Background odors affect behavior in a dot-probe task with emotionally expressive faces

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Odors affect perception of social cues in visual environments. Although often underestimated, people use their sense of smell to guide approach or avoidance behavior in social contexts. However, underlying psychological mechanisms are not well known. Prior work suggested olfactory effects are due to increased attention or arousal, or depend on the congruency between olfactory and visual cues. Our aim was to assess how odors influence attentional processes using a dot-probe task with odor-congruent and odor-incongruent facial expressions (happy, disgusted and neutral expressions paired with pleasant odor, unpleasant odor and no-odor). In a preregistered analysis plan, we hypothesized either faster reaction times attributed to arousal from odors in general, or to faces that were emotionally congruent with the odors. We also hypothesized time-on-task effects specific to the odor compared to the control condition. Using Bayesian linear models, we found strong evidence that the faces were rated as more arousing and emotional in odor contexts. However, the dot-probe task did in fact not provide an effective cue to selective visual attention, and odors did not modulate overall attention to the faces. However, we found a time-on-task effect such that in the unpleasant odor condition, response times decreased over time, whereas in the no-odor and pleasant condition there was a slight increase in response times. We conclude that time-on-task effects is an interesting venue for odor-visual interaction research, and such effects might explain inconsistent findings in the prior research literature.

AFFECTIVE ODORS; FACIAL EXPRESSION; EMOTION; REACTION TIME

1.1. Introduction

In everyday life, information through multiple senses influence our perception and behavior. Olfaction, although often an overlooked sense, may be involved in more ways than previously thought. Especially body odors may be powerful at affecting social perceptions. Information such as gender, personality, friendship and disease can be extracted from other people's body odors (Lundstrom, Boyle, Zatorre, & Jones-Gotman, 2008; Olsson et al., 2014; Sorokowska,

Sorokowski, & Szmajke, 2012). In this study, we were interested in if odors shape visual attention to emotional facial expressions, which are socially relevant cues.

Body odors convey socially important information. Throughout the ages, people have used perfume and soap to successfully mask or modify their body odor (Classen, Howes, & Synnott, 2002; Lenchova et al., 2012). It is not well known what specific compounds in body odors cause behavioral effects, and a complicating matter is that these effects might be context dependent (Lundström & Olsson, 2010). When investigating the affective properties of body odors, these are collected from individuals that are subjected to a condition that the odor is thought to elicit in the receivers, for example sweat from fear induced donors (de Groot, Smeets, Kaldewaij, Duijndam, & Semin, 2012). However, the exact chemical compound that signal the emotion specific information is often unknown. As an alternative to actual body odor, valeric acid has an unpleasant smell that is often used as a substitute for human sweat (Bensafi, 2002; de Araujo, Rolls, Velazco, Margot, & Cayeux, 2005). Valeric acid is one of the main sources of smelly feet and halitosis (Kanda et al., 1990; Scully & Greenman, 2012) and is a disease biomarker in human sweat (Shirasu & Touhara, 2011). Disease cues are thought to engage the behavioral immune system (BIS; Schaller & Park, 2011) by evoking disgust. Disgust influences attentional mechanisms and avoidance behavior toward the source of disgust (Regenbogen et al., 2017; Tybur, Frankenhuys, & Pollet, 2014). Further, images of disgusted faces activate similar cortical areas as evoked by disgusting odors (Wicker et al., 2003). Lilac, although not a body odor, is a positive odor that connotes to bodily cleanliness because it is commonly used in soaps and detergents (Surburg & Panten, 2016). In the present study, we used valeric acid and lilac, ecologically valid odors of opposing valences (pleasant and unpleasant) coupled with facial expressions (happy, disgusted and neutral) to investigate odor effects on visual attention.

Facial perception is often affected by odor contexts. Cook et al. (2017) showed that the rated valence of faces is affected by congruent odors; disgusted faces were rated as more negative in an unpleasant odor context and happy faces were rated as more positive in a pleasant odor context. However, this specific interaction has not been found in other studies (Cook et al., 2015; Cook et al., 2018; Syrjänen et al., 2018). In general, results indicate that affective odors affect valence ratings of faces regardless of their expression (e.g. unpleasant odors cause all facial expressions to be perceived more negatively). Arousal ratings show similar general effects, as faces are rated as more arousing in both pleasant and unpleasant odor conditions regardless of expression (Cook et al., 2015; Syrjänen et al., 2018), although in our prior work

(Syrjänen et al. (2018) happy faces perceived during exposure to an unpleasant odor (incongruent condition) were rated as less arousing. These results indicate that odors might affect subjective evaluations of faces either by stimulus congruence-specific effects, or by unspecific effects in the valence and arousal dimensions.

