substance or not. However, the effect was no longer significant after controlling for sleepiness at the start of the drive. Mean blink duration, which was used as an objective measure of sleepiness, decreased after fragrance administration, as did the frequency of line crossings. The effect was similar for active and inactive fragrance. In summary, fragrance administration in general had a small but significant effect on some but not all of the included measures typically connected to risk in driver fatigue.

The results for the fragrance administration as such are in line with the effects found for fatigue countermeasures like bright light and caffeine. These types of countermeasures might buy the driver some time, in the sense that driving performance might be restored for a short while. Whether this is sufficient to support driving performance until the driver can make a safe stop or not in real traffic remains a topic for future studies. Based on the results of this study, a more large-scale study using the active fragrance studied here in an operational setting is not justified. It is possible that a different dose or strength of the active fragrance could have given a stronger or longer lasting effect on driver sleepiness and performance. Another avenue for further research is to investigate whether longer duration or repeated administration of fragrance has a stronger effect.

2 Sammanfattning på svenska

Trötthet hos förare är en viktig orsak till bilolyckor, och att förebygga trötthet och att hantera trötthet när den uppstår är ett viktigt mål inom bilindustrin. För att nå nollvisionen om noll dödsfall i trafikolyckor är utveckling av innovativa lösningar för att förebygga trötthet ett centralt mål. De motåtgärder som finns i dagsläget för att minska trötthet hos bilförare är inte tillräckligt effektivitet och säkra. De mest effektiva åtgärderna, som att stanna fordonet och ta en tupplur är mycket opraktiska eftersom de kräver att du avbryter din resa eller byter förare. I det här projektet har möjligheten att använda dofter för att motverka trötthet hos förare undersökts. Tidigare forskning har funnit att specifika doftämnen har uppiggande effekter och vissa substanser kan väcka personer från både lätt och djupare sömn.

I denna studie var syftet att undersöka om ett doftsystem kan ha en uppiggande effekt på sömniga förare. Målet med projektet var att utföra tester i en kontrollerad miljö för att avgöra om den aktiva doften är tillräckligt effektiv för att motivera ytterligare utveckling och integration av produkten i fordon. Doften testades på 21 friska men sömndepriverade individer medan de utförde en köruppgift i en simulator. Vi undersökte om doftsystemet hade en mätbar effekt på subjektiv sömnighet, objektiva tecken på trötthet samt körförmåga och uppmärksamhet.

Varje deltagare utförde en monoton köruppgift två gånger. Doft som antingen innehöll aktiv substans eller enbart inaktiv substans administrerades under dessa körningar med en cross-over enkelblind design. Varje deltagare genomförde således en körning med aktiv doft och den andra med en inaktiv doft. Ordningen på aktiv/inaktiv doft randomiserades mellan deltagarna och deltagarna informerades inte om vilken doft de fick.

Förarna självrapporterade hur sömniga de var med hjälp av Karolinska Sleepiness Scale (KSS) var 5:e minut under körningen. Variabilitet i hastighet och lateral position samt linjeöverträdelser (när fordonet korsar en körfältsmarkering) loggades för varje körning för att mäta körförmåga. För analyserna aggregerades data i en minut långa segment runt den tidpunkt då doften administrerades (fem segment före och tio efter). Fysiologiska mätningar av hjärtfrekvens (EKG), blinkningar (EOG) och hjärnaktivitet (EEG) genomfördes under varje körning för att undersöka fysiologiska effekter av doften och för att mäta objektiva tecken på sömnighet. För att mäta förarnas uppmärksamhet och kognitiv prestationsförmåga användes Psychomotor Vigilance Test (PVT) före och efter körningarna.

Subjektiv sömnighet minskade efter doftadministrering, oavsett om doften hade den aktiva substansen eller inte. Effekten var dock inte längre signifikant efter att man tagit hänsyn till skillnader i sömnighet i början av körningen. Genomsnittlig blinkduration, som användes som ett objektivt mått på sömnighet, minskade efter att man fått doft, och det gjorde även frekvensen av linjeöverträdelser, men effekten skiljde sig inte åt mellan aktiv och inaktiv doft. Sammanfattningsvis kunde man se en liten men signifikant effekt på några av de faktorer som vanligtvis är kopplade till olycksrisk hos trötta förare men effekten var inte signifikant för alla faktorer som undersöktes.

Resultaten för doftadministrationen som sådan är i linje med de effekter som hittats för andra motåtgärder mot trötthet som exempelvis starkt ljus och koffein. Dessa typer av motåtgärder kan ge föraren lite tid, i den meningen att körförmågan kan återställas för en kort stund. Huruvida detta är tillräckligt för att föraren ska kunna fortsätta köra tills det är möjligt att göra ett säkert stopp eller inte i verklig trafik förblir ett ämne för framtida studier. Baserat på resultaten av denna studie är en mer storskalig studie med den aktiva doften som studeras här i en operativ miljö inte motiverad. Det är möjligt att en annan dos eller styrka av den aktiva doften, längre exponering för doften eller upprepad administrering av doft kunde ha gett en starkare effekt på förarens sömnighet och prestationsförmåga.

