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RESEARCH ARTICLE

Visually induced motion sickness can be alleviated by pleasant odors

Behrang Keshavarz · Daniela Stelzmann · Aurore Paillard · Heiko Hecht

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Abstract Visually induced motion sickness (VIMS) is a common side effect in virtual environments and simulators. Several countermeasures against VIMS exist, but a reliable method to prevent or ease VIMS is unfortunately still missing. In the present study, we tested whether olfactory cues can alleviate VIMS. Sixty-two participants were exposed to a 15-min-long video showing a first-person-view bicycle ride that had successfully induced VIMS in previous studies. Participants were randomly assigned to one of three groups; the first group was exposed to a pleasant odor (rose) while watching the video, the second group was exposed to an unpleasant odor (leather), and the third group was not exposed to any odor. VIMS was measured using a verbal rating scale (0–20) and the Simulator Sickness Questionnaire. Results showed that only half of the participants who were exposed to the odor did notice it ($n = 21$), whereas the other half failed to detect the odor. However, among those participants who did notice the odor, the rose scent significantly reduced the severity of VIMS compared to the group that did not notice the odor. A moderate positive correlation between odor sensitivity and VIMS showed that participants with higher odor sensitivity also reported stronger VIMS. Our results demonstrate that olfaction can modulate VIMS and that a pleasant odor can potentially reduce VIMS. The relationship between olfactory perception, olfactory sensibility, and VIMS is discussed.

Keywords Visually induced motion sickness · Motion sickness · Simulator sickness · Olfaction · Odor · Smell · Countermeasures

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Introduction

Visually induced motion sickness (VIMS) is a common side effect of simulators, video games, or virtual environments. An acute phase of VIMS is typically characterized by a variety of symptoms, including pallor, cold sweat, dizziness, nausea, or vomiting (see Stanney and Kennedy 1997; Lawson 2014). The precise mechanisms underlying the genesis of VIMS are not fully understood yet (for an overview, see Keshavarz et al. 2014; Golding and Gresty 2005). According to the prominent sensory conflict theory (Reason and Brand 1975; Reason 1978), VIMS is caused by a conflict between or within the visual, vestibular, and/or somatosensory senses. For instance, the illusion of self-motion (vection) can typically be experienced in fixed-based simulators with a screen that covers a large portion of the observer's field of view. In this case, the visual system indicates self-motion, whereas the vestibular and somatosensory senses indicate the observer's veridical and stationary position; as a result, VIMS might be evoked. Note that a sensory conflict does not necessarily entail VIMS. Instead, VIMS is taken to occur when the sensory conflict is novel to the organism, and corresponding adaptation mechanisms have not yet been successfully established. Other theoretical approaches include the role of postural stability (Stoffregen and Riccio 1991; Riccio and Stoffregen 1991) and eye movements (Ebenholtz 1992),

but neither of them is capable of sufficiently explaining the genesis of VIMS (see Keshavarz et al. 2014).

Nausea is one of the cardinal symptoms of VIMS. A number of remedies against motion-induced nausea have been introduced in the past with mixed success, including medical and behavioral countermeasure treatments. For instance, anti-motion sickness drugs (antihistamines, anticholinergics) successfully reduced the level of traditional motion sickness in several studies (for an overview, see Sherman 2002; Shupak and Gordon 2006). However, medical treatment for motion sickness usually comes at the price of (mild to severe) side effects like drowsiness, fatigue, or impaired cognitive abilities, dramatically limiting the application of anti-motion sickness drugs for everyday use (see Golding 2006). The most promising behavioral mechanism to prevent or reduce VIMS is arguably habituation. The human organism usually adapts to nauseating stimuli with repeated exposure, resulting in diminished or (ideally) eliminated VIMS (e.g., Cheung and Hofer 2005; Cowings and Toscano 2000; Hecht et al. 2002). However, habituation is not always the optimal solution for coping with VIMS, since it is time-consuming, cost-intensive, and might not always be applicable. Hence, other behavioral countermeasures against VIMS are highly desirable. Most recently, participants who were exposed to pleasant music during a nauseating video reported significantly less sickness than participants who did not listen to music, indicating that music might be able to reduce VIMS (Keshavarz and Hecht 2014; also Yen Pik Sang et al. 2003a). Additionally, controlled breathing (Yen Pik Sang et al. 2003a), acupressure (Chu et al. 2012), and ginger (Estrada et al. 2007; Lien et al. 2003) were introduced as a potential remedies against VIMS, but most of them showed only limited success and remain controversial. Interestingly, both VIMS and traditional motion sickness are known to be strongest when caused by low-frequent visual or real motion that ranges from 0.06 to 0.4 Hz (see Bos et al. 2008; Duh et al. 2004; Golding and Gresty 2005). Groen and Bos (2008) showed that a moving-base driving simulator that included motion around 0.08 Hz resulted in stronger sickness ratings compared to the same driving simulator that mainly produced higher-frequency motion around 0.46 Hz, indicating that reducing the amount of lower-frequency motion can be a method to decrease VIMS. However, avoiding low-frequent motion might not always be an option for particular research questions (e.g., flight or driving simulators). Also, modifications of the laboratory setting might reduce VIMS; for instance, a smaller field of view (Bos et al. 2008; Keshavarz et al. 2011), minimizing the time lag in virtual reality (Akizuki et al. 2005; Draper et al. 2001) or reducing the use of head-mounted displays (Moss and Muth 2011; Patterson et al. 2006) all decrease VIMS. However, these measures are often problematic. A smaller field of view might reduce VIMS, but it might also reduce the immersive nature of the virtual environment or reduce the level of realism. Hence, other effective countermeasures that do not interfere with a vivid and realistic virtual experience are highly desirable.

