Investigating the effects of two fragrances on comfort in the automotive context

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Abstract What is this the impact of olfactory and visual factors on overall comfort? Can these factors have an effect on the perception of thermal comfort? These questions are particularly interesting in the context of a vehicle car cabin, since it leads to the possibility of visual or olfactory cues being used to maintain passenger thermal comfort at a lower energy cost. In this work, human subject trials (n=47) were performed in a temperature-controlled environment varying air temperature, ambient light (none, yellow, blue) and scent (neutral, peppermint, orange & cinnamon). Multiple linear regression shows olfactory factors to have a larger effect on overall comfort perception than visual factors. Either scent improved thermal perception in a slightly cold environment, while only peppermint improved thermal perception in a slightly warm environment. These results suggest that the use of visual and olfactory factors have the potential to increase car cabin comfort and / or improve the energy efficiency of the car climate system.

Keywords: overall comfort, olfactory comfort, thermal comfort, scent diffusion, fragrance diffusion, automotive context

1 Introduction

EU-funded project DOMUS (www.domus-project.eu) aims at increasing the range of electric vehicles by 25% under a variety of ambient conditions without considering possible improvements on the battery and/or electric engine itself. The research directions include for instance minimizing consumption of components, reducing losses, and removing unnecessary consumptions. The car cabin's heating and cooling system is the car's largest auxiliary load, and this system is closely related to personal comfort. When optimizing the energy consumption of the cabin it is therefore of high importance to monitor the changes made on occupants' comfort level and their implications. The research introduced by this paper contributed to the efforts deployed by the consortium to collect experimental data in order to model personal comfort in a more holistic way. Although the methodology presented is illustrative of the approach taken by the DOMUS project, it is important to highlight that it only presents partial results: all the new comfort factors considered are not shown in the literature review section and the experiments presented consist of only one fifth all the jury tests to be conducted (the majority of them were not yet conducted at the time this paper was submitted).

In the next section, a brief literature review regarding comfort will be introduced. Experimentation will be presented first and will be followed by a presentation of results and analysis. The last section will discuss these findings and the next steps.

2 Literature review

2.1 Thermal comfort

In the automotive context existing thermal comfort model could be integrated with considerations on the human perception factor. Precursors of this approach include Fanger's Predicted Mean Vote (PMV) [5], the Berkeley model and Nilsson's equivalent temperature [13]. While the latter models, particularly PMV, have lasted well and are widely used, they are currently not optimized for holistic comfort representing the relevant multiple comfort dimensions. The factors considered by these models are mainly related to the heat exchanges happening between a human body and its environment (due to air temperature, surface temperature, radiation, and insulation). Their limitations become evident when considering cognitive moderating factors of thermal comfort (e.g. mental state, expectations) as well as non-thermal dimensions of comfort (e.g. acoustic, visual, olfactory) that are mainly absent.

2.2 Overall comfort of the body

Comfort models such as the one proposed by Vink & Hallbeck [16] based on neurosciences are representative of the cognitive process resulting from sensory stimulation. They have been used as inspiration by Loriquet et al. [9] to create a representation of passenger's appreciation (Figure 1) illustrating how human cognitive process resulting from sensory stimulations can lead to comfort, discomfort or to a neutral sensation. The aforementioned representation also considers additional inputs (e.g. attention, memory, mood or expectations) acting as comfort moderating factors. Vink & Hallbeck [16] argue that the output is not one form of comfort or discomfort experience but a wider range of appreciations and that both comfort and discomfort can even be experienced simultaneously (e.g. discomfort originating from the seat and feeling of comfort created by a nice flight attendant).

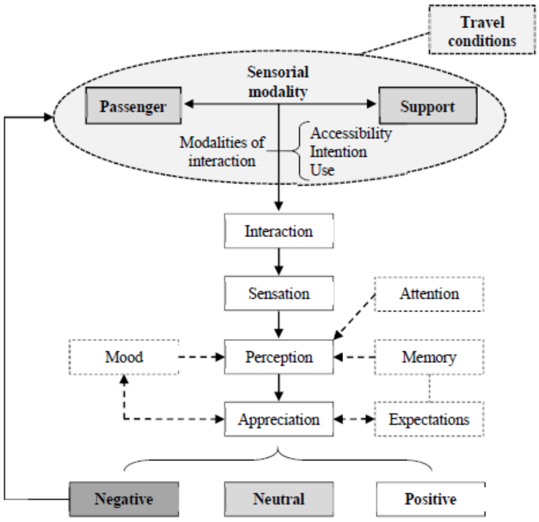


Fig. 1. Comfort of the body: local sensory interaction between the passenger and his environment [9]