Objective measures such as facial expression recognition speed have provided results that facial expressions are recognized faster in an unpleasant odor context (Syrjänen, Liuzza, Fischer, & Olofsson, 2017), indicating that unpleasant odors may increase arousal, benefitting behavioral speed. This fits within a behavioral immune system framework where disease cues, such as an unpleasant odor, causes increased vigilance to environmental cues (BIS; Schaller & Park, 2011). Some studies have shown unspecific effects of valenced odors; in Seubert, Loughhead, et al. (2010) facial expression in general were recognized faster in both pleasant and unpleasant odor conditions. However, in a similar study by Seubert, Kellermann, et al. (2010), there was a general decrease in RTs for disgusted faces only. These results are in line with prior work suggesting that odors may decrease response latencies in an unspecific manner, highlighting the arousing effects of odors (Millot, Brand, & Morand, 2002). Lastly, in Leppanen and Hietanen (2003), happy faces were recognized faster specifically in the pleasant odor condition, suggesting that congruent information from several sensory sources facilitate stimulus processing (see also Olofsson, Syrjanen, Ekstrom, Larsson, & Wiens, 2018). These results indicate that overall arousal properties, as well as specific odor-face emotional congruencies may affect behavioral responses, but that unknown factors, for example subtle experimental context effects, may additionally shape how odors impact face responsivity via the general arousal and specific congruency pathways.

In the visual domain, the standard method to measure attentional bias toward threat-related information is the visual dot-probe task. In this paradigm, two visual stimuli are presented concurrently on either side of a computer screen while participants keep their fixation in the middle of the screen. After 500 ms the pictures are removed and “behind” one of these, a dot is present. The participants indicate which side the dot appears on. If participants are faster at responding to the dot when it is behind a specific type of stimuli (e.g. emotional faces vs. neutral) then this is regarded as attentional bias toward this type of stimuli (Holmes, Bradley, Kragh Nielsen, & Mogg, 2009).

A few studies have investigated odor effects in the dot-probe task. One study using odors and visual objects showed congruency effects on accuracy (Chen, Zhou, Chen, He, & Zhou, 2013).

The authors proposed that odors may broaden visual attention to other objects or a larger visuo-spatial area. A reanalysis of these RT data, obtained via personal communication with the authors, also indicated general arousal effects manifested in fast RTs in the odor condition. So far, only a few studies have investigated the link between odors and facial emotion on the dot-probe task and the effects of spatial attention (Forscher & Li, 2012; Hornung, Kogler, Wolpert, Freiherr, & Derntl, 2017). In a recent study, Forscher and Li (2012) used rose oxide and pine resin as neutral odors, and valeric acid and hexanoic acid as negative odors. The results indicated, somewhat unintuitively, that response latencies were longer for fearful faces in the left visual field in the negative odor condition. Another study found no evidence for attentional effects on faces in the dot-probe task using the human body odor component androstadienone, a compound that has been suggested to affect mood states and attentional processes (Hornung et al., 2017). It should be highlighted that the facial expressions in these studies did not directly match the odor-evoked emotions, as fearful and angry faces were used, whereas unpleasant odors typically elicit disgust (Ferdenzi et al., 2011).

The results in this study will inform whether odors may direct attention toward affective facial expressions, and provide some clues on the mechanism behind odor effects on facial perception, whether it is driven by general arousal effects (faster RTs odor vs no odor conditions), signs of behavioral immune system activation, signaled by decreased response latencies in the unpleasant odor condition, or congruency effects (faster RTs to dot-probes when facial emotion and odors match). Data from an independent experiment in our lab suggested time-on-task effects. In this experiment, response speed became faster over time during odor exposure compared to the no-odor control condition. In this study, we wanted to test four hypotheses, defined in a preregistered analysis strategy, on how odors affect facial perception. First, if arousal effects, measured as decreased response times, will be present in odor conditions compared to a control no-odor condition. Second, whether unpleasant odors lead to faster response times. Third, if odors direct spatial attention when odor and face stimuli are emotionally congruent. Fourth, whether response-times are modulated by time-on-task in a general, or odor-specific, manner.

