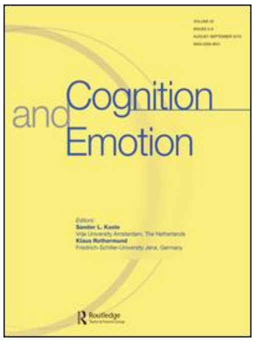

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BRIEF ARTICLE

Disgust lowers olfactory threshold: a test of the underlying mechanism

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ABSTRACT
The olfactory system provides us with rich information about the world, but the odours around us are not always detectable. Previous research has shown that disgust enhances olfactory sensitivity to *n*-butanol. Because *n*-butanol incidentally is mildly negative, it is unclear whether disgust, being a negative, avoidant emotion, enhances sensitivity to stimuli with negative qualities (valence-fit effect), or across stimuli in general (general sensitivity effect). Here we tested these competing hypotheses by examining thresholds to two scents, one positive (phenylethanol) and one mildly negative (*n*-butanol), during a disgust, happiness, and neutral emotion induction. We found that exposure to disgusting pictures lowered olfactory threshold across both scents. Thus our current results replicated the results of previous research, and also revealed support for a general sensitivity rather than a valence-fit effect. This suggests that disgust facilitates the perceptual detection of extremely faint targets presumably because avoidant emotions enhance perceptual vigilance in general.

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Disgust; threshold; sensitivity; olfaction

Emotions are functional because they provide more information about one's situation, thereby allowing individuals to respond adaptively (Levenson, 1999). Much research on the adaptive functions of emotions in perception have focused on vision, demonstrating how emotions such as disgust and/or fear adaptively increases visual contrast sensitivity, and spatial and temporal resolution (e.g. Anderson, 2005; Anderson, Siegel, Bliss-Moreau, & Barrett, 2011; Bocanegra & Zeelenberg, 2011a, 2011b; Phelps, Ling, & Carrasco, 2006; Sherman, Haidt, & Clore, 2012; Yang, Zald, & Blake, 2007). Recently, researchers (Chan, Holland, van Loon, Arts, & van Knippenberg, 2016) have also found perceptual enhancements in olfaction. In that research, participants saw disgust- or fear-inducing pictures while olfactory thresholds towards *n*-butanol were measured. The researchers consistently found that disgust and fear both lowered olfactory thresholds (increased smell sensitivity) to *n*-butanol. Although the effect was replicable, the underlying mechanism remains unclear.

There are three possible interpretations for Chan et al.'s (2016) findings. First, because the manipulated emotions, disgust and fear, are negatively valenced, it is possible that negative emotions in general lower olfactory thresholds. This interpretation is unlikely because sadness increases olfactory threshold (e.g. Pollatos et al., 2007; Schablitzky & Pause, 2014). Second, odours contain information about a particular object (e.g. food spoilage) or environment (e.g. smoke); although it is important to detect them, detection may be difficult these odours sometimes manifest in extremely low concentrations. Because disgust and fear are both avoidant emotions, these emotions lowered olfactory thresholds due to vigilance evoked by avoidant emotions to faint odours in general. We call this the *general vigilance hypothesis*.

Nevertheless, an alternative explanation remains. This interpretation hinges on the use of *n*-butanol in assessing olfactory thresholds. Although some researchers regard *n*-butanol as a neutral odour

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(Hummel, Sekinger, Wolf, Pauli, & Kobal, 1997), in our pretests, participants found it somewhat negative; this is corroborated by other researchers (Schreder et al., 2008). See the Online Supplementary Material (OSM) for more information. Because both the independent (disgust and fear) and dependent variables (scent) were negative, individuals might have a lowered olfactory threshold because the valence of the emotion matched the valence of the scent. We call this the *valence-fit hypothesis*.[1]

Research has indicated that perceptual performance is improved when the valence of one's psychological state matches that of the stimuli (Niedenthal & Setterlund, 1994). For example, when negative or neutral words were flashed on screen at threshold durations, sad participants compared to controls recognised more negative words than positive words (Powell & Hemsley, 1984; Small, 1985). However, other research has suggested that fear can improve perceptual performance even when neutral stimuli such as gabor patches (Phelps et al., 2006), grey squares/numbers (Sherman et al., 2012), and Landolt circles (Bocanegra & Zeelenberg, 2011a, 2011b) were used. Therefore, both the general vigilance hypothesis and valence-fit hypothesis could hold.