In the present study, we determined the role of olfaction as a potential method to alleviate VIMS. To our knowledge, studies regarding olfaction and VIMS are sparse. Only one recent study has directly addressed the role of olfaction with respect to motion sickness (Paillard et al. 2014). In their study, the authors exposed 18 participants to off-vertical axis rotations (OVAR) and added a pleasant, unpleasant, and neutral odor to determine the effect of odors on motion sickness. The addition of a pleasant or unpleasant odor during OVAR did not affect the occurrence of motion sickness symptoms at all. Despite the null effect reported by Paillard et al., we believe that olfaction might indeed be linked to the occurrence of VIMS in different ways. Firstly, anecdotal reports suggest that odors can ease traditional motion sickness, but to our knowledge scientific findings supporting this assumption are almost nonexistent. The efficacy of continuously inhaled essential oils to reduce postoperative nausea and morning sickness during pregnancy has been demonstrated (Ferruggiari et al. 2012), but it is not known whether these oils can also reduce VIMS. Secondly, several studies reported that women are highly sensitive to specific odors during their pregnancy (Cameron 2014), and that such odors can evoke feelings of strong discomfort and nausea (Hummel et al. 2002). This finding suggests that nausea might be linked to odors in general; however, the question whether odors are linked to VIMS in particular remains to be answered. Thirdly, a study by Sobel et al. (1998) showed that odors activate parts of the cerebellum that are known to be related to the biology of nausea (for an overview, see Yates et al. 2014). Taken together, olfaction might indeed be linked to nausea in various ways, but the effect of odor on motion-induced nausea (or VIMS) has not been investigated so far. The aim of the present study was to fill this gap.

We exposed participants to a video showing a bicycle ride recorded from a first-person view that was previously used to successfully induce VIMS (e.g., Keshavarz and Hecht 2012, 2014). Participants were exposed to one of two different odors that were meant to be perceived as either pleasant or unpleasant. A third group of participants acted as a control group and was not exposed to any odor while watching the video. For the unpleasant odor, we chose a *leather* scent, and for the pleasant odor, we chose a *rose* scent. As the perception of odors is highly subjective and the interpretation of odors can be strongly context-dependent, it is rather difficult to make a generally valid distinction between pleasant and unpleasant odors. For instance, the leathery smell of a new car might be unpleasant to some persons, whereas others might judge the smell as pleasing.

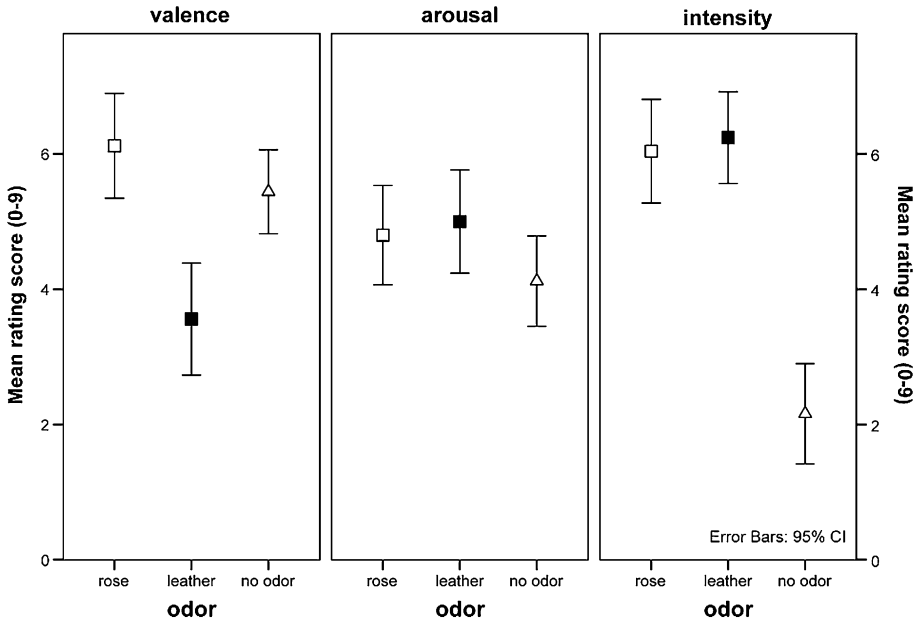

Fig. 1 Mean ratings of valence, arousal, and intensity for each odor during the pre-study. *Error bars* indicate 95 % confidence intervals

To ensure that rose and leather were suitable odors for our study, we chose both scents on the basis of previous global ratings, suggesting that rose is typically rated as pleasant (e.g., Brauchli et al. 1995), whereas leather is typically rated as unpleasant (e.g., Doty et al. 1984), presumably because it is reminiscent of goat or other live stock odors. We also collected valence and intensity ratings for rose and leather in a pre-study with 25 participants to further ensure that the odors that we used were appropriate (see Fig. 1 and "Methods" for details). The results of the pre-study confirmed that leather was rated as significantly less pleasant than rose and that both odors were suitable for the purpose of the present study. Thus, we will refer to rose as the *pleasant* odor and to leather as the *unpleasant* odor in the following. The main purpose of the study was to determine the role of the odor's valence with respect to VIMS severity. Based on the previous reports on odors and nausea/general discomfort, we assumed that a pleasant odor would result in reduced VIMS.

Methods

Participants

Sixty-two healthy young adults (47 females, $M_{age} = 23.72$, $SD_{age} = 6.62$; 15 males, $M_{age} = 25.87$, $SD_{age} = 6.24$) volunteered in this study. All participants gave written consent prior to the experiment and stated that they were in a normal state of health (i.e., no cold, no vestibular dysfunction, and no chronic diseases). Participants had normal or corrected-to-normal vision and were naïve with respect to the purpose of the study. The stimuli were administered in accordance with the Declaration of Helsinki. Participants received partial course credit and were informed that they were free to abort the experiment at any time without being penalized. Sixteen participants stopped the experiment prematurely due to severe VIMS. However, they were not excluded from the data analysis.