Bubb [2] has also discussed the interactions between comfort from different sensory stimulations and overall (dis)comfort in the automotive context. His analysis led to a pyramid-shape figure (Figure 2) inspired by the Maslow pyramid. A discomfort sensation from sensory parameters situated on the lower part of the pyramid are able to convey an overall discomfort regardless of the sensation provided by parameters situated above. According to Bubb, in a bad smelling but thermally comfortable environment, one would feel uncomfortable because of odors: the thermal environment having no influence on the overall comfort perception in this context. The discomfort thresholds for which these kind of interactions apply have nevertheless not been defined.

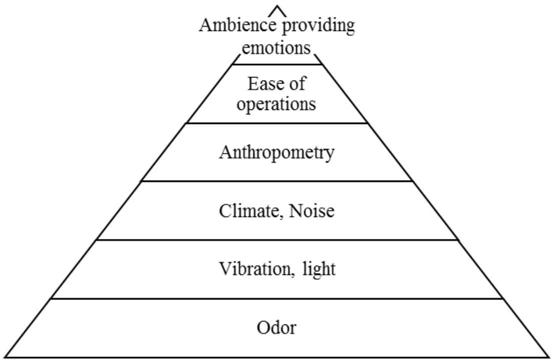


Fig. 2. Comfort dimension (translated from [2])

Other researchers suggest that certain sensory stimulation themselves - such as light illumination and color, air pollution, noise [3] as well as ambient scent [8] - can act as comfort appreciation moderating factors of thermal comfort. Experimentations conducted in room [6] and aircraft cabin [17] environments have shown that the color of lighting can significantly impact thermal comfort appreciation. From a physiological perspective, research has also suggested that light stimulation stops the synthesis and release of melatonin which has a major role in regulating body temperature [11]. Morita et al. [10] suggested that this is one of the causes why preferred ambient temperature is significantly lower when exposed to light (i.e. body temperature is higher) than when it is not (i.e. body temperature is lower). Neuroscience has shown that perceived odors have a strong link to memory, attention, reaction times, mood, and emotion [1]. More specific researches on the impact of fragrances (e.g. coffee - warm, mint - cold) on the perception of thermal comfort have also been undertaken with so far undisclosed results [8]. The experiments presented in this paper examine similar research questions applied in context of an automotive vehicle.

3 Experimentation

3.1 Factors considered

In this work, three experimental factors were considered: “ambient scent” and “ambient light colour” (within-subject variables: multiple conditions experienced by each respondent) as well as “air temperature” (between-subject variable: one condition experienced by each respondent), These factors are highlighted in Table 1.

The ambient light colours tested (“no light”, “blue” and “yellow”) and air temperature (close to comfort according to thermal comfort models) followed guidelines of similar experimentations in building interior [3][6] and aircraft cabin contexts [17]. In order to select the ambient scents for the experimentation a pilot study was conducted. Eight scents (essential oils presented in diffusers) were evaluated by a panel of 5 persons according to their pleasantness and propensity to convey warm or cold sensations. The two fragrances selected were “peppermint” (above average pleasantness score + conveys a cold sensation) and “orange & cinnamon” (above average pleasantness score + conveys a warm sensation). The “neutral” scent condition was achieved using a neutral deodorizer (“Envii Bed Fresh” - selected following subjective assessment) and ventilating the cabin for 2 minutes.

Many other factors were controlled in order for the data collection to be comparable with other DOMUS experimentations. The list of factors to consider, their baseline value (noted [BL] in the table below) as well as measurement methods were aligned among DOMUS consortium members. This information is summarized in Table 1.