Statens väg- och transportforskningsinstitut (VTI) var projektledare för studien och deltagande parter i projektet var Volvo Cars, Moodify, och Karolinska Institutet (KI). Moodify ansvarade för att utveckla doftsystemet som utvärderades i projektet. Doftsystemet har sitt ursprung i forskning utförd på Weizmann Institute of Science i Israel och de medverkade som vetenskapliga rådgivare i projektet.

3 Background

Driver fatigue is one of the major causes of car accidents, and solutions for the prevention of fatigue has been the focus of research in the automotive industry for many years. Most drivers feel sleepy behind the wheel from time to time, but often continue to drive nonetheless (Armstrong, Obst, Banks, & Smith, 2010; Zwahlen, Jackowski, & Pfäffli, 2016). This behaviour can eventually lead to traffic crashes, and may result in severe injuries and fatalities (Connor et al., 2002). It has been estimated that sleepiness at the wheel is associated with a more than a twofold increase in the risk of motor vehicle accidents (Bioulac et al., 2017). Given that 1.35 million people are killed in road crashes every year (World Health Organization, 2018), it is clear that driver fatigue is a serious problem on our roads that needs to be addressed.

Driver fatigue can arise for several reasons. The most obvious one is sleepiness, which is defined as a physiological drive to fall asleep (Dement & Carskadon, 1982). Sleepiness is affected by sleep deprivation, extended duration of wakefulness and time of day. Traffic safety wise, subjective sleepiness ratings are highly linked to the likelihood of lane departures in simulators and to line crossings on real roads (Åkerstedt, Anund, Axelsson, & Kecklund, 2014b). Another possible contributing factor is task related fatigue. Fatigue is different from sleepiness in the sense that it is defined as a suboptimal psychophysiological condition caused by exertion (Phillips, 2015). Certain characteristics of driving, like task demand and driving environment, can produce task related fatigue in the absence of any sleep-related cause. Task-related fatigue can come from either overload or underload (May & Baldwin, 2009; Phillips, 2015). Overt signs of different types of fatigue may overlap, but the countermeasures are different (May & Baldwin, 2009). If the driver is fatigued due to overload, an appropriate countermeasure would be to stop driving and thus temporarily shut off demands of sustained attention. If fatigue is due to underload, then activation helps more than rest (Gershon, Ronen, Oron-Gilad, & Shinar, 2009; Oron-Gilad, Ronen, & Shinar, 2008; Rayes, Short, Meyer, & Llaneras, 2019).
Solutions for fatigue countermeasures during driving have not yet reached a satisfactory level for effectiveness and safety. The most effective ones, such as taking a break and napping, are highly intrusive in the sense that they require you to stop the vehicle or shift drivers. Other, less intrusive, measures like bright light, blue light and caffeine/energy can be helpful to some extent but do not provide a solution (Bjorvatn et al., 2007; Horne & Reyner, 1996; Lowden, Akerstedt, & Wibom, 2004; L. Reyner & Horne, 2002; L. A. Reyner & Horne, 1998; Schwarz et al., 2012; Taillard et al., 2012). Further research into countermeasure alternatives is needed.

In the current study, the possibility of using odors to counter driver fatigue has been explored. So far, only a few studies have investigated the effects of odors on driver fatigue (Hirata, 2001; Okazaki, Haramaki, & Nishino, 2018; Raudenbush, Grayhem, Sears, & Wilson, 2009). There is some evidence that the administration of cinnamon and peppermint scent leads to increased ratings of alertness, decreased temporal demand, and decreased frustration in drivers (Hirata, 2001; Raudenbush et al., 2009). Also, several studies have shown that pulsed delivery of odors (e.g., peppermint) can help enhance operator performance (Ho & Spence, 2005; Mahachandra, Yassierli, & Garnaby, 2015).