Apparatus, stimuli, and design

The stimulus consisted of a video (14 min 15 s long) showing a bicycle ride through the city of Mainz, Germany, recorded in first-person view. The video was captured with a Sony video camera, which was mounted on the handlebars of a bicycle. Participants were seated in a height-adjustable chair 200 cm in front of a 191 cm × 144 cm large projection screen (field of view: 51° horizontally, 40° vertically) in a dimly lit room. A plastic chinrest was fixed with eye height adjusted to the center of the screen (116 cm above ground) to minimize participants' head movements. Video resolution was 600 × 480 pixels with a refresh rate of 60 Hz.

A one-factorial between-subjects design was chosen. Depending on the experimental group, participants were either exposed to a pleasant odor (rose), to an unpleasant odor (leather), or to no odor (control[1]) while watching the

[1] Note that the experimental settings (i.e., stimuli, apparatus, and response measures) were identical with a study published recently by Keshavarz and Hecht (2014). In their study, the role of music was tested when participants were exposed to the same video that was used in the present study. Due to the identical procedure, the control group ("no sound") used by Keshavarz and Hecht (2014) acted as a control group for the present study as well.

bicycle video. Note that we deliberately chose a between-subjects design over a within-subjects design to prevent adaptation or habituation effects. Also, a within-subjects design would have forced us to inform participants about the existence of the odors prior to the test sessions, which we aimed to avoid to prevent expectancy or priming effects. Participants were randomly assigned to one of the three groups. The two odors were selected based on global ratings that labeled rose as pleasant (e.g., Brauchli et al. 1995) and leather as unpleasant (e.g., Doty et al. 1984). A small odorless felt plate was prepared with 0.10 mg (5 drops of 0.2 mg each) of pure rose or leather perfume oil concentrate (not mingled with alcohol) and was attached directly underneath the chinrest. The odors were provided by Firmenich, Switzerland, and were both synthetically created. The rose scent (*natureprint rose centrifolia*) contains phenylethyl alcohol, geraniol, and citroneol components and is described by the manufacturer as being "feminine and flowery, sweet and fruity (lychee), and slightly spicy (peppery)." The leather scent (*natureprint leather)* mainly consists of phenolic compounds (cresol) and is described as "masculine, feral, harsh, and smoky" (personal communication, December 2014). Both odors are unique compositions and are not commercially available for sale. To ensure that odor intensity was identical for each participant, the time between preparing the felt plate and starting the stimulus was held constant at 2 min. The odor dispenser was hidden from view during the whole experiment. In a pre-study, 25 participants (none of whom participated in the follow-up study) judged the level of valence, arousal, and intensity for the neutral felt plate (without any odor), as well as for the felt plate prepared with the rose and leather odor, respectively. The self-assessment manikin (SAM, Bradley and Lang 1994), a nonverbal pictorial self-rating scale that was designed to measure emotions for different stimuli (e.g., pictures), was used for the odor ratings. Each SAM dimension ranges from 0 to 9, with 0 representing the lower end of each scale (i.e., very unpleasant, non-arousing, and non-intense) and 9 representing the upper end of each scale (i.e., very pleasant, very arousing, and very intense). The pre-study ratings for each odor are shown in Fig. 1. Non-parametric tests (Friedman) for related samples including odor as a factor (rose, leather, neutral) were performed for valence, arousal, and intensity ratings. A significant effect of odor was observed for the odor's valence, $\chi^2 = 11.96$, $p = .003$, with single comparisons (Wilcoxon), indicating that rose was judged as significantly more pleasant than leather, $Z = -3.01$, $p = .003$. However, the comparison between rose and the neutral felt plate missed significance, $Z = -1.68$, $p = .094$. No significant differences between rose and leather showed with respect to the odors' arousal and intensity. Based on these results, we assumed that rose and leather were suitable odors for the purpose of our study. Note that we deliberately chose to waive extremely unpleasant odors (such as sulfur) to rule out nausea from olfactory stimulation alone and to avoid potential ethical issues.

Motion sickness and olfactory measures

Visually induced motion sickness was measured in two ways. Firstly, participants had to rate their level of VIMS every minute using the Fast Motion Sickness Scale (FMS; Keshavarz and Hecht 2011). The FMS is a verbal rating scale ranging from 0 (no sickness at all) to 20 (severe sickness) and was designed to capture discomfort, stomach awareness, and nausea in particular. Note, however, that the FMS was not designed to measure other VIMS-related symptoms such as oculomotor disturbances (e.g., eye strain and blurred vision), disorientation/dizziness, or other sensations (boredom, excitement, etc.). The FMS consists of a single question that asks participants about their current level of well-being (i.e., "How do you feel now on a scale from 0 to 20?"). That is, participants have to choose a single score from the FMS that best represents their well-being and have to verbally report it to the experimenter. Prior to the experiment, participants were informed that the FMS was designed to measure only the nausea component of VIMS (i.e., nausea and/or stomach awareness); hence, they were asked to ignore other sensations such a fatigue, boredom, or enjoyment when choosing their FMS score. The main advantage of the FMS is that it is easy to assess, intuitive to use, and that it allows capturing the time course and the onset of VIMS. Compared to other verbal rating scales, the FMS has been cross-validated using the Simulator Sickness Questionnaire (SSQ, Kennedy et al. 1993). In the validation study of the FMS (Keshavarz and Hecht 2011), we found high correlations between the peak FMS score (i.e., the highest FMS score reported through the total time of stimulus presentation) and the SSQ subscales nausea ($r = .828$), disorientation ($r = .795$), oculomotor ($r = .609$), and the total score ($r = .785$). High correlations between the FMS and the SSQ subscales were also reported in our other studies using both the FMS and the SSQ (e.g., Keshavarz and Hecht 2014). Secondly, participants had to fill in the SSQ immediately after stimulus offset [note that we deliberately chose not to assess the SSQ prior to the experiment to prevent potential priming effects that can influence the SSQ ratings (see Young et al. 2007)]. The SSQ is a standardized questionnaire including 16 items that are judged on 4-point Likert scales (0 = not at all, 1 = slight, 2 = moderate, and 3 = severe). The SSQ contains three subscales (nausea, disorientation, and oculomotor) and can be cumulated to a total score using pre-defined factor weightings.