Table 1. Description of main factors considered

Factor investigated	*Test case 1*	*Test case 2*	*Test case 3*	*Test case 4*	*Test case 5*	*Test case 6*	*Test case 7*
Ambient scent	Neutral [BL]	Peppermint	Orange & cinnamon	Neutral [BL]	Neutral [BL]	Peppermint	Orange & cinnamon
Space lighting	Dimmed (<800lux) white (3000-4000K) light [BL]						
Ambient light color	No [BL]	No [BL]	No [BL]	Blue	Yellow	Blue	Yellow
Thermal env. – air T°C	Between subject variable (17.1°C, 19.5°C, 22°C [BL], 23.5°C, 24.6°C)						
Thermal env. – else	No additional radiation source, controlled air velocity (<0.2m/s), controlled relative humidity [BL]						
Sound env.	Recording of EV car at constant speed at given loudness [BL]						
Seating	Automotive seat [BL]						
Attention	Standard task: Mobile Tacking Task [BL]						
Participant	Minimum 8 participants per test case, between 20 and 70 years old, both genders represented (min. 3 participants per test case) [BL]						
Participant state	Preconditioned to thermal environment, standard clothing (0.76clo), controlled metabolic rate (1.2 MET) [BL]						

3.2 Set-up and protocol

Forty-seven participants took part, each undergoing an hour individual session. They all worked at Toyota Motor Europe in Belgium. Following the DOMUS guidelines, both genders were well represented (female [38%], male [62%]). Attention was also paid to have a diverse panel coving all subregions of Europe (Northern [13.5%], Western [42%], Eastern [13.5%], and Southern Europe [31%]) and a wide range of age groups (20-29 [46%], 30-39 [26%], 40-49 [19%], and 50-59 [9%]). The experimentation took place in a thermal chamber. They went through the protocol described in Figure 3 in order to evaluate five to seven test cases (described in Table 1). Test case 1 to 5 were administrated first in a random order. The two last ones were considered only if time allowed it. This means that they all experienced at a given temperature different ambient light colors and scents. Each day a new temperature was set and attention was paid to have at least 8 participants a day and an homogenous gender distribution. As this paper focuses on interaction between thermal and olfactory perception only results from the test cases labelled 1, 2, and 3 will be discussed in the next sections.

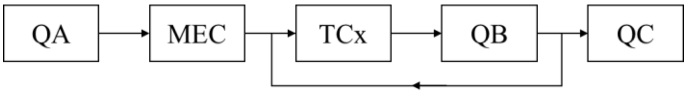


Fig. 3. Simplified experimentation protocol

Each section of the protocol is introduced below:

QA (questionnaire A) consisted in the collection of participants' demographical data, noise and thermal sensitivity as well as temperature history.

MEC consisted in the calibration phase of the magnitude estimation method [15]. It allowed them to understand and familiarize with the unusual format of this method. It was selected to assess and compare the comfort sensation from different sensory channels because it gives more freedom and flexibility to participant when assessing and comparing these abstract notions. In practice it consisted in expressing each comfort sensation felt by drawing a straight line and writing a positive number (longer line and higher number correspond to higher comfort) .

TCx (test case x) represent the moment participants experienced a specific test case in a car cabin. Each test case consisted of a two minutes period within which participants were instructed to perform a task on a tablet while listening to an EV car noise through a headset (more details in Table 1). Before each test case, when participants were not yet in the vehicle, the experimenter set the environment of the cabin to correspond to the next test case planned. Questionnaire B were distributed at the beginning of each test case.

QB (questionnaire B) consisted in the evaluation of the test case experienced. It was filled in the cabin and is composed of three sections. The first section focused on thermal sensation with 7-point scales from cold to hot [7]. The second section consisted in a comfort assessment of five sensory components (thermal, acoustic, seating, visual environments, and seating) as well as overall comfort using the magnitude estimation method

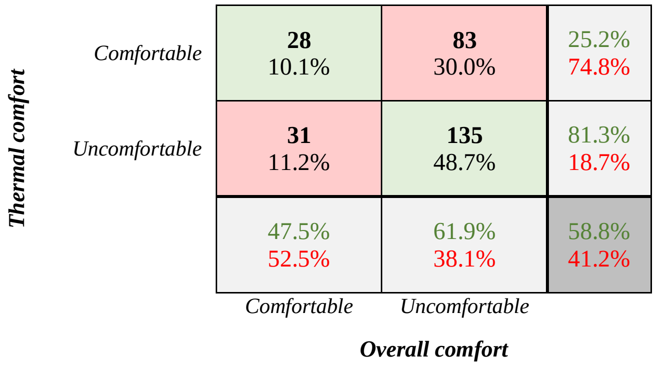
[15]. The last section of this questionnaire consisted in a 9-point hedonic scale aiming to gather a liking score for each sensory channel [4] to complement the comfort rating collected in previous sections.