Humans rely on their sense of smell to read emotions and communicate socially (Semin & De Groot, 2013). We produce, transmit and receive odor messages. Like other senses (visual, auditory, haptic), smell delivers information that triggers a psychological and physiological effect (Lundström & Olsson, 2010; McClintock, Jacob, Zelano, & Hayreh, 2001; Savic, 2014; Yeshurun & Sobel, 2010). Because of methodological and technological issues, research on the human sense of smell had fallen behind, but in recent years olfactory research in humans has advanced immensely (de Groot, Smeets, Kaldewaij, Duijndam, & Semin, 2012; Endevelt-Shapira et al., 2018; Gelstein et al., 2011; Luebke & Pause, 2015; Lundström, Boyle, Zatorre, & Jones-Gotman, 2007; Olsson et al., 2014; Savic, 2002; Wysocki & Preti, 2004). Fragrances affect humans through at least two separate routes; the olfactory and the trigeminal (Shusterman & Hummel, 2009). The Trigeminal nerve (CN5) controls facial muscles and reacts to specific odors. The effect of trigeminal smells resembles a tingling sensation and sometimes pain (Shusterman & Hummel, 2009). Chemosignal-based olfactory solutions that are non-intrusive have been developed and have shown promising effects on vigilance and alertness in laboratory studies stress (Endevelt-Shapira et al., 2018). The active scents can be subliminal (unconscious) fragrances developed from social chemosignals that act directly on the olfactory system in the brain without the participant awareness (in other words, the fragrances have no perceivable smell). These can be augmented with trigeminal components that

render the stimulus perceptible, and significantly increase its potency. Unlike most olfactory smells, trigeminal smells have a strong effect of waking up (from actual sleep) (Heiser et al., 2015). In a study by Stuck et al. (2007) participants were exposed to both olfactory and trigeminal stimulation of different concentrations during sleep. They found that participants can be woken up from both light sleep and slow wave sleep using trigeminal manipulations (Stuck et al., 2007). Similarly, a strong trigeminal smell has been incorporated into a fire-alarm for the deaf (Goto, Sakai, Mizoguchi, Tajima, & Imai, 2015). There are no known side effects or adverse effects of using these components. The impact of these fragrances on fatigued drivers, however, remains to be investigated.

4 Aim, research questions, and methods

The aim of this study was to investigate if a fragrance system incorporating trigeminal components can have an alerting effect on sleepy drivers. The fragrance was tested on healthy but sleep-deprived individuals while they performed a driving task in a controlled laboratory environment. The possible effects of fragrance exposure on driver sleepiness, performance and attention were evaluated.

Based on previous laboratory findings, it was hypothesized that the alerting fragrance would:

- Decrease subjective driver sleepiness.
- Decrease objective signs of sleepiness (long blink durations).
- Cause physiological arousal that can be measured using physiological monitoring equipment.
- Improve driver vigilance/attention performance as compared to sham treatment.
- Enable the driver to continue driving

A driving simulator experiment was performed to determine the possible efficacy of the alerting fragrance in a driving context. Each participant performed a monotonous driving task twice. An alerting fragrance or an inactive substance was administered during these driving tasks using a cross-over single-blind design (Table 1). Hence, each participant performed one drive with an alerting fragrance and the other with an inactive treatment. The order of active/inactive fragrance was randomized between participants, and the participants were not informed on condition identity.

4.1 Participants

Twenty-one shift workers were recruited by advertisements on Facebook and at workplaces, 12 male and 9 female. They were 30-60 years old (mean 45, SD 10). A self-report screening procedure ensured that they were healthy and had a normal sense of smell. Specific exclusion criteria were BMI <18 or >30, being prone to motion sickness, pregnancy, sleep disorders, diabetes, cardiovascular disease, neurological disease and use of prescription medicine or sleeping aids. All drives were performed in the morning after working a night shift to ensure that participants were sleep deprived. The participants were instructed to abstain from alcohol intake three days before the test and caffeine the night before the test as well as to stay awake the entire night before the test.

The study was conducted in accordance with the declaration of Helsinki and informed consent was obtained by all participants. The study protocol was approved by the Swedish Ethical Review Authority (dnr 2020-04054). The participants received a compensation of 1000 SEK (about 100 EUR). Data collection was performed between 12 April and 14 May 2021 and infection control procedures were applied to minimize the spread of COVID-19.

4.2 Design and Procedures

The participants performed the driving task in a simulator (Figure 1), driving on a monotonous road to manipulate driver fatigue, including both sleepiness due to sleep deprivation and task-related fatigue due to underload. The driving scenario was an 80 km/h rural road that with randomized traffic in the opposite direction but with no traffic in the same direction as the participant was driving.

Figure 1 Simulator.

The fragrance or inactive substance was administered by the test leader when the participant fell asleep, here defined as eye closure for more than 3 seconds. The event of falling asleep was determined by an experimenter observing the participant. If the participant did not fall asleep, the fragrance was administered anyway after approximately 45 minutes of driving. After smelling the active/inactive fragrance, the participants continued driving until they either fell asleep a second time, or for a maximum of an additional 20 minutes. After each drive the participants answered a brief questionnaire and performed a Psychomotor Vigilance Test (PVT). The main objective measure of sleepiness was long blink durations defined as blinks > 0.15 s (Fors et al., 2011). Driving behaviors assessed included speed and lateral position (mean±SD) as well as line crossings and lane departures.