After stimulus offset, participants first filled in the SSQ. Then, those participants who noticed an odor during the

experiment had to rate valence, arousal, and intensity of the odor that they had been exposed to during the experiment. Participants who did not notice an odor did not fill in the ratings. Similar to the pre-study, we used the SAM rating scale (Bradley and Lang 1994). Note that each participant exclusively rated the odor that was presented during stimulus exposure (either rose or leather), but did not rate the complementary odor. After the ratings, participants were informed that an odor dispenser had been attached to the chinrest during the experiment. The true scent of the odor was only revealed during debriefing at the very end of the experiment. Two additional questionnaires regarding participants' olfactory sensitivity were assessed as well, namely the Chemical Odor Sensitivity Scale (COSS; Bailer et al. 2006) and a questionnaire regarding the overall importance of olfaction to the participants (IO; Croy et al. 2010). The COSS contains 11 items (e.g., "When I enter into freshly painted rooms, I easily develop difficulty in breathing." or "Strong smell of paint gives me a feeling of nausea.") that are rated using a 6-point Likert scale ranging from 0 (strongly disagree) to 5 (strongly agree). Higher scores on the COSS indicate greater odor sensitivity. The COSS has been shown to be highly reliable and is used to capture general sensitivity to odors. The IO questionnaire consists of 20 questions that have to be rated on a 0 ("I totally disagree") to 3 ("I totally agree") scale. The questionnaire can be divided into the three subscales *application* (e.g., "I sniff on food before eating it." or "Before drinking coffee/tee, I intentionally smell it."), association (e.g., "The smell of a person plays a role in the decision whether I like him/her." or "I feel rather quickly disturbed by odors in my environment."), and consequence (e.g., "When I don't like the odor of a shampoo, I don't buy it." or "I try to locate the odor, when I smell something."). A score for each subscale and a total score can be calculated by summing the scores for each item response, with higher scores reflecting greater odor sensitivity. Also, two items regarding aggravation are included in the questionnaire as well ("Without my sense of odor, life would be worthless." and "To me it is more important to be able to smell than to be able to see."). To determine the subjective assessment of odor sensitivity without interference of the odor experience in our laboratory, we administered the odor questionnaires between 2 and 4 weeks after the experimental session.

Procedure

Participants were randomly assigned to one of the three experimental groups. All participants successfully passed a Romberg Test (e.g., Black et al. 1982) of vestibular dysfunction prior to the experiment. Before the participants entered the laboratory, the experimenter prepared the small felt plate with 0.10 mg of either rose or leather essence and attached it to the front of the chinrest. The experimenter made sure that participants could not see the felt plate being attached to the chinrest. Also, the time between attaching the felt plate and starting the stimulus was held constant at 2 min for each participant to prevent changes in odor intensity due to different exposure times to fresh air. Participants were not informed about the existence or the purpose of the odor. The experimenter verbally asked the participants to rate their level of VIMS every minute during stimulus presentation by choosing a single score from the FMS scale. The first FMS score was reported immediately before stimulus presentation began and acted as a baseline measure for VIMS. Stimulus presentation was terminated whenever participants asked to stop stimulus exposure due to severe VIMS or for other reasons, or when the video had reached its regular end. After stimulus offset, the SSQ was filled in immediately, followed by the odor ratings. Participants had to indicate whether or not they noticed an odor during the test session, before they were informed that an odor dispenser had been attached to the chinrest during the experiment and were debriefed about the purpose of the study. Before releasing the participants, the experimenter ascertained that all VIMS-related symptoms had subsided. The COSS and the IO questionnaires were electronically (via email) administered between 2 and 4 weeks after the experimental session.

Results

Motion sickness

For all statistical analyses, the Statistical Package for Social Sciences (SPSS version 21, IBM) was used. A priori significance level was set to $\alpha = 0.05$.

Forty participants were exposed to either a pleasant or unpleasant odor during stimulus presentation. The mean SSQ subscores as well as the mean peak FMS scores (i.e., the highest FMS score reported during stimulus presentation) are shown in Fig. 2. A one-way ANOVA including the factor odor (rose, leather, no odor) revealed no significant differences between the groups for the SSQ subscores nausea, $F(2, 59) = 0.587$, $p = .559$, oculomotor, $F(2, 59) = 0.067$, $p = .936$, disorientation, $F(2, 59) = 0.686$ $p = .507$, the total score, $F(2, 59) = 0.205$, $p = .815$, as well as for the peak FMS score, $F(2, 59) = 0.113$, $p = .894$.

However, only half of the participants ($n = 21$) noticed the presence of the odor during stimulus presentation at all. The distribution of participants who did and did not notice the odor during stimulus presentation is given in Table 1.