Our present research sought to disentangle these two hypotheses and also to replicate previous research (i.e. Chan et al., 2016). That is, how general is the disgust-threshold effect – does disgust improve olfactory sensitivity to various odours irrespective of the scent's valence (the general vigilance hypothesis) or only to odours that have specific valence qualities (valence-fit hypothesis)? We addressed this question by using one positive scent, phenylethanol ("rose"), and one mildly negative scent, *n*-butanol (as used by Chan et al. [2016]). Here we focused only on one avoidant emotion, disgust (i.e. fear was omitted), and contrasted its effect with two other emotions: neutral and happiness. A happiness condition was included to allow a second and stronger test of the valence-fit hypothesis. That is, if the valence-fit hypothesis holds, then *n*-butanol thresholds would be lowered only in the disgust condition and phenylethanol threshold would be lowered only in the happiness condition. However, if the general vigilance hypothesis holds, olfactory thresholds would be lower in the disgust condition compared to the neutral and happiness conditions, irrespective of the odour's valence. Also, the general vigilance hypothesis would not predict any effect of the happiness induction on olfactory thresholds.

Method

Participants and design

Sixty non-anosmic participants (48 females) were recruited from Radboud University. Their mean age was 21.4 ($SD = 2.2$). All participants abstained from smoking, drinking alcohol or coffee, and eating 1 h before the experiment. The sample size needed to achieve 80% power for the contrast between disgust and neutral conditions for *n*-butanol was 35 ($d = 0.49$,[2] dependent samples *t*-test, two-tailed), but because we did not know the effect size for phenylethanol, we recruited more participants. Our current sample size has 96% power to detect the disgust vs. neutral conditions contrast for *n*-butanol.

We used a 3 (Emotion: disgust [D], neutral [N], and happiness [H]) × 2 (Scent type: *n*-butanol, phenylethanol) fully within-participants design. Participants were randomly assigned to one of the six emotion counterbalanced orders (DNH, DHN, NDH, NHD, HDN, HND); within each emotion order, half of the participants were tested with *n*-butanol first, and the other half with phenylethanol first.

Procedure

Our procedure followed Chan et al. (2016) closely, with two exceptions: the inclusion of the happiness condition and the use of phenylethanol in addition to *n*-butanol. Hence, we next report the procedures briefly; interested readers may refer to the OSM for details.

We assessed olfactory threshold with only the threshold battery of Sniffin' Sticks (Hummel et al., 1997). Pictures were used to manipulate emotions. A separate sample of 11 participants (6 female, $M_{age} = 22.45$, $SD_{age} = 1.57$) rated the 33 neutral pictures (e.g. office stationery), 36 happy pictures (e.g. babies and puppies) and 33 disgusting pictures of contaminated food-items on pleasantness, using a scale ranging from 1 (*Not at all*) to 7 (*Definitely*). Happy pictures were rated as significantly more pleasant ($M = 5.80$, $SD = 0.49$) relative to Neutral pictures ($M = 3.99$, $SD = 0.22$), $F(1, 10) = 171.38$, $p < .001$, $d = 4.75$, which were in turn rated as significantly more pleasant relative to disgust-inducing pictures ($M = 1.54$, $SD = 0.36$), $F(1, 10) = 779.15$, $p < .001$, $d = 8.17$.

Olfactory threshold was assessed intermittently within the emotion manipulation. Emotions and scent type were manipulated in blocks. On each trial