Table 1 Brief overview of the procedures.

Procedure	Time (min)
Welcome + Briefing	10
Physiological monitoring set-up	50
PVT	10
First drive (including set-up and familiarization)	Until falling asleep (maximum 45)
Administration of fragrance (active or inactive)	
Continue driving	Until falling asleep (maximum 20)
PVT	10
Rest	20
Second drive (including set-up)	Until falling asleep (maximum 45)
Administration of the other fragrance (active or inactive)	
Continue driving	Until falling asleep (maximum 20)
PVT	10
Debriefing and removal of electrodes	10
Total	**5 hours**

4.3 Fragrance

The active fragrance had a combination of chemosignals and trigeminal components. Active and inactive fragrance were administered automatically by a nebulizer. The tube from the nebulizer containing the fragrance (active or inactive) was attached to the participants' chest using Velcro straps and the tube opening was directed towards the nose (Figure 2). The experimenter pressed a button at the time of fragrance administration which triggered the nebulizer for the desired duration. The participants were informed that the study included evaluations of different fragrances, but they did not know how many fragrances, at which time point they would be administered, and what the expected effects of the fragrances were.

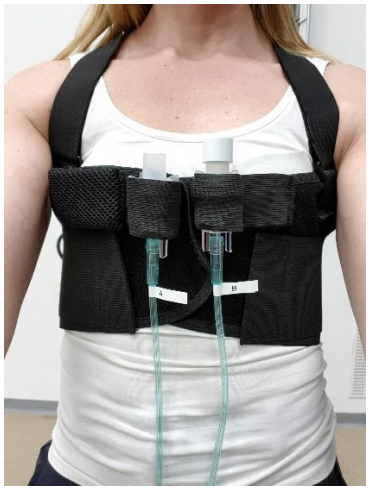

Figure 2 Fragrance tubes.

4.4 Sleepiness

Self-reported sleepiness was assessed using the Karolinska Sleepiness Scale (KSS) every 5 min during the driving task. The KSS is a rating scale ranging from 1 (highly alert) to 9 (having to fight to stay awake) (Åkerstedt & Gillberg, 1990). The reported value is meant to correspond to the average feeling during the last 5 min. In the analyses, the last rating before fragrance administration was compared to the first rating after receiving the fragrance.

4.5 Driving performance

Speed variability, lateral position variability and line crossing frequency (the vehicle crossing the lane demarcation line) were logged for each drive. For the analyses, data were aggregated in one-minute segments around the point in time when the fragrance was administrated (five segments before and ten after). Minute -1 is the minute before fragrance administration and minute +1 is the minute directly after receiving the fragrance. Line crossings and standard deviation (SD) in lateral position were included in the analyses.

4.6 Physiological assessments

Physiological assessments were performed during each drive to investigate potential arousing effects of the fragrance and to track objective signs of sleepiness. The data were aggregated in the same one-minute intervals as described for the driving performance data above.

Electrophysiological data were recorded with eego sports (ANT Neuro, Hengelo, the Netherlands). Electrocardiogram (ECG, lead II), a vertical electrooculogram (EOG), respiration (chest strap) and a 64-channel electroencephalogram (EEG) were recorded. Results from ECG and EOG recordings are presented here. Physiological data were acquired with a sampling rate of 512 Hz but later down-sampled to 256 Hz. The ECG was band-pass filtered between 0.3 and 30 Hz and the EOG was band-pass filtered between 0.3 and 11.5 Hz. All filtering was carried out with zero-phase 5th order Butterworth filters.

Heart beats (R-peaks) were extracted from the ECG using a filterbank approach (Afonso, Tompkins, Nguyen, & Shen, 1999) and an RR time-series was derived as the time difference between heart beats. The corresponding normal to normal (NN) time series was obtained by a recursive procedure where RR intervals were removed if they differed from the mean of the surrounding RR intervals with more than 30 % (Karlsson, Hörnsten, Rydberg, & Wiklund, 2012). Heart rate was here expressed as mean beats per minute (bpm) in each segment and heart rate variability was quantified as the root mean square of successive differences (RMSSD) between normal heartbeats (Shaffer & Ginsberg, 2017).

The blink parameters were extracted from the vertical EOG signal with an automatic blink detection algorithm (Jammes, Sharabty, & Esteve, 2008). Two blink duration-based parameters were calculated; the mean blink duration and the number of eye blinks with a duration longer than 0.150 seconds (Fors et al., 2011).