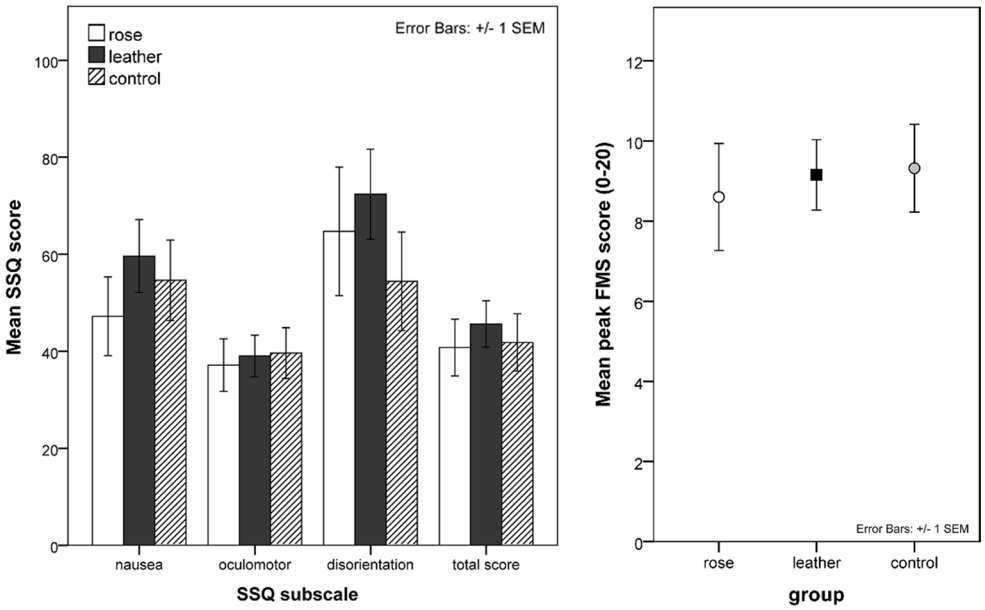

Fig. 2 *Left panel* shows the mean SSQ scores for the three subscales nausea, oculomotor, and disorientation, and the total score separated by group (rose, leather, control). The *right panel* shows the mean peak FMS scores (i.e., highest score reported during stimulus presentation) for each of the groups. *Error bars* indicate the standard error of mean

Table 1 Number of participants who did and did not notice the odor (rose or leather) during stimulus presentation

	Noticed the odor		
	Yes	No	Total
Odor			
Rose	11	9	20
Leather	10	10	20
No odor	n/a	n/a	22
Total	21	19	62

Note that none of the participants spontaneously identified the scent. Thus, we scored those who—upon questioning—said that there was an unusual smell as having noticed the odor. Based on whether participants had noticed the odor that was present in their condition, we re-categorized participants into four new groups: into those who noticed an odor with the rose stimulus (*rose*), those who noticed an odor in the leather condition (*leather*), those who did not notice any unusual odor regardless of the scent that had actually been present (*not noticed*), and the control group that was not exposed to any odor (*no odor*). Of the 21 participants who noticed the odor, eight indicated that the scent was unfamiliar to them. The other 13 participants recognized it as *disinfection spray* (9), *dental clinic smell* (2), *elderflower* (1), and *exhaust fumes* (1).

The mean SSQ scores and the mean peak FMS score (i.e., highest FMS score reported during stimulus presentation) for each group are given in Fig. 3, whereas the time course of MS and the average peak FMS score (i.e., the highest FMS score reported during stimulus exposure) are shown in Fig. 4.

A robust test of equality of means[2] (Welch) including the factor odor (rose, leather, not noticed, no odor) was performed for the peak FMS score, the SSQ total score, and the SSQ subscales nausea, oculomotor, and disorientation. The test revealed a main effect of odor for the peak FMS score, $F(3, 27) = 3.298$, $p = .036$, as well as for the SSQ subscales nausea, $F(3, 27) = 4.164$, $p = .015$, disorientation, $F(3, 26) = 4.143$, $p = .016$, and the total score, $F(3, 26) = 3.592$, $p = .027$. The result for the SSQ subscale oculomotor missed significance, $F(3, 26) = 0.787$, $p = .512$. Post hoc tests (nonparametric Tamhane corrected) showed significant differences between rose and the group who did not notice the odor regarding the peak FMS score ($p = .034$), and the SSQ subscales nausea ($p = .010$), disorientation ($p = .036$), and the SSQ total score ($p = .018$). All other groups did not vary significantly (p's > .05).

A repeated-measures ANOVA including the within-subjects factor time and the between-subjects factor odor (rose, leather, not noticed, no odor) was calculated to analyze the time course of MS. Note that participants who stopped stimulus exposure prematurely ($n = 16$) were not excluded from this analysis; instead, the last FMS score reported before dropout was continuously implemented for the following time slots. The rmANOVA (Huynh–Feldt corrected $\varepsilon = 0.20$) revealed a significant effect of time, $F(15, 798) = 62.20$, $p < .001$, $\eta_p^2 = 0.517$, and a significant interaction of time and odor, $F(45, 798) = 2.13$,

[2] We chose a nonparametric test over an ANOVA as the sample sizes were small in some of the groups ($n < 10$) and varied extensively between the groups, violating the assumptions of ANOVAs. However, note that we also calculated ANOVAs and found similar results.

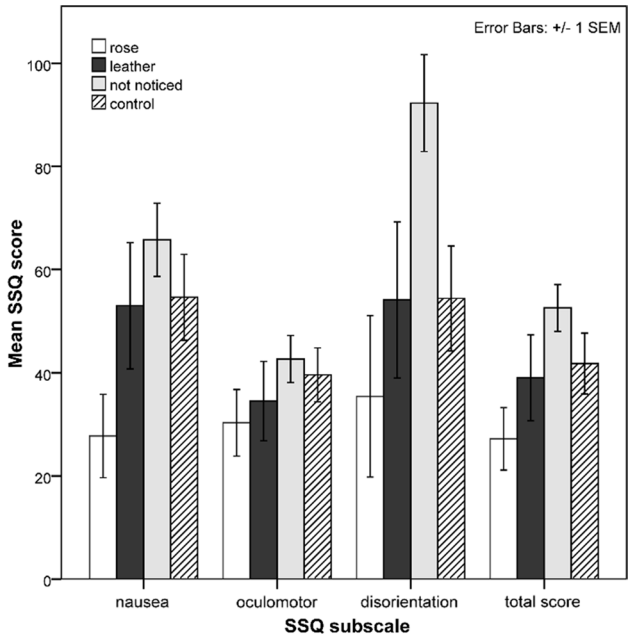

Fig. 3 Mean SSQ score for the three subscales nausea, oculomotor, and disorientation, and the total score separated by the restructured factor group (rose, leather, not noticed, control). *Error bars* indicate standard error of the mean

$p = .032$, $\eta_p^2 = 0.099$, indicating lowest FMS scores over time for the group that noticed rose. Simple contrast comparisons showed significant differences between the group that noticed rose and the group that did not notice the odor ($p = .010$), and a marginally significant difference between the group that noticed rose and the control group ($p = .073$). No main effect for the between-subjects factor odor showed $F(1, 58) = 2.59$, $p = .061$, $\eta_p^2 = 0.118$.

