I Smell Trouble: Using Multiple Scents To Convey Driving-Relevant Information

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ABSTRACT

Cars provide drivers with task-related information (e.g. "Fill gas") mainly using visual and auditory stimuli. However, those stimuli may distract or overwhelm the driver, causing unnecessary stress. Here, we propose olfactory stimulation as a novel feedback modality to support the perception of visual notifications, reducing the visual demand of the driver. Based on previous research, we explore the application of the scents of lavender, peppermint, and lemon to convey three driving-relevant messages (i.e. "Slow down", "Short inter-vehicle distance", "Lane departure"). Our paper is the first to demonstrate the application of olfactory conditioning in the context of driving and to explore how multiple olfactory notifications change the driving behaviour. Our findings demonstrate that olfactory notifications are perceived as less distracting, more comfortable, and more helpful than visual notifications. Drivers also make less driving mistakes when exposed to olfactory notifications. We discuss how these findings inform the design of future in-car user interfaces.

CCS CONCEPTS

• **Human-centered computing → Interaction techniques**; *Empirical studies in HCI*;

KEYWORDS

Perception; Olfaction; Smell; Odour Stimulation; Multimodal Interfaces; Notification Systems; In-Car User Interfaces.

ACM Reference Format:
Dmitrijs Dmitrenko, Emanuela Maggioni, Marianna Obrist. 2018. I Smell Trouble: Using Multiple Scents To Convey Driving-Relevant Information. In *2018 International Conference on Multimodal Interaction (ICMI '18), October 16–20, 2018, Boulder, CO, USA.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3242969.3243015

1 INTRODUCTION

Olfactory interaction has gained a new momentum recently [47]: it has been proposed for wearable technologies [1, 15], VR/AR [10, 21, 44, 50], multimedia synchronisation [42, 54], multisensory theatres [20, 24], and art [3, 35, 36, 40], but less so in the context of driving [14]. Scent stimulation could be beneficial to reduce the visual overload of the driver [9]. Furthermore, modern vehicles already have some of the hardware necessary for olfactory stimulation (e.g. air compressor, powerful ventilation system).

The sense of smell is the most complex and challenging human sense [5], but at the same time, it is a very powerful interaction medium [30] enabling humans to extract meaningful information [52]. For example, it has been shown that odours trigger automatic and implicit retrieval of mental representations of information related to the object the scent is coming from [9], and enable automatic access to terms semantically related to odours [25]. Taken together, this research indicates the potential of smell for introducing a new semantic layer into interaction design and the perception of visual information. Here, we investigate to what extent olfactory stimuli can be used for this in the context of driving. To overcome the scent unfamiliarity problem [7, 31, 56], we introduce olfactory conditioning [34] to instruct drivers on the associations between scents and driving-relevant messages.

To guide the investigation of smell for conveying driving-relevant information, we first need to decide what scent-delivery device to use. Based on the specifications of previously designed devices [3, 13, 43, 57] we extracted the following three requirements for the delivery of three different scents in our study: (1) no scent cross-contamination, (2) no lingering, and a (3) delivery distance of ≥50cm (to avoid interference with the steering task). To meet these requirements, we decided to adapt the device of [12].

Secondly, we need to choose the right scents. Previous work has shown the arousing effect of the scents of peppermint and lemon [6, 51] and the calming effect of the scent of lavender [22, 41]. Since events like short inter-vehicle distance and lane departure can be classified as highly alerting [13], we decided to assign them to the scents of peppermint and lemon respectively. The event of speeding is often associated with risky decisions and time pressure [18]. For this reason, we assigned it to the calming scent of lavender.

In summary, this paper demonstrates for the first time (i) the use of olfactory conditioning in the context of driving (to apply the previously established olfactory mapping [13]) and (ii) the exploration of how multiple olfactory notifications influence the driving behaviour. It also discusses the (iii) design opportunities of smell for the in-car interaction.