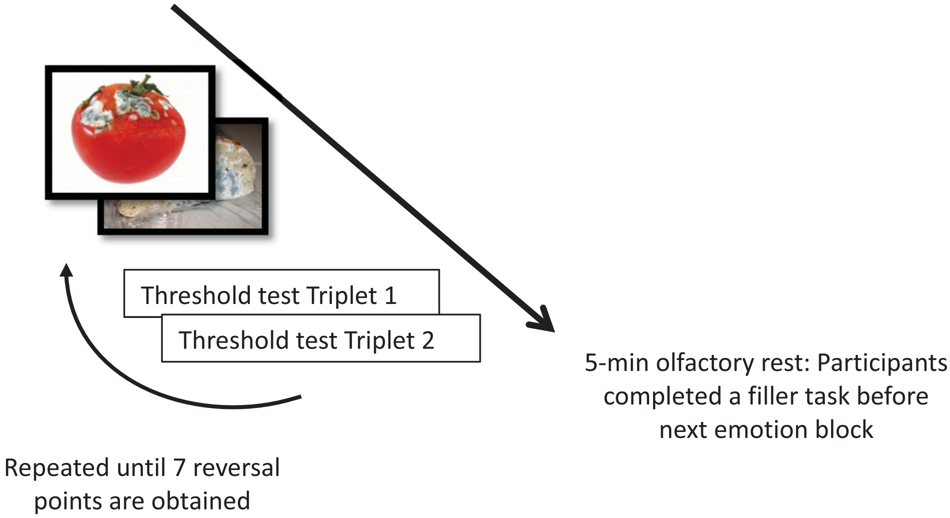

Figure 1. Procedure of our experiment for the disgust block.

participants viewed two pictures (5 s each), followed by two rounds of olfactory threshold assessment. In each round, participants sniffed one triplet of odour-infused Sniffin Sticks and had to discriminate the stick containing the target odourant (*n*-butanol or phenylethanol) from two other blanks. See Figure 1. The olfactory assessment began with the faintest target stick and the concentration of subsequent target sticks depended on the participant's response (adaptive descending staircase paradigm): If the participant's response was incorrect, the next triplet would contain a more concentrated target odorant; if the response was correct, the next triplet would contain a lower concentrated target odorant. The two-pictures-two-sniffing rounds trials repeated until seven reversal points (correct-to-incorrect and incorrect-to-correct responses) were obtained. Threshold was computed as the mean of the last four reversal points, where a score of 1 denotes lowest sensitivity (highest threshold) and 16 denotes highest sensitivity (lowest threshold). Although it is possible that participants knew what the manipulation, measurement, or hypothesis were about, it is unlikely that such knowledge compromised our results. This is because while being blindfolded, participants had to choose one of three sticks (three-alternative forced-choice) that smelled different, and odour concentration was adjusted on every trial based on participants' previous response. These features made it extremely difficult to guess what the correct response on each trial was.

Lastly, participants completed a manipulation check: they sniffed a blank stick, Stick #2 (high concentration) of phenylethanol and *n*-butanol, all separately and in a randomised order; they then completed valence ratings of each odour from (1) *Not at all pleasant* to (7) *Highly pleasant*. Then, participants completed demographic measures and the Disgust Sensitivity Questionnaire (Van Overveld, de Jong, Peters, & Schouten, 2011; overall Cronbach's alpha = .79), which measures the tendency to experience disgust in daily life. The prime × disgust sensitivity analysis appears in OSM: C. Participants were finally thanked and debriefed.

Results

Scent valence manipulation checks

The valence rating for the neutral blank ($M = 4.05$, $SD = 0.85$) did not differ from the midpoint (i.e. 4.0) of the scale, $t(59) = .42$, $p = .67$. Compared to the neutral blank, phenylethanol smelled more positive ($M = 4.72$, $SD = 1.77$), $F(1, 59) = 12.7$, $p = .001$, $\eta_p^2 = .17$, whereas *n*-butanol smelled more negative ($M = 3.38$, $SD = 1.56$), $F(1, 59) = 7.49$, $p = .008$, $\eta_p^2 = .11$; hence the difference in valence between phenylethanol and *n*-butanol was strong, $F(1, 59) = 15.9$, $p < .001$, $\eta_p^2 = .21$.

Because the scent valence manipulation check was conducted after the sixth experimental block, we also included other independent variables (i.e. Scent order and Emotion order) in our analyses on valence. The main effects of Scent order and Emotion order on valence, $Fs < 0.60$, $p > .70$, on scent valence were nonsignificant. We also found no significant Scent type × Scent order × Emotion order interaction, or Scent type × Emotion order interaction, $Fs(10, 94) < 1.24$, $ps > .27$, on scent valence. We did, however, find an unanticipated Scent type × Scent order interaction, $F(2, 47) = 10.51$, $p < .001$; when thresholds for *n*-butanol were assessed first, the valence ratings for *n*-butanol ($M = 2.67$, $SD = 1.42$) were lower as compared to the neutral blank ($M = 4.23$, $SD = 0.56$) and phenylethanol ($M = 5.33$, $SD = 1.18$), $ts(29) > 5.63$, $p < .001$. However, when thresholds for phenylethanol were assessed first, the valence ratings for *n*-butanol ($M = 4.10$, $SD = 1.81$), neutral blank ($M = 3.83$, $SD = 0.59$), and phenylethanol ($M = 4.10$, $SD = 1.68$) did not differ significantly, $ts(29) < 0.87$, $ps > .39$.