QC (questionnaire C) consisted in an evaluation of the task. The questionnaire used for this section was the NASA Task Load Index [12].

4 Results and initial analysis

4.1 Overall comfort components

In total, 303 test cases have been evaluated by the 47 participants. A confusion matrix was created (Figure 4) based on thermal and overall comfort scores reported by participants in QB. According to it, thermal and overall comfort scores are correlated in only 58.8% of the cases. It is also interesting to observe that only 47.5% of the test cases for which overall comfort was achieved were also reported as thermally comfortable. At the other end of the spectrum, when overall comfort was not achieved, participants felt thermally uncomfortable in only 61.9% of the cases. This shows that, at least in the experimental setup, holistic comfort is much more than thermal comfort. For a good understanding of the confusion matrix (Figure 4), it is important to note that in "comfortable" corresponds to evaluations of "like slightly" (6th on a 9-point scale) and higher, and that "uncomfortable" corresponds to evaluations of "neither like nor dislike" (5th on the 9-point scale) and lower.



Thermal comfort	Comfortable	Uncomfortable	
Comfortable	**28** 10.1%	**83** 30.0%	25.2% 74.8%
Uncomfortable	**31** 11.2%	**135** 48.7%	81.3% 18.7%
	47.5% 52.5%	61.9% 38.1%	58.8% 41.2%

Fig. 4. Confusion matrix

Based on all participant evaluations, the overall comfort score (reported by participants in QB) has been expressed as weighted sum of each sensory comfort score (also reported in QB) using a linear regression (1). Given the coefficient of determination (R^2=0.916), 92% of the variability of the dependent variable *Overall (comfort)* is explained by the 5 explanatory variables. Given the p-value (< 0.0001) of the F statistic computed in the ANOVA table, and given the significance level of 5%, the information brought by the explanatory variables is significantly better than what a basic mean would bring. Model parameters are presented in table 2. The model therefore fits relatively well the comfort scores expressed by the participants in the condition of the experiment: static lab context, no extreme conditions (e.g. very cold temperature, scents commonly accepted as unpleasing). It is therefore to be interpreted with care.

$$Overall = -4.239 + 0.316 \times Olfactory + 0.273 \times Thermal + 0.200 \times Visual + 0.185 \times Acoustic + 0.179 \times Seating \qquad (1)$$

Table 2. Model parameters

Source	*Value*	*Standard error*	*t*	*Pr > |t|*	*Lower bound (95%)*	*Upper bound (95%)*
Intercept	-4.239	1.336	-3.173	0.002	-6.868	-1.610
Olfactory	0.316	0.027	11.802	< 0.0001	0.263	0.369
Thermal	0.273	0.028	9.864	< 0.0001	0.218	0.327
Visual	0.200	0.031	6.453	< 0.0001	0.139	0.262
Acoustic	0.185	0.026	7.066	< 0.0001	0.133	0.236
Seating	0.179	0.031	5.786	< 0.0001	0.118	0.240

In equation (1) an emphasis has been made on the comfort sensations related to the three variables of the experimentation (i.e. air temperature, ambient light color, ambient scent). Comparing their relative weight, it can be observed that olfactory (dis)comfort appears to be the most influential. Notably, in Bubb's model (Figure 2), olfactory discomfort was also presented as having the most influence on overall discomfort. The second component having the most weight appears to be thermal comfort with visual comfort placing third on this relative comparison. Acoustic and seating comfort will need complementary experimental data (planned by other partners in the DOMUS consortium), with test cases focusing on other experimental factors, in order to be discussed in the relative comparison.