Odor ratings

After stimulus presentation, participants had to rate the level of valence, arousal, and intensity for the odor that they have been exposed to during the experiment. Participants who did not notice the odors were not included in this analysis. Figure 5 shows the mean ratings for the two odors, leather and rose. A nonparametric test (Mann–Whitney) revealed a significant effect of valence, $U = 23.00$, $p = .040$. No significant differences for arousal, $U = 30.00$, $p = .132$, and intensity, $U = 37.00$, $p = .334$ were observed.

Compared to the valence ratings for rose and leather collected in the pre-study, both odors were rated as less positive after the actual experiment. Nonparametric tests (Mann–Whitney U test) showed significantly lower valence scores for rose, $U = 77.00$, $p = .036$, and for leather, $U = 63.50$, $p = .050$, when they were rated after the experiment. No difference for arousal and intensity showed (p's ranging from .102 to .754).

Odor sensitivity

After stimulus exposure, participants' odor sensitivity was measured using the COSS and the IO. Seven participants had to be eliminated from the analyses due to incomplete questionnaires. The mean scores for COSS and IO for each group are given in Table 2. Note that data regarding odor sensitivity are not available for the control group, as the control group was tested in a previous study and odor sensitivity was not measured.

A one-factorial ANOVA including the factor odor (rose, leather, not noticed) was calculated for the cumulated

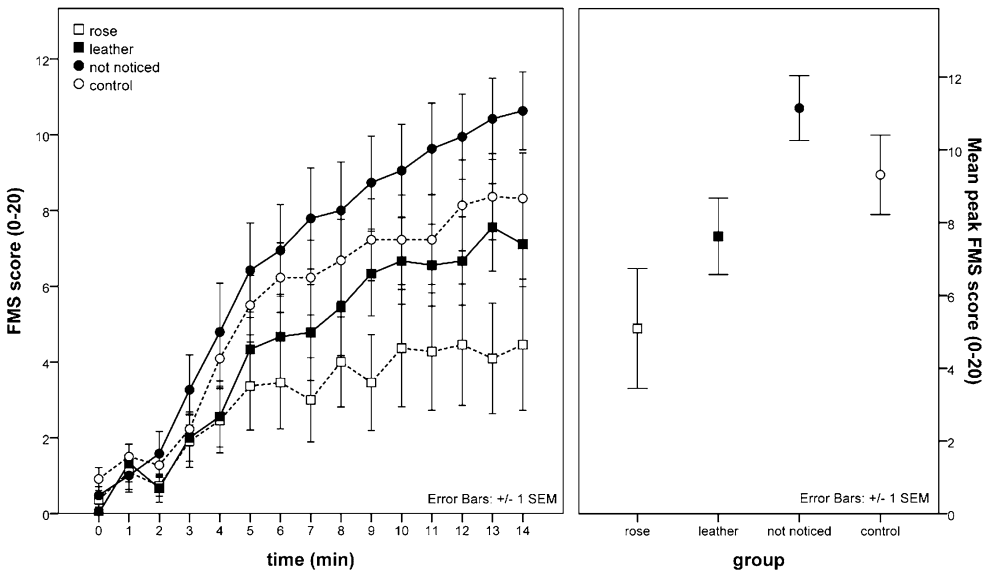

Fig. 4 *Left panel* shows the time course of FMS scores minute by minute for each of the four restructured groups (rose, leather, not noticed, and control). The *right panel* shows the mean peak FMS scores (i.e., highest score reported during stimulus presentation) for each of the groups. *Error bars* indicate the standard error of mean

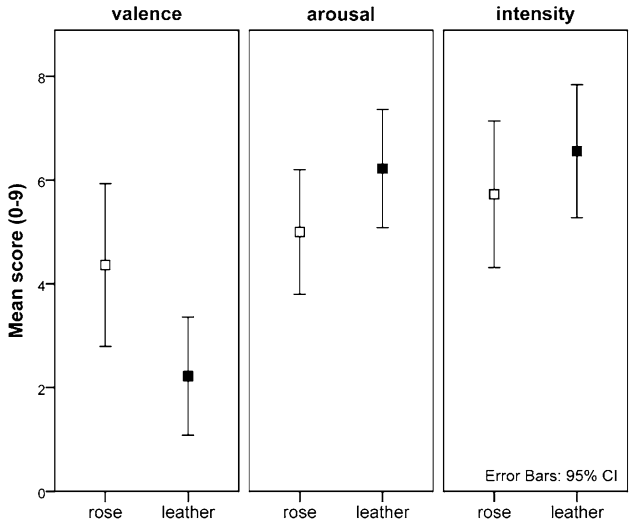

Fig. 5 Mean ratings for valence, arousal, and intensity for the two odors rose and leather. Data were collected via questionnaire (self-assessment manikin, SAM) after stimulus presentation. *Error bars* indicate the 95 % confidence interval

Table 2 Mean (SD) odor sensitivity scores measured by the COSS and the OI, separated by odor

	Odor		
	Rose noticed	Leather noticed	Not noticed
COSS	13.89 (6.27)	22.25 (7.90)	23.57 (10.26)
OI	33.13 (10.60)	39.00 (7.02)	35.92 (6.13)

COSS and IS scores. A significant main effect of odor showed for the COSS scores, $F(2, 30) = 4.17$, $p = .025$, but not for the IS scores, $F(2, 30) = 2.04$, $p = .147$. Post hoc tests (Tukey) showed that COSS ratings for the group that noticed rose was significantly lower compared to the group that did not notice the odor ($p = .020$), indicating that odor sensitivity was weaker in the rose group. All other groups did not differ significantly (p's > .05).

Pearson correlations showed weak-to-moderate (non-significant) positive correlations between the COSS and the VIMS ratings, including the peak FMS score ($r = .356$, $p = .053$), as well as the SSQ subscales nausea ($r = .319$, $p = .086$), oculomotor ($r = .243$, $p = .195$), disorientation ($r = .129$, $p = .497$), and the total score ($r = .240$, $p = .202$). The correlations between the IS scores and the MS scores ranged from −0.105 to 0.093 and clearly missed significance.