2. Methods

We recruited 42 participants from an undergraduate subject pool. Of these participants, one was removed for lack of task compliance (hit rate at chance level) and one participant was removed because of an odor stimulus error. Thus, in total 40 participants consisting of 22

females (55%) and at a mean age of 26.2 (SD = 6.82) years constituted the final sample that all analyses are based on. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the regional ethics board 2017/2277-32 (www.epn.se/stockholm).

In this preregistered study, sample size was beforehand determined to consist of a minimum of 40, and a maximum of 60 participants, based on previous experiences. We did not employ an optional stopping rule; the final sample size was determined pragmatically, by our limited time and resources. In a previous study investigating odor effects in dynamic faces on RTs, only 21 participants were enough for decisive Bayes factors (Syrjänen et al., 2017). We opted for a larger sample size in the present study to get a more precise estimate of the effect size.

After signing an informed consent, participants completed a form with demographic questions. The participants were briefed about the general motivation of the experiment, the structure of the experiment, the various tasks, and what type of feedback they would be given upon completion of the experiment. The experiment was performed in a well-ventilated room and consisted of three separate blocks, each block differed only in odor context, for each block a set of 10 unique male and 10 unique female actors were randomly assigned to avoid potentially unknown effects of the visual stimulus, after each block there was a 3-5-minuter resting period to avoid odor contamination between blocks.

2.1. Stimuli

The visual stimuli consisted of pictures of faces from 60 actors (30 female) from the KDEF database (Lundqvist, Flykt, & Öhman, 1998), expressing happiness, neutral emotion, and disgust. All pictures were converted to grayscale, an ellipse with a uniform gray background was added to hide hair and ears of the actors, and lastly, the line between the face and background was blurred using the command line tools in ImageMagick ("ImageMagick," 2017). In addition, the Matlab toolbox SHINE (Willenbockel et al., 2010) was used to adjust the images so that the luminance was matched between them. For each block a set of 20 (10 female) unique actors were randomly assigned to avoid stimulus effects. On each trial, one face stimulus was shown on each side of a central fixation cross, and one face had an emotional expression. Each picture combination (i.e. neutral + emotional) was shown 4 times to balance the side of the dot-probe, and the side of the emotional expression (dot-probe presented on left and right sides, behind neutral and emotional facial expressions). Stimuli were presented in three blocks, each consisting of 160 trials and separated by a brief pause. The stimulus blocks

corresponded to three different odor conditions: No odor, lilac odor (Stockholms Eter & Essencefabrik), and valeric acid odor (Sigma-Aldrich). The unpleasant (valeric acid) and pleasant (lilac essence) odors were carefully diluted with a nearly odorless solution (Propylene glycol, 1,2-propanediol 99%, Sigma-Aldrich). Based on previous psychophysical investigations, we used a concentration of 30% for both odors, which represents moderate intensity (Syrjänen et al., 2018). In the present study, odor exposure was achieved through placing odorized cotton pads in an elastic cotton tube that was attached under the nose of participants, as in our previous studies (Syrjänen et al., 2017; Syrjänen et al., 2018). A blank cotton pad was used in the “no-odor” control condition. All subjects were exposed to all three odor conditions, and the order of odor exposure, as well as the order of stimuli within each block, were fully randomized.

In a separate validation experiment, we asked an independent participant sample ($n=35$), to rate both the lilac and valeric acid odors on several dimensions. The results confirmed that at equal concentrations the odors were well matched in intensity ratings, but differed predictably in terms of valence. Importantly, we also asked the participants to match the odors with facial expressions; predominantly, valeric acid was most strongly associated with a disgusted expression, and, lilac was most strongly associated with a happy expression, validating our notion of odor-face congruency (for complete details, see attached supplementary materials).