2 RELATED WORK

The main focus of olfactory research in the automotive context has been on fighting the drowsiness in driving, where the scents of peppermint [17, 48], and lemon [23, 58] were applied. However, as we are in the early stage of olfactory research in HCI, we can learn and draw upon prior work in psychology and neuroscience. The most relevant findings are tackling the activation of the central neural system [4, 32, 55]. We build on this work for the investigation of olfactory interaction in a visually loaded automotive context.

To overcome unfamiliarity with the medium [7, 31, 56] and to let the driver know the meaning of each scent, we propose the use of olfactory conditioning suggested by [34]. We can differentiate

ICMI '18, October 16–20, 2018, Boulder, CO, USA
2018. ACM ISBN 978-1-4503-5692-3/18/10…$15.00
https://doi.org/10.1145/3242969.3243015

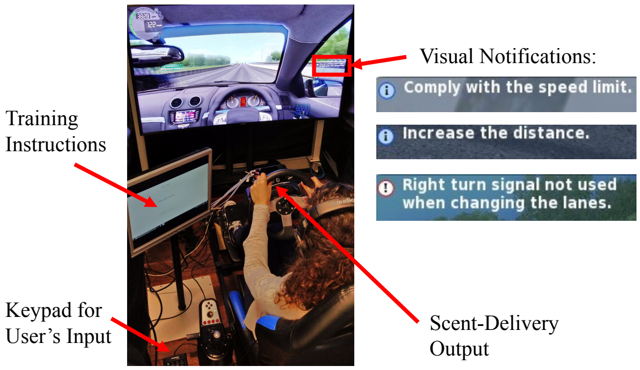

Figure 1: Setup of the driving simulator in the olfactory interaction space with a participant.

between the long- and short-term memory training. Long-term memory training takes 12-18 weeks and requires participants to sniff scents for 5-15s each, two times a day. Examples of such studies can be mainly found in therapeutical contexts [11, 19, 26]. Short-term memory training takes less than 10 minutes. Examples for that have been demonstrated in motion perception [34], chemosensory [53], and verbalisation [29] studies.

To ensure the effectiveness of olfactory conditioning, a success rate needs to be set, which is challenging to define. In long-term olfactory memory studies, there is a well-established training and test procedure [19, 33]. In the research on short-term olfactory memory, different approaches assess participants' performance differently. However, the common success rate is >60% [29].

In olfactory studies, it is crucial to select the right scent-delivery device. Funato et al. [17] has classified such devices as "fixed" and "wearable". Wearable devices are very compact [1, 15], but Funato et al. also points out a very important argument against wearables in the car, namely, their potential to interfere with the driving task (driver's hand movements). For this reason, fixed position devices are more suited for the car-driver interaction. There are several prototypes of this kind (e.g. [2, 46, 57]), but they do not satisfy our three main requirements (no scent cross-contamination, no lingering, ≥50cm delivery distance). For this reason, we decided to adapt the device of Dmitrenko et al. [12].

3 THE STUDY

We ran a within-participants study to explore the effect of three notifications ("Slow down", "Short inter-vehicle distance", and "Lane departure") conveyed either as visual only or combined visual-olfactory stimuli (two conditions). The scents of lavender, peppermint, and lemon were used accordingly. The order of the two conditions was randomised.

3.1 Setup

The experiment was set up in a dedicated olfactory interaction space, built out of materials that do not absorb scents. It also has a powerful air extractor (as per [12]).

Participants were sitting in a driving simulator seat (*FK Automotive*) equipped with the *Logitech G27* steering wheel in front of a curved screen (55", 60Hz refresh rate), on which the first-person view from the driver's position was rendered. We used the *City-CarDriving 1.5* simulator software for this purpose, which was chosen due to its support for left-hand driving and traffic rules. The following text was displayed on the right side of the screen (see Figure 1): "Comply with the speed limit" (if the participant exceeded the speed limit, e.g. 110km/h on motorway), "Increase the distance" (if the inter-vehicle distance was too short, <10m), "Right/Left turn signal not used" (in the case of a lane departure).