Discussion

The present study tested the effect of olfactory stimulation on the severity of VIMS. Participants were exposed to a pleasant (rose), unpleasant (leather), or to no odor while watching a video. Half of our participants failed to notice the odor. We therefore restructured our dataset and reassigned participants to four new groups, including a group that noticed the rose odor, a group that noticed the leather odor, a group that failed to notice a specific odor, and a control group that did not receive any odor. Our results showed that VIMS varied subject to the odor's valence. That is, participants reported less VIMS when they noticed a pleasant odor during the experiment compared to the participants who did not notice an odor. The unpleasant odor did not reduce VIMS significantly. Note, however, that all participants reported increased VIMS ratings after stimulus exposure, confirming the previously reported nauseating effect of the visual stimulus (Keshavarz and Hecht 2012, 2014).

To our knowledge, Paillard et al. (2014) performed the only testing of odor effects on motion sickness. Contrary to our findings, the addition of a pleasant or unpleasant odor during OVAR did not affect the occurrence of motion sickness symptoms in their study. We can think of three reasons explaining the contradicting findings: firstly, OVAR is known to be a highly powerful stimulus for inducing motion sickness (Denise et al. 1996; Quarck et al. 2000) and has been shown to be more powerful than visual stimulation (Bijveld et al. 2008; Cian et al. 2011). In fact, OVAR-induced motion sickness is possibly too strong to be alleviated by subtle behavioral countermeasures such as odors. The visual stimulus used in the present study, in contrast, produced only moderate sickness scores (FMS scores mostly below 10) and may thus have provided a better chance for odor effects to surface. Secondly, we used different odors compared to the study by Paillard et al. (rose vs. geraniol/limonene). We therefore cannot dismiss the nature of the odor as the crucial factor that reduces VIMS instead of the odor's valence. Finally, Paillard et al. used a facemask that was soaked with a pleasant or unpleasant odor, making this experimental manipulation rather conspicuous. The odor dispenser used in the present study was hidden from the participants' view, and odors went entirely unnoticed by half of our participants.

Note that before re-structuring our data, no significant difference showed between the initial groups (rose vs. leather vs. no odor). This result indicates that odors can only alleviate VIMS if they are actually noticed by the participant. Thus, odors that go unnoticed or are possibly perceived subconsciously are unlikely to affect the severity of VIMS. However, our results demonstrate the potential of pleasant odors to reduce the severity of VIMS. In the following, we will discuss two potential explanations for this finding, including a direct link between olfaction and nausea and an attributional explanation. We also take a closer look at the role of explicit odor sensitivity as a mediating factor with respect to VIMS severity.

Direct link between olfaction and VIMS

Olfactory perception follows an indirect and a direct pathway from the olfactory bulb to the orbitofrontal cortex and the olfactory cortex, respectively. The latter pathway is known to also innervate multiple regions of the brain that are involved in other processes, such as memory or emotion (see Stern et al. 2011, pp. 61–63). However, areas responsible for the genesis of nausea (e.g., area postrema and vestibular system, see Yates et al. 2014) are not known to be innervated by the olfactory pathways, and potential neural connections between nausea and olfaction are yet to be defined. However, it has been frequently noted that unpleasant odors can elicit nausea, even though the underlying mechanisms might not be fully understood. Pregnant women, for example, commonly report nausea caused by unpleasant odors. Swallow et al. (2005) collected nausea ratings of 271 pregnant women and found that of those women who suffered from morning sickness, three-fourths reported that odors (e.g., from food) were a prominent trigger for their nausea (see also Goodwin 2002). Similarly, odors can cause anticipatory nausea in some chemotherapy patients (see Bernhardson et al. 2009). These patients do not only suffer from nausea after chemotherapy treatment, but can also feel nauseated solely by the smell of the hospital where the treatment session is taking place (e.g., Fernández-Marcos et al. 1996; Kamen et al. 2014); classical conditioning has been named as the most prominent explanation for anticipatory nausea. Nevertheless, the above-listed studies all provide evidence that unpleasant odors can worsen or even cause nausea, whereas studies showing a positive and nausea-relieving effect of odors are rare. Some essential oils (peppermint) have been named as potential remedies for postoperative nausea and morning sickness in pregnant women, but the efficacy of such aromatherapies is controversial. For instance, Tate (1997) found significantly reduced postoperative nausea when peppermint oil was used as treatment, whereas a control group that received no anti-nauseating medication reported stronger nausea. On the other hand, Ferruggiari et al. (2012) studied 70 women postoperatively and treated them either with traditional antiemetic medication, with the inhalation of peppermint oil (aromatherapy group), or with the inhalation of vaporized saline (control group). The treatment was started as soon as the women reported nausea following their surgery. The authors did not find significant differences between the treatments with respect to the level of nausea.

Taken together, the above-mentioned findings and the results from the present study indicate that olfaction does arguably contribute to nausea. However, the precise mechanisms and neural links between olfaction and nausea are not understood. The present study is the first to report an alleviating effect of pleasant odors on the severity of VIMS and is meant to be thought-provoking with regard to the use of odors as a remedy against VIMS. Nevertheless, further empirical evidence in favor of (or in disagreement with) our findings is indispensable to precisely determine the role of olfaction for VIMS in the future.

Attributional effects of odor on VIMS

Only half of our participants who were exposed to a pleasant or unpleasant odor did in fact notice the odor. The failure in olfactory perception for half of the participants might be traced back to inter-individual differences in olfactory thresholds (Stevens et al. 1988; Keller et al. 2012). If the odor intensity was indeed below threshold for half of our participants,[3] then the participant who did notice the odor could have been at the advantage to let the odor offset or "explain" the initial symptoms of nausea, that is, participants in the rose condition may have focused on the pleasant emotion associated with the rose scent, which may have distracted from the VIMS symptoms. Participants in the leather condition could have attributed their first symptoms to the unpleasantness of the odor, thus weakening the link between the visual stimulus and these symptoms. Participants with a high threshold, in contrast, had failed to notice the odor, which prevented them from engaging such a mechanism. Interestingly, Paillard et al. (2011) reported that motion-sick participants had a higher olfactory threshold, which is in accordance with our finding that participants who did not notice the odor did report stronger VIMS.