2.2. Procedure

The experiment was divided in three blocks with different odor contexts outlined in Figure 1. Each block consisted of four different tasks, in order of appearance:

- Rating the odor valence and intensity
- Performing the dot-probe task
- Rating the odor valence and intensity again
- Rating the arousal and valence of each of the faces shown during the dot-probe

Dot-probe task

Rating task

Figure 1. The upper panel describes the dot-probe task and the lower panel the rating tasks. Note that in the odor rating task, the words “rate the odor” were used instead of faces in the visual display.

Before starting the experiment, the experiment was described in detail and then practiced. Ratings of odor valence and arousal were performed on a SAM-scale (Bradley & Lang, 1994). The dot-probe task was based on standard procedures and stimulus durations used in previous research such as Holmes et al. (2009) and Hornung et al. (2017). Each trial in the dot-probe task consisted of a fixation cross at the center of the screen, and participants were instructed to keep their gaze on it for the complete duration of each trial. The fixation cross was flanked on both sides of two pictures of faces, one neutral and one emotional (either happy or disgusted), these pictures were removed after 500 ms, and behind one of these a dot was present. The task of the participant was to respond to whether the dot appeared on the left or right side. After 500 ms, the dot was removed, responses outside of the appearance of the probe and 1000 ms after the removal of the probe were considered as misses. To reduce predictability, a random wait interval (0-200 ms. in steps of 50 ms.) was added to the end of each trial. After the dot-probe task participants rated the odor valences, and then the valence and arousal of all face stimuli, using the SAM-scale (Lang, Bradley, & Cuthbert, 2008).

2.3. Analysis

To account for response accuracy, we calculated the percentage correct responses for each participant and odor condition. As we did not have any prior expectations of odor effects on accuracy, and as performance was near ceiling 97.8% (SD = 2.52), we didn't analyse these results further. For the dot-probe task, the first trial was associated with longer RTs compared to following trials. We removed the first trial in all blocks from each participant to increase the robustness of our data, but no statistical conclusions were affected by this removal. Further, we removed responses within 200 ms of dot-probe onset and responses occurring 1000 ms after probe onset (<1% of trials; the lower limit was erroneously described as 100 ms instead of 200 ms in the pre-registration, but this difference had no effect on results). All RT analyses were performed on correct trials only.

We used the linear models (lmBF) function in the BayesFactor package in R to calculate BFs for each of our hypotheses. In each statistical test, we considered participants and actor as random effects. In all models, we compared main effects and interaction models versus subject only model (i.e. variance explained by experimental manipulations or individual differences). Specifically, for odor ratings we modelled the interaction and main effects of odor and time for both valence and arousal ratings. We performed similar analysis for face ratings with the addition of the variable facial expression. Lastly, similar analyses were performed for the dot-probe task with the addition of the variable probe location. We interpret the size of BFs according to the recommendations of Raftery 1995 as referred to by Jarosz and Wiley (2014). An advantage of Bayes factors is that they may provide positive evidence for either the null or for the alternative model. In addition, compared to traditional null hypothesis significance testing (NHST) results, BFs provide the relative likelihood of the models, thus the larger a BF, the stronger evidence it provides for an effect (in contrast, in NHST, a p -value of .001 is not "more significant" than $p = .05$, strictly speaking the alpha level reflects a binary decision to reject the null hypothesis). To illustrate the effects, we computed posterior distributions with 100000 iterations. We used these posterior distributions to calculate 95% credible intervals (CIs). To test specific hypotheses, we performed order restriction analyses as suggested by Morey and Wagenmakers (2014). In this type of analysis, the posterior distribution is used to calculate how common a specific pattern of result is (e.g. pleasant odor is rated as more positive than the no-odor that is rated as more positive than the unpleasant odor), the Bayes factor of the order restricted model can then be compared with other Bayes factors.

One of the strengths of using Bayesian inference is that prior knowledge may be used in conjunction with the obtained data, the BFs thus reflects how much your prior belief was

shifted (strengthened or weakened) by the results. We used a preregistered Cauchy prior scale of .2 (indicating that we expected small effects) for the alternative hypothesis to define our prior belief about the possible effect sizes. A Cauchy prior provides a good alternative to a completely uninformative prior. In addition, it has some desirable properties (namely, scale invariance, consistency, and consistency in information) that motivate its use in the BayesFactor R package (Rouder, Morey, Speckman, & Province, 2012). A Cauchy prior has fatter tails than a normal, thus allowing for more extreme observations. Defining a Cauchy prior scaling factor allows to have more or less diffuse prior beliefs on the parameters under the alternative. Following the current standards, we use subscripts on BF to refer to the models compared. Accordingly, the BF for the alternative relative to the null is denoted BF_{10} , while the BF for the null relative to the alternative is denoted BF_{01} .