4.7 Psychomotor vigilance performance

A PC-based PVT was used to capture attention and cognitive performance before and after the drives (Khitrov et al., 2014). The PVT was set up according to Loh, Lamond, Dorrian, Roach, and Dawson (2004), with random stimuli onsets with an inter stimulus interval of 2–10 s and a total test duration of 10 min. The PVT is a widely used test of vigilant attention with high reliability and predictive validity as well as a lack of aptitude and learning effects (Basner & Dinges, 2011). Increased sleepiness levels typically result in longer mean reaction times (RT) and higher percentages of lapses/misses (here defined as RTs >500 ms). Responses with RTs <100 ms were identified as false starts. PVT metrics were aggregated by trial, i.e., a baseline trial and then trials after each drive.

4.8 Statistical analyses

Results are generally presented as means with standard deviations (SD). Subjective sleepiness was analyzed with a repeated measures ANOVA. Timepoint (before and after fragrance) was included as the repeated factor and fragrance (active or inactive) as an independent factor. The first KSS rating of each drive was included as a covariate The possible effects of fragrance administration on physiology and driving performance were analyzed using linear mixed models. Separate regression models were created with each of the outcome measures as the dependent variable. Fragrance (active or inactive) and time (one-minute intervals from -1 min to +5 min) were included as within-subjects variables. Participant was included as a random factor. Note that the factor time was in relation to fragrance administration rather than time driven. If the time effect was significant, pairwise comparisons were made between time = -1 and time = +1 through +5. Bonferroni correction was used to compensate for multiple comparisons in post hoc tests. PVT was analyzed using a repeated measures ANCOVA with fragrance (active vs inactive) as the repeated factor and baseline PVT as a covariate. Questionnaire data was analyzed using chi-square tests and Wilcoxon signed rank test. The significance level was set to 0.05. Statistical analyses were performed in IBM SPSS statistics version 25 (IBM Corp., Armonk, NY, USA).

5 Goal

The goal of the project is to provide enough evidence to determine whether the alerting fragrance is effective enough to justify further development and integration of the product.

The data collected in this project enables an analysis of if and how the alerting fragrance possibly affects sleepiness and performance in a relevant driving context. Subjective sleepiness and performance were compared between driving tests where the active fragrance was used and tests where an inactive fragrance was administered. The key performance indicators of this project were related to sleepiness reduction and sustained driver performance. The primary measurable objective was a significant reduction in the number of long blink durations (>0.15 s) for at least 10 minutes past administration of active fragrance. The secondary measurable objective was to achieve a subjective sleepiness of KSS <6 for at least 10 minutes past administration to enable the driver to continue driving until he/she can find a safe place to pull over and rest. If the alerting fragrance showed satisfactory effect, design guidelines for a prototype for in-vehicle administration of the fragrance would be developed and further projects for larger scale demonstration in relevant and operating environments will be planned.

6 Results and goal completion

The simulator study was successfully completed with 21 sleep deprived participants. In 17 of the 42 drives, the participant fell asleep. Mean driving time until falling asleep was 26 min (SD = ±12). There was no statistically significant difference in the number of participants falling asleep between trials with active vs inactive fragrance. Eleven participants received the active fragrance during the first drive and ten during the second drive.

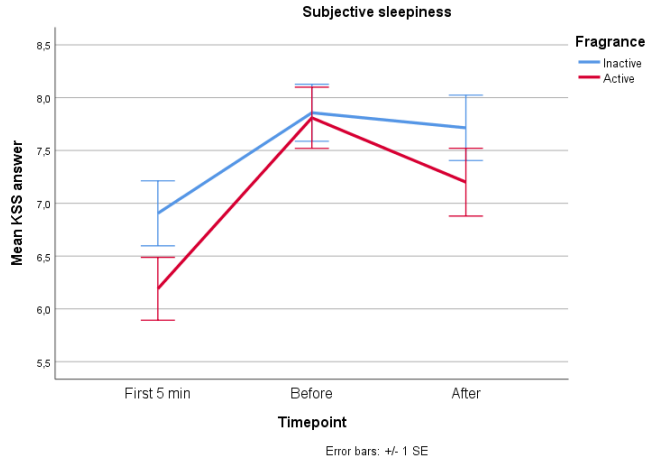

Figure 3 Subjective sleepiness (KSS) before and after fragrance administration.