4.2 Effect of liked olfactory environment on thermal and overall comfort

In the previous sub-section it has been seen that, in the context of the experimentation conducted, olfactory (dis)comfort was the main component of overall (dis)comfort. The discussion will now shift to the influence of both fragrances (i.e. "peppermint" and "orange & cinnamon" essential oil) on thermal sensation as well as on thermal and overall comfort for two thermal environments: slightly cold (below 22°C) and slightly warm (above 23°C). In order to keep the analysis concise and relevant only test cases for which the fragrances diffused were perceived as neutral or were liked by the participants (reported in QB – hedonic scale) will be discussed in this section. It should be noted that although a pilot test has been conducted, the liking of both fragrances appeared very subjective as they were both disliked (rated from "dislike slightly" to "dislike extremely") by approximately 50% of the respondents. Notably, fragrances were generally more appreciated by female participants as this percentage decreased to 40% for this subgroup. Furthermore, it has been observed that the thermal environment does not influence the liking rate (e.g. "peppermint" fragrance is not more appreciated in warmer thermal environments).

The analysis was made possible by the fact that air temperature was a between-subjects variable. It was therefore possible to compare participants' evaluation of the test case with a neutral scent (Test case #1 in Table 1) with their ratings of the same environment with only the scent changed (Test case #2 & #3 in Table 1). Due to limited sample size, we will not be able to further discuss diversity sensitivity (gender, age, region) in this paper. This will only be possible once all DOMUS experimentations will be conducted.

Figure 5 shows the mean influence of the presence of each fragrance on appreciation of thermal comfort (i.e. 9-point scale from "dislike extremely" to "like extremely") and thermal sensation (i.e. 7-point scale from "cold" to "hot") for temperatures set below 22°C. Both fragrances appear to improve the appreciation of the thermal environment (left on Figure 5), with orange & cinnamon further contributing to improving the thermal sensation felt by the participant in this context (i.e. feel warmer). On the contrary peppermint returns a colder thermal sensation which corresponds to the observation from the pilot test. No significant differences could be observed when comparing participants' evaluation of test cases with fragrance and with neutral scent. The observations have therefore to be considered as tendencies.

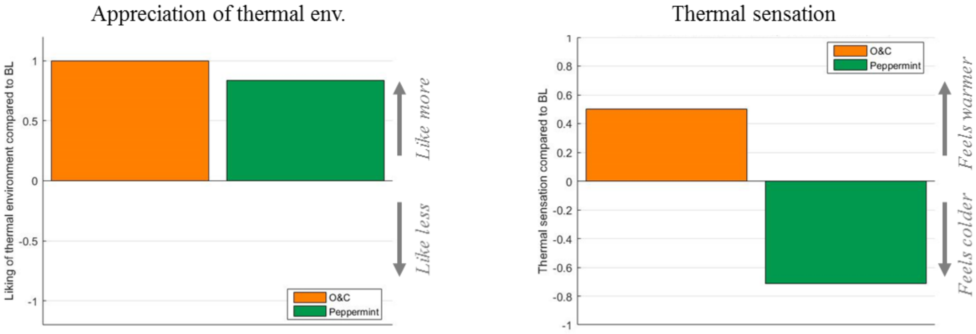


Fig. 5. Effect of peppermint and orange & cinnamon scent on thermal perception in a slightly cold environment

The interactions between olfactory, thermal environments and overall comfort discussed above as well as in section 4.1 have been visualized in Figure 6. When possible, circled schematic graph have been inserted in order to represent existing relationships between items (e.g. linear). The symbol "+" indicates that the fragrance has a positive impact on the evaluation it is related to, whereas "~" represents a neutral impact, and "-" a negative impact. The red cross (marked “X”) indicates that the thermal environment did not appear to have an influence on olfactory comfort appreciation (as further described previously). Particular attention have been given to individuation of eventual links between the two. As it can be seen, when liked, the presence of the two fragrances tested affects the thermal sensation and the thermal comfort appreciation.