To further the cumulative progress of science and help in establishing reproducible results and aid in future meta-analyses we provide full experimental data and analysis scripts including the preregistration at the following url: will be available upon publication.

3. Results

3.1. Manipulation checks

We started by testing whether our odor manipulation worked as intended. The results for valence ratings showed that a main effects model was very strongly preferred over the subject only model ($BF_{10} > 150$), indicating that valence ratings were affected by the odors, and this model was more than 150 times more likely than the alternative model. We further performed an order restriction analysis to ensure that the odors ratings were in the predicted direction. The results provided very strong evidence ($BF_{10} > 150$), indicating that the pleasant odor was rated as more positive than the no-odor which in turn was rated as more positive than the unpleasant odor, this relationship is illustrated in Figure 2. As odor adaptation might explain the presence or absence of effects, we also tested the effect of odor ratings over time, and found that a main effects model was very strongly preferred over the interaction model ($BF_{10} > 150$), indicating that changes in odor valence between first and second rating was trivial.

Figure 2. The left panel shows the median valence ratings and 95% credible intervals (CIs) computed from the posterior distribution. The panel on right hand side shows the median arousal ratings with 95% CIs.

We performed similar analyses for the arousal ratings of the odors. We found very strong evidence in support of odors affecting the odor arousal ratings ($BF_{10} > 150$). We also performed an order restriction analysis on the posterior distribution by comparing the two odor conditions against the no-odor control condition. The results showed very strong evidence ($BF_{10} > 150$), that the pleasant and unpleasant odors were consistently rated as more arousing than the no-odor condition, this effect is illustrated in the right panel of figure 2. Similar to valence, we tested if arousal ratings decreased by the end of the experiment. Also for arousal, the main effects model with only odor category was very strongly preferred over the interaction model ($BF_{10} > 150$), indicating no meaningful changes in odor arousal between first and second rating (i.e. no evidence of habituation).

3.2. Preregistered analyses

We first wanted to know if the odors affected the perceived emotional properties of the faces. Thus, we started by testing whether rated face valence was affected by odor context. A model that included both odor and expression received very strong support ($BF_{10} > 150$), as illustrated in Figure 3. This model was very strongly preferred ($BF_{10} > 150$), over a model with expression only as factor. Adding the number of trials to the model was preferred over the expression only model by ($BF_{10} > 150$), however, a model with odor and expression as factors were preferred

over the model with trials ($BF_{10} = 37.17$). Finally, the null model was preferred over both interaction models (odor x expression and odor x expression x time) with a $BF_{01} > 150$.

Figure 3. The left panel shows the mean valence rating for each face expression, averaged across all odor conditions, with 95% credible intervals (CIs) computed from the posterior distribution. The left panel shows the effect of odor on face valence across facial expressions with mean ratings and 95% CIs (note that as the effects are small, we present the means as deviation scores from the grand mean).

Second, we asked whether the arousal ratings of the faces were affected by odor context. Here, the expression-only model provided strongest evidence ($BF_{10} > 150$), over the subjects-model illustrated in the right panel in figure 4. The expression model was preferred with a BF_{10} of 82.21 over the second-best model with the main effects odor, expression and trials as factors, which in turn was preferred by a BF_{10} of 4.86 over the odor and expression main effects model. We also confirmed, using an order-restricted model, that pleasant and unpleasant together were rated as more arousing than the no-odor condition ($BF_{10} > 150$), see left panel in figure 4 for mean change. Finally, the null model was preferred over both interaction models (odor x expression and odor x expression x time) with a $BF_{01} > 150$.

Figure 4. The panel on left hand side shows the mean arousal ratings for each expression and 95% credible intervals (CIs) computed from the posterior distribution. The right panel shows the effect of odor on face arousal ratings across facial expressions with 95% CIs (note that as the effects are small, we present the means as deviation scores from the grand mean).