Mean subjective sleepiness (KSS) was 6.9 (SD = ±1.4) for the first five-minute segment of the drive with active substance and 6.2 (SD = ±1.4) for the first five-minute segment of the drive with inactive substance. This confirms that participants on average experienced signs of sleepiness at the start of the drives (Figure 3).
The mean KSS before fragrance administration was 7.9 (SD = ±1.3) in the drive with inactive substance and 7.7 (SD = ±1.3) in the drive with active substance (Figure 3). The mean KSS after fragrance administration was 7.7 (SD = ±1.4) after inactive and 7.2 (SD = ±1.4) after active fragrance. In the repeated measures ANOVA, the time effect was significant, indicating that KSS decreased after administration of fragrance (F= 8.154, p=0.007). In Figure 3, a tendency towards a larger decrease in subjective sleepiness after administration of the active fragrance can be seen but the effect did not differ significantly between the active and inactive fragrance (F=0.5845, p=0.449) and no significant interaction effect between timepoint and fragrance was found (F= 2.816, p=0.101). Thus, the active fragrance, per se, did not seem to exhibit a statistically significantly different effect on subjective sleepiness compared to the inactive substance. KSS scores were lower at the beginning of the trials with active substance and after controlling for sleepiness at the start of the drive by including the first KSS rating as a covariate, the time effect was no longer significant (F=3.006, p=0.091). The goal of an average KSS < 6 after the intervention was not reached.

Table 2 Results from the linear mixed models analyses of driving performance and physiology.

	Intercept	*p-value*	*Fragrance*	*p-value*	*Time*	*p-value*	*Fragrance*Time*	*p-value*
Line crossings	50.71	0.000	0.03	0.867	5.96	0.000	0.82	0.534
SD lateral position	168.56	0.000	0.45	0.506	1.13	0.349	0.72	0.610
SD speed	58.24	0.000	0.17	0.679	1.23	0.297	1.36	0.243
Blink duration	438.02	0.000	1.48	0.229	3.75	0.003	0.39	0.856
Long blinks	60.08	0.000	0.77	0.386	0.60	0.703	0.75	0.590
Heart rate	1134.75	0.000	0.24	0.630	0.68	0.640	1.42	0.220
RMSSD	1395.20	0.000	0.88	0.353	1.32	0.258	0.29	0.918

Results for the frequency of line crossings follow those for KSS quite closely. There were significantly fewer line crossings in every one-minute segment after fragrance administration (time = +1 to +5) compared to the minute before receiving the fragrance (time = -1) but no main effect of fragrance type or interaction between time and fragrance. There were no significant effects for SD of lateral position or speed (Table 2, Figure 4).

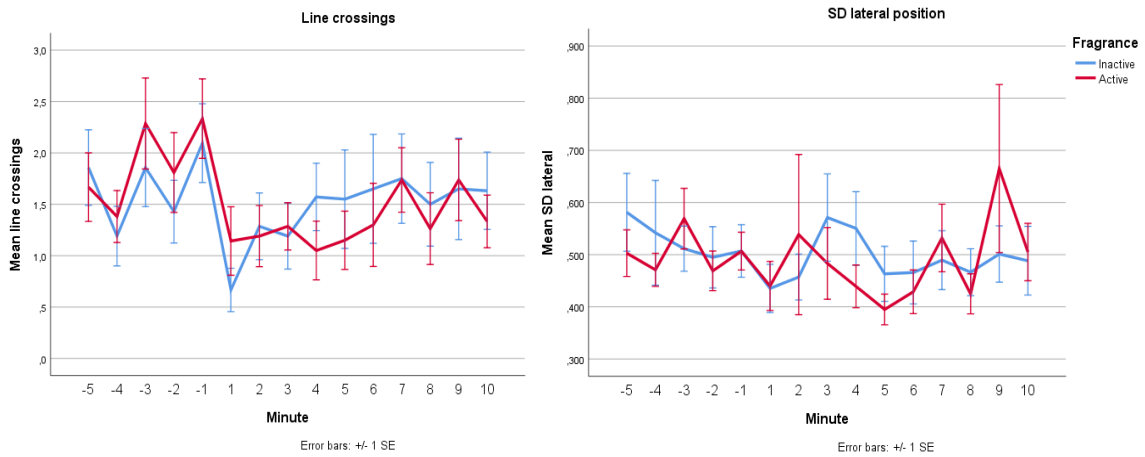

Figure 4 Driving performance measures five minutes before and ten minutes after fragrance administration.

There was no effect of fragrance administration on the number of long blinks (>150 ms) (Table 2, Figure 5). The goal to achieve a reduction in the number of long blink durations after the intervention was thus not reached. Blink durations on the other hand were significantly shorter for the first ($p<0.001$) and second ($p=0.019$) one-minute interval after fragrance administration (Figure 5) but there was no main effect of fragrance nor interaction effect between time and fragrance for the blink related measures. Similar to the results regarding KSS above, Figure 5 shows a trend towards a stronger effect of active substance on blink durations, but the effect did not reach statistical significance.