To establish that the valence of the scents were indeed different, an independent sample of 41 individuals rated the valence of *n*-butanol, phenylethanol, and the neutral blank in a counterbalanced order. This time, no Scent type × Scent order effects were found, $F(10, 66) = 1.51$, $p = .16$. However, the valence of *n*-butanol ($M = 2.46$, $SD = 1.09$) was still significantly lower than the valence of the neutral scent ($M = 3.36$, $SD = .99$), $t(39) = 7.39$, $p < .001$, which was in turn lower than the valence of phenylethanol ($M = 4.56$, $SD = 1.31$), $t(39) = 2.81$, $p < .001$.[3]

Main analyses

We first performed a 3 (Emotion: Disgust, neutral, and happiness) × 2 (Scent type: *n*-butanol vs. phenylethanol) × Disgust sensitivity (continuous factor: linear covariate) × 6 (Emotion order) × 2 (Scent order: *n*-butanol first vs. phenylethanol first) mixed analysis of covariance (ANCOVA) with Emotion and Scent type as within-participant factors and Disgust sensitivity as covariate. The sphericity assumption was not violated, Mauchly's $W = .92$, $\chi^2(2) = 3.61$, $p = .16$. Neither Emotion order nor Scent order produced any main or interacting effects, all $Fs < 1.80$, $ps > .12$, $\eta_p^2 < .12$. Hence, subsequent analyses were collapsed across Emotion orders and Scent orders.

A 3 (Emotion) × 2 (Scent type) × Disgust sensitivity (continuous factor: linear covariate) mixed ANCOVA was performed. Because variances in thresholds were systematically larger in phenylethanol than in *n*-butanol (see Figure 2), Mauchly's $W = .89$, $\chi^2(2) = 6.90$, $p = .03$, we report Greenhouse-Geisser corrections when comparing means between scents. There was no main effect of disgust sensitivity, $F(1, 58) = .61$, $p = .44$, $\eta_p^2 = .10$, no three-way interaction, $F(1.80, 104.13) = .35$, $p = .68$, $\eta_p^2 = .006$, and no two-way interactions of disgust sensitivity with Scent type, $F(1.80, 104.13) = .41$, $p = .53$, $\eta_p^2 = .007$, or disgust sensitivity with Emotion, $F(1.90, 104.13) = 1.43$, $p = .24$, $\eta_p^2 = .02$.

The crucial test of the valence-fit hypothesis, the Emotion × Scent type interaction, was nonsignificant, $F(1.79, 105.82) = .85$, $p = .42$, $\eta_p^2 = .01$ (see Figure 2). Bayesian analysis is especially suited to quantify the evidence for this null hypothesis. We used JASP's (JASP Team, 2018) Bayesian ANOVA, which implements five models (null model, main effect of emotion, main effect of scent, main effects of emotion + scent, and emotion × scent interaction); the prior on the fixed effect was set to 0.5. This default prior is sensible because both the valence-fit and general vigilance hypotheses are possible. The JZS Bayes factor

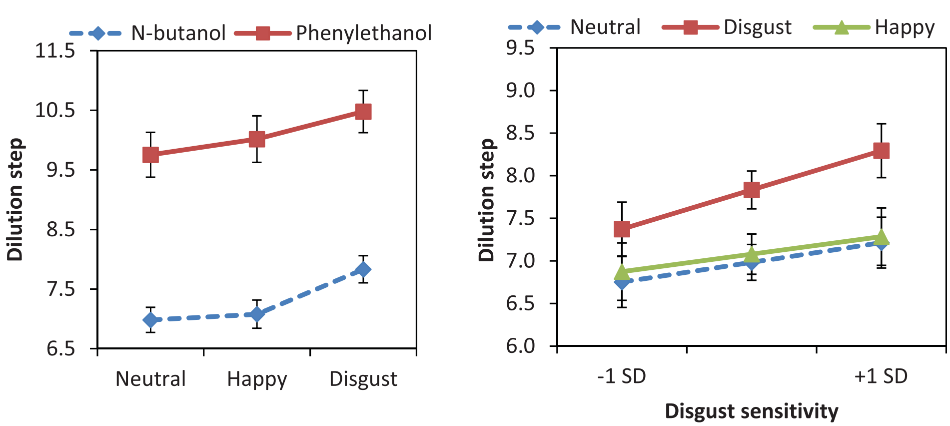

Figure 2. Results of emotion and scent type on thresholds (A), and emotion and disgust sensitivity on *n*-butanol threshold (B). A higher dilution step means a lower threshold. Error bars depict standard errors.