Finally, we tested the odor effects on the dot-probe task. The subject-only model was preferred ($BF_{01} > 150$) to the main effect models of odor and probe emotion both alone and together, and the interaction model with odor and probe emotion. To illustrate this no-effect (Figure 5), we calculated difference scores between emotional and neutral probes for each emotion (e.g. probe behind disgusted expression – probe behind neutral when opposite expression was disgusted). Theoretically, this should maximize any effect as probes behind emotional faces should be faster because this side is attended, while probes behind neutral expressions should be slower as this side is unattended. However, there was evidence of no such effect.

Figure 5. Reaction time difference scores between emotional versus neutral probes (with 95% credible intervals). Note that positive values here indicate slower responses to the emotional side vs neutral.

Lastly, we modelled the interaction of odor effects and time-on-task effects, as per our pre-registered hypothesis, finding that this model was preferred to the subjects-only model ($BF_{10} = 7.36$), providing positive evidence for an interaction effect that is illustrated in Figure 6. The null effects model was preferred ($BF_{01} > 150$), over all other main effect and interaction models in the dot-probe task.

Figure 6. The interaction effect of odor and time-on-task on reaction times. The shaded areas around the fit-lines show the 95% credible intervals (CIs) computed from the posterior distribution.

3.3. Exploratory analyses

As some previous research has indicated that there might be gender effects in odor perception (Larsson, Nilsson, Olofsson, & Nordin, 2004; Olofsson & Nordin, 2004), we added participant gender as a factor. In no case did we find that a model containing gender was the best model, thus considering gender did not affect how we interpret the findings in this study. As we provide both data and analysis scripts freely available online, we welcome interested researchers to explore effects of gender or other variables in this data set.

4. Discussion

How do odors affect attention to facial expressions? The results in this study indicated that odors did not help direct attention to congruent facial expressions, at least as measured with the dot-probe paradigm. Instead, our pre-registered analysis strategy revealed a novel finding; decreased response latencies in the unpleasant odor condition appeared as a function of time-on-task. Our results also indicated that face ratings are affected by contextual odors. Faces, independently of their expressions, were rated as more negative in the unpleasant odor condition and more positive in the pleasant odor condition, replicating results of previous studies (Cook et al., 2015; Cook et al., 2018; Syrjänen et al., 2018). Similar to previous research, faces were also rated as more arousing during odor exposure compared to the no-odor control condition (Cook et al., 2015; Syrjänen et al., 2018). Manipulation checks confirmed that the ratings of odor valence and intensity confirmed our expectations. Importantly, we found strong evidence that results could not be explained by habituation effects to the odors. The odors were rated just as valenced and arousing before and after the dot-probe task, indicating that participants did not habituate to the odors.

The results in this study provided clear evidence for no overall attentional effects by facial emotion, odors or the interaction between facial emotion and odors, indicated by a very strong Bayes factor supporting the null hypothesis and almost identical RTs across conditions. A possible reason for not finding attention effects to congruent facial expressions might be attributed to the unspecific valence effects of odors on faces as indicated by the ratings. The results in a separate sample showed that valeric acid was congruent with disgusted faces and the lilac essence was congruent with happy faces (see supplemental materials). Brain imaging studies provide support for at least the close connection between disgusted faces and odors (Wicker et al., 2003). Although odors and facial expressions are predictably matched in explicit tasks, this association is not reflected in automatic attentional capture as measured by the dot-

probe task. The dot-probe paradigm has been seen as a gold standard for measuring attentional bias towards emotional stimuli, especially when comparing high and low anxious populations (Kappenman, Farrens, Luck, & Proudfit, 2014). However, lately these measures have been accused of low reliability (Kappenman, MacNamara, & Proudfit, 2015; Waechter, Nelson, Wright, Hyatt, & Oakman, 2013). In fact, this type of reflexive orienting toward salient stimuli is very fast, in the time range of 50-100 ms whereas saccades come later at 100-300 ms after stimulus onset (Müller & Rabbitt, 1989). Although these facts do not rule out initial attention towards salient stimuli, there is ample time for several attentional shifts before the appearance of the dot-probe, none the least, the results indicate that odors may not facilitate attention to emotional stimuli in the dot-probe task. Even though the dot-probe task might not be ideal to capture attentional effects, several EEG studies have shown that emotional faces capture attention in an automatic fashion in the dot-probe task, as measured by the lateralized N2pc component (Brosch, Pourtois, Sander, & Vuilleumier, 2011; Eimer & Kiss, 2007; Holmes et al., 2009). Future studies of olfactory effects of attentional capture might benefit from complementing behavioral assays with EEG. Several authors now believe that earlier results in the dot-probe paradigm might result from failure in some individuals to disengage from threatening stimuli, leading to faster RTs to the dot-probe, whereas non-anxious individuals already shifted attention away from the stimulus when the probe appears (Salemink, van den Hout, & Kindt, 2007). Some new research also indicates that previously seen emotional effects in the dot-probe task might have been driven by low-level stimulus features (Hedger, Garner, & Adams, 2019). Thus, the dot-probe task might not be an optimal measure of spatial attention, at least in a non-selected population. Earlier promising results might also be influenced by selective reporting, which is why we recommend future studies to include pre-registered analyses plans and publishing also of negative results.