The olfactory conditioning and test instructions were presented to the participants on a second screen (17", 60Hz refresh rate) located left of the steering wheel (see Figure 1). Participants gave their responses to the questions using a numeric keypad located under the second screen.

We presented the scents in an automated way, adapting a custom-made and fully controllable scent-delivery device [12]. The device delivered the scented air from a tank of compressed clean air. The clean air was propelled through glass jars containing 6g of 100% pure essential oils (*"miaroma"* essential oils from *Holland & Barrett Int. Ltd.*) of lavender (*Lavandula officinalis*), peppermint (*Mentha arvensis*), and lemon (*Citrus limon*) with an air pressure of 0.5 bar. The scent-delivery output was located behind the steering wheel and pointed towards the participant's face. The distance from the output to the face was 38-68cm (M= 50.67, SD= 7.73), depending on how participants adjusted their seat. We measured this distance using an ultrasonic transceiver located just under the output. The flow of air was controlled using electric valves and an Arduino board connected to a computer [12]. Participants wore headphones, playing the sound of the driving simulator, to cancel any external sounds (noise made by the scent-delivery device was 30dB).

3.2 Procedure

Upon arrival, participants were given an olfactory screening sheet, the information sheet, and a consent form to sign.

3.2.1 Step 1: Olfactory Training and Testing. The experiment started with a single session short-term olfactory memory training procedure (see [53]) followed by a test. We presented all three notifications one-by-one (three times each) in a randomised order (based on the Latin square) for 19s each, where the scent was delivered for the first 5s [12]. For the test, each scent was delivered three times again. After each delivery, participants were asked which notification is the current scent associated with. They responded to these questions using a keypad. If they answered at least six questions out of nine (>60% [29]), they were asked to proceed with the driving task. Otherwise, they were asked to repeat the training. The total of three attempts were given for the participants to score six correct answers. If they failed all three attempts (not occurring in our study), the experiment finished without the driving phase. This step took six minutes without repetitions (in the case of making three or more mistakes).

3.2.2 Step 2: Driving Phase. The driving started on a motorway and participants were instructed to drive in any direction, following the traffic rules. We split the nine minutes long driving phase into three chunks (three minutes each). For the first three minutes, participants were given a chance to familiarise themselves with the driving simulator and no data about their driving behaviour was recorded at this stage.

After the first three minutes, we started recording the occurrences of the "Slow down", "Short inter-vehicle distance", and "Lane departure" notifications, which were displayed as text for three seconds (on the right side of the screen, see Figure 1) each time participants committed the corresponding driving mistake. At the start of the experiment, participants were instructed on where the visual notifications would appear on the driving simulator's screen and for how long (no participants reported having missed the visual notifications). The method of counting the number of mistakes to quantify the driving behaviour has already been successfully employed in the past [16, 27, 28]. For either the second or the third chunk of three minutes (randomised order), visual notifications were also accompanied by the corresponding scent (lavender, peppermint, or lemon). There was a break of 19s used between scent deliveries (as per [12]) to avoid scent habituation. The driving phase finished with a "Please stop driving" message displayed on the second screen.

3.2.3 Step 3: Post-Experiment Questionnaire. When the driving task was finished, participants were asked to complete a self-report questionnaire. It contained questions on how distracting, helpful, and comfortable the visual and olfactory modalities were, as well as how much the participants liked each of the two modalities. The responses were provided on a 7-Point Likert scale (1= "Not at all", 7= "Very much"). The study took 15-20 minutes in total.

4 RESULTS

In this section, we present the results of the olfactory test, the driving behaviour evaluation, and the self-reported perception of the visual and olfactory notifications.

4.1 Participants

A total of 22 participants (22-43 years old), with a mean age of 31.33 years (*SD*= 5.81, 8 females) volunteered for this study. Participants' driving experience varied between 1 and 28 years (*M*= 9.52, *SD*= 7.91). One participant did not complete the study due to motion sickness and was excluded from the data analysis. Participants have reported having no olfactory dysfunctions, adverse reactions to strong smells, respiratory problems, or flu, and not being pregnant. They were recruited on an opportunity-sampling basis. The study was approved by the local university's ethics committee. All participants expressed written consent.