(including the interaction term vs. just having the two main effects in the model) is $BF_{01} = 16.7$, indicating that the data were more likely to be observed under the null than under the alternative hypothesis. This is substantial evidence that the interaction does not explain additional variance. Because the valence manipulation check did not uphold in all scent order conditions, the valence-fit hypothesis was tested within each scent order condition. In none of the scent order conditions was the Emotion × Scent type interaction significant, $Fs(2, 28) < .34$, $ps > .67$, $\eta_p^2 < .03$.

The critical test for the general vigilance hypothesis is the main effect of emotion, which was significant, $F(1.88, 105.82) = 24.9$, $p < .001$, $\eta_p^2 = .30$. Follow-up analyses revealed that exposure to disgusting pictures lowered thresholds compared to exposure to neutral, $F(1, 59) = 41.83$, $p < .001$, $\eta_p^2 = .42$, and happy pictures, $F(1, 59) = 23.4$, $p < .001$, $\eta_p^2 = .28$; thresholds in the Neutral and Happiness conditions did not differ from each other, $F(1, 59) = 3.09$, $p = .08$, $\eta_p^2 = .05$. There was also a main effect of Scent type, $F(1, 59) = 43.9$, $p < .001$, $\eta_p^2 = .42$, but this is uninteresting because thresholds differ among odorants. Importantly, for each scent order, the main effects were significant in both scent orders, $Fs(2, 28) > 4.55$, $ps < .02$, $\eta_p^2 > .25$, and the comparisons between emotion conditions were likewise the same: exposure to disgusting pictures lowered thresholds compared to exposure to neutral, $Fs(1, 29) > 9.42$, $ps < .005$, $\eta_p^2 = .25$, and happy pictures, $Fs\ (1, 29) > 4.11$, $ps < .05$, $\eta_p^2 = .12$; thresholds in the Neutral and Happiness conditions did not differ from each other, $Fs(1, 29) < 1.41$, $ps > .20$, $\eta_p^2 < .05$. Taken together, despite the unsuccessful manipulation check in one of the scent order conditions, the valence-fit hypothesis is rejected in both scent orders and the results are consistent with the general vigilance hypothesis in both these conditions. Just as important, these set of results also replicated the main findings of Chan et al. (2016) who found that disgust lowered olfactory threshold to *n*-butanol.

Discussion

In summary, we found that exposure to disgusting pictures decreased thresholds to *n*-butanol (a mildly negative scent) and phenylethanol (a positive scent). Exposure to happy pictures did not affect thresholds to either scent. These results suggest that exposure to disgusting pictures facilitates the perceptual detection of extremely faint olfactory targets not because the negativity of disgust is compatible with the negativity of the olfactory target, thus ruling out the valence-fit hypothesis. In fact, by comparing thresholds of a positive and mildly negative scent across exposure to positive, negative, and neutral emotional stimuli, our design constituted a stringent test of the valence-fit hypothesis. Our current research clarifies the underlying mechanism behind how disgust enhances olfactory sensitivity, and our results are hence consistent with the idea that disgust triggers a general perceptual vigilance towards environmental olfactory cues (i.e. the general vigilance hypothesis).