A novel finding in this study was that response latencies decreased as a function of time-on-task in the unpleasant condition, whereas, RTs increased slightly in the no-odor and pleasant condition. These results could not be explained by, for example, differing rates of adaptation of the odors. The fact that both of the odors were rated as equivalently arousing and valenced indicates that the unpleasant odor condition differs in some other aspect. Previous research has shown that disgust-evoking pictures hold attention longer (van Hooff, Devue, Vieweg, & Theeuwes, 2013), and unpleasant smells are detected faster (Boesveldt, Frasnelli, Gordon, & Lundstrom, 2010). A recent study by Damjanovic, Wilkinson, and Lloyd (2018) reported similar time-on-task effects in an emotional face visual search task; response times decreased

over time in the unpleasant odor condition and they increased in the pleasant odor condition. Apart from the aforementioned study, these types of effects are seldom reported in the literature. We propose that such time-on-task effects could in fact explain some of the inconsistent results in prior studies. We could not see any general odor effects on RTs, or odor-visual congruency effects on accuracy such as in Chen et al. (2013) in the dot-probe task. The considerably lower accuracy in Chen et al. (2013), indicates that task difficulty differed between these studies. Although our study differs from that of Chen et al. (2013) in that they did not focus on time-on-task effects, we speculate that overall effects of odors are most readily observed in difficult tasks. Previous studies have shown for example that when controlling for task difficulty, congruent odors may facilitate object recognition (Hochemberger, Busch, & Ohla, 2015). These result also suggests the possibility of a valence-specific effect that fits into the behavioral immune system (BIS) framework (Schaller & Park, 2011). According to this view, when the BIS is active, a suite of behavioral actions are triggered (e.g. active monitoring for pathogen cues). Speculatively, the participants may increase their vigilance throughout the task in the presence of disease-signaling odor cue. Whereas, in the presence of a safety cue, the pleasant odor, or a no-odor condition, task performance is decreased slightly due to fatigue.

Possible limitations of the present work include lack of explicit consideration of possible gender interactions, and the possibility of order effects. Previous research has shown that gender might affect odor perception, especially odors associated with disgust (Ferdenzi et al., 2013). However, adding gender as a factor did not provide a better explanation of our data. Potential gender effects should range between small and medium effects sizes, and considering the sample size in the present study, the experiment was well powered to detect within-subject effects, rather than between subject effects related to gender. Future studies focusing on gender effects should adjust sample sizes accordingly. Another limitation might be order effects, as preceding odor blocks might influence following odor blocks in unintended ways. However, we argue that specific design choices in the present study alleviates these concerns, for example there was ample time between blocks for participants to rest and the room to ventilate, and furthermore, the order of odor blocks was also randomized. Future studies might control for potential order effects by a between-subjects design where each participant is only subjected to one odor condition.

In conclusion, we replicated previous findings of general odor effects on both valence and arousal ratings of faces. A novel finding was that response speed was decreasing as a function of time in the unpleasant odor condition whereas the slopes were slightly increasing in the no-

odor and pleasant odor condition. We found strong evidence against the notion that affective odors facilitate attention to congruent facial expressions as measured by the dot-probe task. We suggest that future research in odor effects on facial perception should consider time-on-task effects. Further, we suggest that a promising avenue for the pursuit of attentional odor effects is to use EEG methodology, in order to capture more fine-grained processes than may be present in behavioral measures.

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7. Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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