4.2 Olfactory Test

Only one of the 22 participants had to repeat the training procedure to complete the olfactory test with a >60% success rate. All the other participants completed the olfactory test in their first attempt. 76% of participants assigned the scents to the correct messages with no or only one mistake, 10% of the participants made two mistakes, and 14% three.

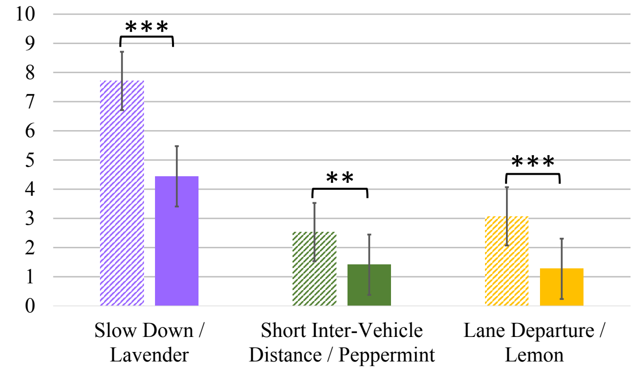

Figure 2: Mean number of mistakes made by participants in the process of driving. Striped bars represent the driving phase in which participants received visual notifications and solid bars - the driving phase with visual-olfactory notifications. Error bars, ± s.e.m., $**p < .01$; $***p < .001$

4.3 Driving Behaviour Data

We performed a dependent t-test for paired samples to analyse the number of driving mistakes when receiving visual and combined visual-olfactory notifications (see Figure 2).

Participants had significantly fewer instances of exceeding the speed limit (*t(20)= 4.552, P<.001*) when receiving visual "Slow down" notifications accompanied by the scent of lavender (*M*= 4.44, *SD*= .39), than in the case of visual-only notifications (*M*= 7.71, *SD*= .83). They also made significantly fewer mistakes of a short inter-vehicle distance (*t(20)= 4.027, P<.01*) when receiving the corresponding visual notifications accompanied by the scent of peppermint (*M*= 1.41, *SD*= .10), than in the case of visual notifications only (*M*= 2.53, *SD*= .26). Finally, the same effect was observed for the "Lane departure" notification, where participants made significantly fewer mistakes (*t(20)= 7.802, P<.001*) when receiving visual notifications combined with the scent of lemon (*M*= 1.27, *SD*= .07), than in the case of visual notifications only (*M*= 3.07, *SD*= .22).

4.4 Self-Report Data

We performed a dependent t-test for paired samples to analyse the perceived levels of distraction, helpfulness, liking, and comfort of the visual and olfactory modalities (see Figure 3).

The olfactory modality (*M*= 2.29, *SD*= 1.45) has been reported significantly less distracting (*t(20)= 5.510, P<.001*) than the visual modality (*M*= 4.57, *SD*= 1.78). Participants also found the olfactory modality (*M*= 5.00, *SD*= 1.14) more helpful (*t(20)= -5.477, P<.001*) in understanding the notifications than the visual (*M*= 3.00, *SD*= 1.87). Moreover, the olfactory modality (*M*= 5.38, *SD*= 2.19) was liked significantly more (*t(20)= -7.345, P<.001*) than the visual modality (*M*= 2.19, *SD*= 1.40). Finally, the olfactory modality (*M*= 5.19, *SD*= 1.25) was perceived significantly more comfortable (*t(20)= -4.298, P<.001*) than the visual (*M*= 3.10, *SD*= 1.64).