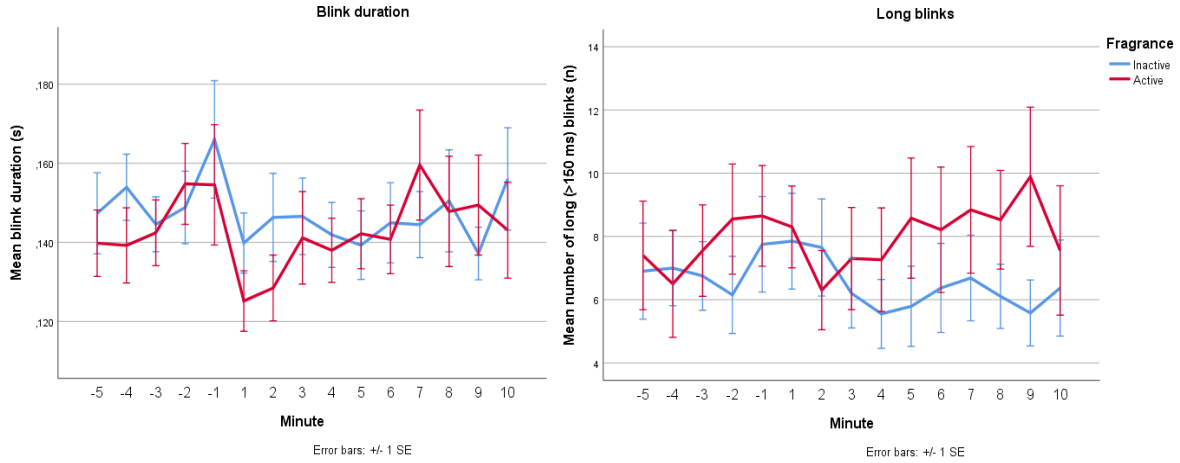

Figure 5 Blink duration and number of long blinks five minutes before and ten minutes after fragrance administration.

Heart rate and heart rate variability (RMSSD) showed no significant time, fragrance, or time*fragrance effects (Table 2, Figure 6).

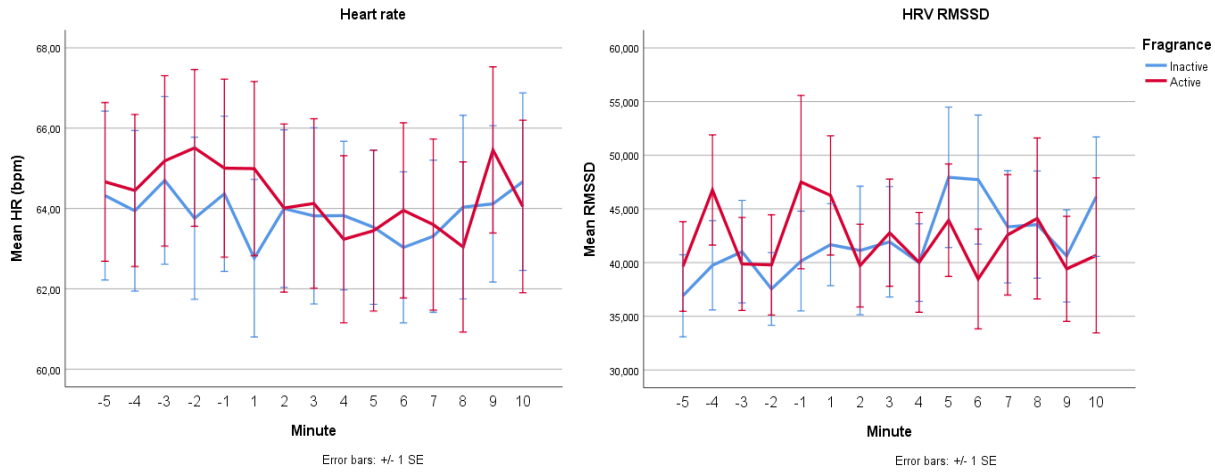

Figure 6 Heart rate and heart rate variability (HRV RMSSD) five minutes before and ten minutes after fragrance administration.

Psychomotor vigilance performance tests after the drives showed a significant effect of fragrance administration on mean RT after controlling for baseline performance (F=14.0, p=0.001). The response times were shorter after the drive with active fragrance (mean RT 349 ms, SD 96) compared with inactive fragrance (mean RT 359 ms, SD 131). This indicated that the participants were slightly more alert after the drive with active substance. The number of lapses was not significantly different between tests.

Figure 7 shows the participants' experience of the fragrances during the drives in terms of how tiring vs alerting and how pleasant vs unpleasant they were. Wilcoxon signed ranks tests showed that the active substance was perceived as significantly more unpleasant (W=119.5, p=0.040) but the difference in perceived alerting effect was not statistically significant (W=111.0, p=0.098).