Such an attribution mechanism would also explain the reduced (but not significantly so) VIMS ratings when participants noticed the unpleasant odor, compared to the group that did not notice the odor at all. This finding is quite surprising as we had expected simple additive effects of the unpleasant odor and VIMS. If perceptual threshold differences are at the heart of the effects, then the assumption of additive emotional effects may be too simple as an explanation. Likewise, a mere attentional explanation is unlikely to suffice. If odors were to act (regardless of their nature) as a distractor that draws away the participants' attention from the actual stimulus, then attention and distraction should be potential remedies against VIMS. However, they are probably not, as shown by Yen Pik Sang et al. (2003b). The authors exposed two groups of participants to a nauseating stimulus (rotating chair), asking one group to count backwards during stimulus exposure (distracted group) and

[3] Note that the threshold is likely to be one incorporating attention as we did not alert participants to the fact that there was an odor. Thus, the psychophysical threshold in a forced choice scenario could be much lower.

asking the other group to perform no further action (control group). The two groups did not differ regarding sickness severity, indicating that distraction alone is unlikely to reduce the level of motion sickness.

Interestingly, in the present study, none of the participants who noticed the odor during stimulus exposure could correctly identify the odor as rose or as leather. Most participants reported that the odor smelled like disinfection spray, regardless of whether rose or leather was presented. Although this finding might indicate that the odors that we used were possibly ambiguous and not easily determinable, we believe that the odor's *valence* is more crucial than its correct *labelling*. Our results clearly demonstrate that the severity of VIMS was alleviated by the odor that was perceived to be more pleasant, regardless of whether the subject identified it correctly as rose or not. On the other hand, this finding also indicates that odors are strongly context-related. As there was no obvious reason for participants to perceive a rose or leather odor (i.e., neither a rose nor leather equipment was visible during the experiment), participants might have attributed the odor to laboratory-related sources, such as cleaning products that are commonly used in such facilities. However, it remains to be answered by future studies how the presence of a matching object (e.g., rose or leather equipment) and, more importantly, how a distinct odor that is correctly identified as such, would affect the severity of VIMS in a similar context. Although we do not expect that a more salient odor would have a stronger impact on the severity of VIMS, further investigations are desirable.

Odor sensitivity and VIMS

Subjective ratings of valence, arousal, and intensity were collected prior to and after stimulus exposure for both rose and leather, respectively. Note that the pre-study contained exclusively a subset of participants who did not participate in the actual study. Both prior to and after the study, leather was rated as significantly less pleasant than rose, confirming that rose and leather were suitable odors for the purpose of the present study. Interestingly, rose and leather were rated as less pleasant after stimulus exposure compared to the pre-study. This finding could be due to the fact that most participants were still nauseated when they made their odor judgments after the experiment. Support for this assumption is given by Herz (2005, also Herz et al. 2004), who showed that olfactory valence responses can indeed vary subject to the emotional state in which they are perceived. In other words, if an odor is perceived in an unpleasant context (such as while feeling nauseated), it will consequently be rated as less pleasant compared to ratings of the same odor that are made in a more pleasant context. Furthermore, our results are also (at least partially) in accordance with the findings reported by Paillard et al. (2014), who reported a reduction in valence ratings regarding their unpleasant odor (i.e., petrol) after successfully inducing VIMS. Note, however, that Paillard et al. only found reduced valence ratings for their unpleasant odor, whereas the pleasant odor (i.e., limonene) was in fact rated as more pleasant after stimulus exposure. Similarly, our study only revealed significant changes regarding the odors' valence and not the odors' intensity as reported by Paillard et al. Rose and leather were judged as similarly intense both in the pre-study and after the actual experiment, dismissing odor intensity as a potential explanation for our findings.

We also measured participants' odor sensitivity using two different questionnaires, the COSS and the IO. We found moderate positive (but nonsignificant) correlations between the VIMS ratings (peak FMS score and all SSQ scores) and the COSS, indicating that participants who had higher olfactory sensitivity also reported higher VIMS scores. Interestingly, correlations were only found between the VIMS ratings and the COSS scores, but not between the VIMS ratings and the IO scores. Although both questionnaires were designed to measure general olfactory sensitivity, the COSS includes questions that are more specific for chemical components of odors (e.g., "Strong smell of paint and smoke makes me dizzy." or "Exhaust gases are very unpleasant for me."), whereas the IO focuses more on determining the importance of olfaction for daily life (e.g., "Without my sense of smell, life would be worthless." or "I sniff at food before eating it."). Interestingly, we found significant differences in odor sensitivity within our experimental groups: participants who noticed the rose odor had significantly lower odor sensitivity (i.e., lower COSS scores) compared to the other three groups. Could the exposure to a pleasant smell have increased the perceptual threshold? It has been shown that an unpleasant smell raises the attentional and/or arousal level and that a pleasant odor has an opposite effect (Colzato et al. 2014; Li and Yeh 2011; Michael et al. 2005). Such an elevated arousal might, in turn, have a negative effect on motion sickness. At this point, such a mechanism remains speculative but seems to merit further investigation.

Conclusion

The present study tested the role of olfaction as a countermeasure against VIMS. Participants were exposed to a pleasant odor (rose), to an unpleasant odor (leather), or to no odor (control group). Half of the participants failed to notice the odor and were post hoc re-assigned to a fourth group (odor not noticed). Results showed that the pleasant odor resulted in significantly less VIMS compared to the group that did not notice the odor. Experimenting with

olfaction might lead to an affordable, easy-to-assess, and non-hazardous method to alleviate VIMS.

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