5 DISCUSSION

This paper is the first to demonstrate the use of olfactory conditioning to instruct drivers which olfactory notification is assigned

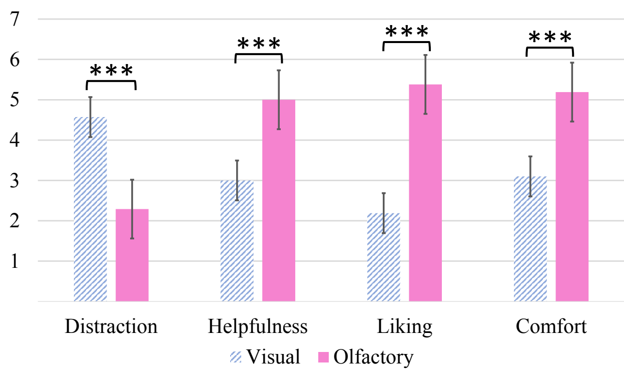

Figure 3: Mean ratings of distraction, helpfulness, liking, and comfort of the visual and olfactory modalities (1= "Not at all", 7= "Very much"). Error bars, ± s.e.m., $***p < .001$

to which driving-relevant message (based on the conditioning procedure of [34]). The results show that all participants were able to correctly assign at least six scents out of nine (in line with prior work achieving >60% success rate [29]).

Moreover, the driving behaviour data shows that participants made significantly less mistakes when receiving visual-olfactory notifications. This is in line with previous findings on the positive effect of ambient scents on performing the driving task (e.g. lemon scent promoted better braking performance in [39]). Such results suggest that scents are a promising notification modality in the car.

Furthermore, in our study, olfactory feedback was perceived less distracting, more helpful, and more comfortable than the visual notifications alone. The olfactory modality was also liked more than the visual. This might be because visual notifications were not salient enough. However, the findings on scents match the current automotive trends regarding the wellbeing in the car (e.g. like in a new Mercedes-Benz[1], Bentley[2], or BMW[3]).

The driving simulator software we have used does not allow customisation of visual notifications. Results might change if different visual stimuli (e.g. icons) and in a different location on the screen are used. However, there is evidence that the olfactory feedback in combination with the visual information can help us become more aware of notifications without the need to shift our attention. Understanding crossmodal integrations can enable better design of in-vehicle notification systems. More studies on multimodal in-car interaction (e.g. like [49]) should be carried out.

Although olfaction is related to many constraints, including interpersonal and cultural differences, health issues (e.g. adverse reactions to certain scents), and ventilation, our findings underline the benefits of the olfactory modality. When the olfactory stimulation is applied, controlling the delivery parameters [12], we can achieve both a better interaction performance and a better user experience. Such a finding is very important for the design of in-car user interfaces.

[1]https://www.mercedes-benz.com/en/mercedes-benz/innovation/a-fragrance-for-the-new-s-class/
[2]https://www.bentleymotors.com/en/world-of-bentley/mulliner/personal-commissioning/personalising-your-bentley.html
[3]http://www.bmwblog.com/2015/07/03/she-created-the-smell-of-the-all-new-bmw-7-series/

6 CONCLUSION AND FUTURE WORK

The findings of our user study suggest that (when scent-delivery parameters are controlled) olfactory notifications can, not only increase our hedonic experience, but also act as a non-distracting, helpful, and comfortable interaction modality. Moreover, olfactory feedback has the potential to improve our driving behaviour, giving us hints we could have missed when relying on visual stimuli only (e.g. in cases of exceeding the speed limit, short inter-vehicle distance, and lane departure).

Future research can now start investigating scents for more complex driving tasks (e.g. overtaking slower vehicles [37]) and other notifications (e.g. "Traffic jam ahead"). It is also worth exploring olfactory notifications in the presence of a secondary task (e.g. using a radio or a touchscreen [45]) and in combination with other visual (e.g. ambient lights [38]) and auditory [8] stimuli. Finally, studies in a real car interior would demonstrate the effectiveness of olfactory notifications in the presence of other ambient scents and scent absorbing materials.

7 ACKNOWLEDGMENTS

The authors thank Jose Luis Berna Moya, Robert Cobden, and Anna Konstantinova for their help on various stages of this project.

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme under the grant agreement No 638605 and No 737576.

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