Rejecting the valence-fit hypothesis does not mean that the general vigilance hypothesis is the only acceptable alternative. One reason is because neither our current nor previous research (Chan et al., 2016) is able to rule out the role of arousal. As such, future research may manipulate anger (negative, high arousal emotion), or erotic arousal. If the arousal hypothesis holds true, then anger and erotic manipulation would decrease the threshold. Another reason is that level of induced disgust (seeing a visual stimuli on screen) could be low; this is because our pretest manipulation checks required participants to rate the disgust stimuli on “pleasantness”, rather than on disgust specifically. Hence it is unclear how much disgust and/or fear were induced, even when the disgust-inducing stimuli were similar to that of past research (e.g. Curtis, Aunger, & Rabie, 2004). Future research may consider using more visceral manipulation (e.g. touching slimy stuff) and more specific manipulation check measures. Finally, our experimental design was not set out to confirm the general vigilance hypothesis specifically, though results are certainly consistent with the general vigilance hypothesis. This is because the general vigilance hypothesis entails three aspects of generality: between emotions, within modality, and between modalities. Fully testing these aspects of generality would require various manipulations beyond the scope of this research. Next, we elaborate various ways future research may follow-up from our current work.

First, we exposed participants to pictures related to disgust, an avoidant emotion. Although previous research has found that fear, another avoidant emotion, lowers threshold to *n*-butanol (Chan et al., 2016), it is unknown whether this effect extends to phenylethanol. Future research may wish to investigate this. Hence, until more avoidant emotions are tested, we will not know if the general vigilance hypothesis applies to all avoidant emotions. Second, within the olfactory modality, "general vigilance" may imply that exposure to disgust stimuli should enhance olfactory sensitivity to many scents, not just two scents. Our aim was not to show how general the effect of exposure to disgust stimuli on different scent thresholds is. We carefully chose two scents that differ in valence because this allowed us to examine which of two competing hypothesis was a better explanation for previous research (Chan et al., 2016). It was crucial that we used *n*-butanol and not other disgust-evoking odours (e.g. putrescine) because substituting *n*-butanol with another odorant would not answer the doubts cast by Chan et al.'s (2016) research. However it remains an open question to what extent our findings generalise across all scents. Future research may test additional scents of various characteristics (e.g. positive vs. negative, food vs. nonfood, etc.) to explore how our effects might generalise across different scents.

Third, the question about generality between modalities is more feasible to answer. Here, "general vigilance" may imply that exposure to disgust stimuli should enhance sensitivity across perceptual modalities. Previous research revealed that disgust lowered threshold in visual perception (e.g. Sherman et al., 2012), and we extended this work to olfaction. It is interesting to test whether disgust might also lower thresholds across other sensory modalities. However, one must note that a functional perspective of emotions must work in tandem with a functional perspective of a particular perceptual modality. Because a major function of disgust is to help the organism avoid pathogens (e.g. Tybur, Lieberman, Kurzban, & DeScioli, 2013), it is useful for an organism in a disgust state to be able to detect subtle traces of pathogens. Pathogenic objects (e.g. rotten food) often have distinctive visual appearance, smell, taste, and tactile feel that signal possible spoilage, but pathogenic objects do not have distinctive sounds. Hence there may be strong evolutionary associations between disgust and vision, olfaction, gustation, and somatosensation, but not between disgust and audition. As such, disgust may also lower gustatory and haptic thresholds but not auditory thresholds.

To conclude, the current research bolsters the idea that avoidant emotions lower olfactory thresholds, for positive and mildly negative smells. However it may be too simplistic to assume that avoidant emotions such as disgust and fear lower thresholds to all sensory modalities without considering why it would be adaptive for that particular sensory modality to have a lowered threshold. Further research is needed to determine how general the effect of avoidant emotions is on perceptual vigilance, between more scents types, and between sensory modalities.

Notes

1. It is also possible to conceptualize this as a "motivational orientation-fit" hypothesis (see Higgins, 2005) if the focus is on the avoidant nature of disgust instead of its valence.
2. This was the average effect size the disgust vs. neutral conditions in Chan et al. (2016).
3. The diagnosticity of the scent valence manipulation checks may be limited when such checks are obtained after 10–15 mins of threshold measurements. When individuals rated the valence of one or more target scents after one or several blocks of threshold measurements, it was unclear how carryover effects and prolonged sniffing changed individuals' evaluation of the scent. As such, the original order effects in the scent valence evaluation could be accidental. In any case, the threshold effects were found within each scent order (see Results). Hence the order effect in scent valence ratings does not threaten our conclusions about the valence-fit hypothesis.

Author contributions

All authors designed the experiments. R.v.D ran the experiment. R.v.D. and K.Q.C. analysed the data. K. Q. C wrote the manuscript. R.W.H. and A.v.K. provided critical revisions to the manuscript.

Disclosure statement

No potential conflict of interest was reported by the authors.

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