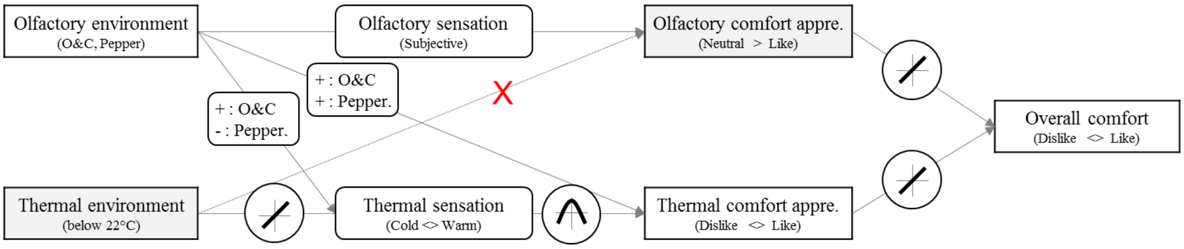


Fig. 6. Thermal and olfactory interactions in a slightly cold environment

A similar analysis than the one described previously has been conducted for the test cases at slightly warm temperatures (23-25°C). It has been summarized in the figure 7. In this context, it appears that the introduction of fragrances in the car cabin has no effects on thermal sensation. The olfactory sensation given by peppermint contribute though to increased thermal comfort appreciation.

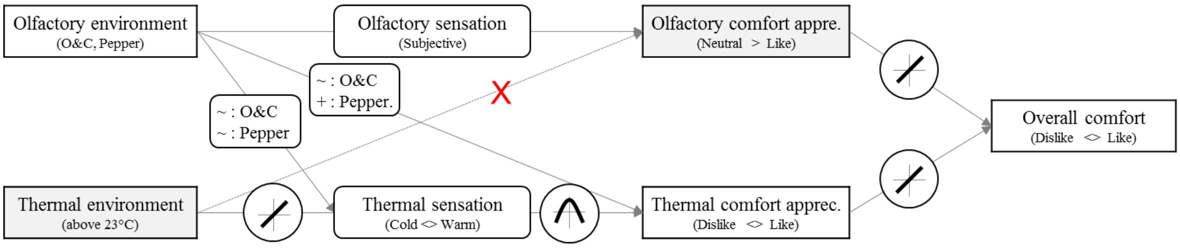


Fig. 7. Thermal and olfactory interactions in a slightly warm environment

5 Discussions and next steps

Analyzing participants’ comfort scores, we observed that overall comfort is more than just thermal comfort. They indicate that olfactory (dis)comfort is another major component of overall (dis)comfort. The linear regression model obtained with the data from 303 test case evaluations showed that from this experimental context it even had the most weight. Liking a scent is nevertheless a very subjective matter as both fragrances tested were disliked by about 50% of the participants.

The second step of the analysis focused on the other half of the respondents (liking or being neutral about the fragrance) as in a real situation only them would be more inclined to have the scents diffused in their vehicle. For them, scents appeared to have an interesting effect on thermal sensation and comfort in both slightly warm and slightly cold environments. In slightly cold environments, the presence of either one of the two fragrances tends to improve the thermal comfort, whereas this observation is only valid for “peppermint” in slight warm environments (stable for “orange & cinnamon”). When comes to impact on thermal sensation, influences from scents could only be observed at colder temperatures. In this context, results were in line with the hypotheses formulated after the pilot study: “orange & cinnamon” fosters a warmer sensation, whereas “peppermint” yields a colder sensation.

Customers already have today various possibilities to diffuse scents in their vehicle (accessory modules, embedded in some recent vehicles). The findings of this research suggest that these can be effective solutions to improve overall comfort of vehicle occupants (assuming that the fragrance diffused is appreciated by the occupants). Additionally, such systems might be able to improve thermal comfort before an appropriate temperature is reached or to maintain the level of comfort while lowering the energy consumption of the HVAC unit.

Complementary studies covering additional use cases (e.g. transient thermal environment), a larger participant panels (allowing representative results regarding diversity sensitivity), a more natural environment (e.g.

while driving), and a wider range of fragrances are envisioned as next steps. Beyond comfort considerations, fragrances have shown to be effectively changing occupants behaviors (e.g. calm, energized), shaking off drowsiness or conveying certain messages [14]. It would therefore also be valuable to integrate such considerations (when applicable) in future comfort studies.

The experimentation described in this paper was part of a collaborative effort to model comfort in automotive vehicles taking into account new factors. Additionally to air temperature and ambient scent (discussed in the paper), factors such as ambient light color (collected in the experimentation described) but also irradiation, task load, noise or thermal asymmetry will be inputs to the DOMUS holistic comfort model. It will be presented in an upcoming deliverable from the DOMUS project and in publications from the partners involved.

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