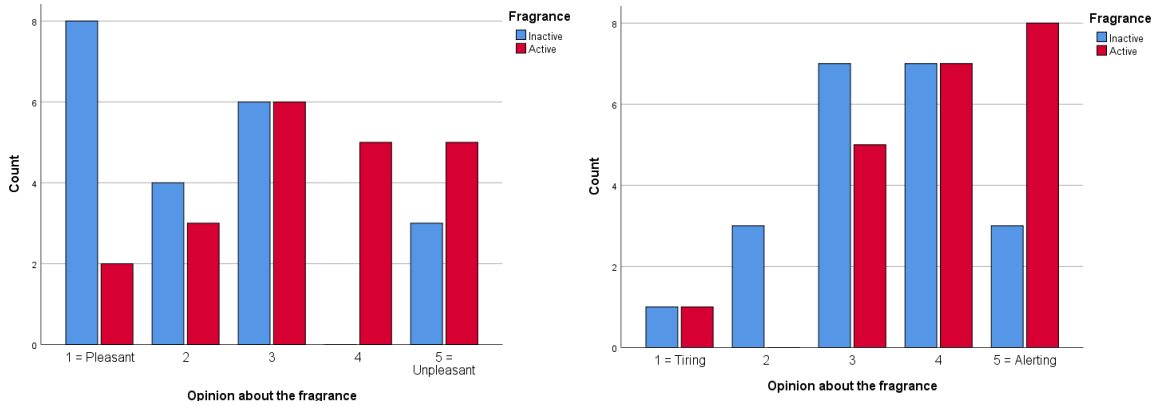

Figure 7 Opinions about the fragrances.

7 Dissemination and publications

7.1 Dissemination of knowledge and results

Project results will be communicated through VTIs regular channels for communication of research results. The project has also been associated to SAFER, the vehicle and traffic safety centre at Chalmers University of Technology. Through this arena, the project has been presented to partners working with similar research and the project results will be communicated to all connected partners.

Utilisation of project results	Mark with X	Comment
Increase knowledge in a specific area	X	The project contributes to the knowledge about countermeasures for driver fatigue and sleepiness.
Be passed on to other advanced technological development projects		
Be passed on to product development projects	X	The results will be used to guide further development of alerting fragrances.
Introduced to the market		
Used in investigations, regulations, permit matters/political decisions		

7.2 Publications

In addition to the current report, a conference paper and a scientific article is in preparation.

8 Conclusions and further research

Subjective sleepiness decreased after fragrance administration, irrespective of whether the fragrance had the active alerting substance or not. However, the change was relatively small and mean KSS ratings remained above 7 in both conditions. For reference, a review of KSS sensitivity as an indicator of insufficient sleep and impaired waking function show that KSS levels above 6 in general are related to increased impaired driving performance and increased number of incidents (Åkerstedt, Anund, Axelsson, & Kecklund, 2014a). Thus, a stronger effect would have been desirable to assure that the fragrance had a positive effect on driver alertness and performance

Mean blink duration, which was used as an objective measure of sleepiness, decreased after fragrance administration, as did the frequency of line crossings. This can be compared with other research that has shown that blink durations >150 ms are associated with an increased risk for line crossings on rural roads (Fors et al., 2011). However, no significant effect could be seen on the number of long blinks (>150 ms) or on physiological arousal measured via heart rate.

In summary, fragrance administration in general had a small but significant effect on some but not all of the included measures typically connected to risk in driver fatigue. Some effects, such as the blink durations, only lasted a couple of minutes. Others, like the reduced frequency of line crossings, lasted for the full five minutes analyzed after fragrance administration. The type of fragrance on the other hand had no significant effects.

The results for the fragrance administration as such are in line with the effects found for fatigue countermeasures like bright light, blue light and caffeine/energy as discussed in the introduction. They are also similar to the effects of hitting a milled rumble strip (Anund, Kecklund, Vadeby, Hjälmdahl, & Åkerstedt, 2008).The effects on sleepiness and performance are measurable, but relatively small. As effects did not differ between the fragrances, it seems like the main influence on driver state in this study came from the “startle” effect achieved by the fragrance administration. Thus, it is clear that if driver fatigue is sleep-related, due to sleep deprivation or driving at night-time,

only sleep will recuperate the driver in the long run (Ruggiero & Redeker, 2014). However, it may be that other types of countermeasures, such as this startle of fragrance or other similar actions, might buy the driver some time, in the sense that driving performance might be restored for a short while. Whether this is sufficient to support driving performance until the driver can make a safe stop or not in real traffic remains a topic for future studies.

Based on the results of this study, a more large-scale study using the active fragrance studied here in an operational setting is not justified. It is possible that a different dose or strength of the active fragrance could have given a stronger or longer lasting effect on driver sleepiness and performance. Another avenue for further research is to investigate whether longer duration or repeated administration of fragrance has a stronger effect.

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