Smelling the space around us:

Odor pleasantness shifts visuospatial attention in humans

Luca Rinaldi [1,2], Emanuela Maggioni [1,2], Nadia Olivero [1,2], Angelo Maravita [1,2] & Luisa Girelli [1,2]

[1] *Department of Psychology, University of Milano-Bicocca, Milano, Italy*

[2] *NeuroMI, Milan Center for Neuroscience, Milano, Italy*

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* Corresponding author:

Luca Rinaldi
Dipartimento di Psicologia, Università degli Studi di Milano-Bicocca, Piazza dell'Ateneo Nuovo 1, Edificio U6, 20126 Milano, Italy.
Tel.: +39 6448 3865
E-mail address: l.rinaldi2@campus.unimib.it

Abstract

The prompt recognition of pleasant and unpleasant odors is a crucial regulatory and adaptive need of humans. Reactive answers to unpleasant odors ensure survival in many threatening situations. Notably, although humans typically react to certain odors by modulating their distance from the olfactory source, the effect of odor pleasantness over the orienting of visuospatial attention is still unknown. To address this issue, we first trained participants to associate visual shapes with pleasant and unpleasant odors, and then we assessed the impact of this association on a visuospatial task. Results showed that the use of trained shapes as flankers modulates performance in a line bisection task. Specifically, it was found that the estimated midpoint was shifted away from the visual shape associated with the unpleasant odor, whereas it was moved towards the shape associated with the pleasant odor. This finding demonstrates that odor pleasantness selectively shifts human attention in the surrounding space.

Keywords:

Olfactory system, Odor pleasantness, Visuospatial attention, Line bisection; Approach-avoidance behaviors.

Introduction

'Don Abbondio and Perpetua needed no keys to enter their house. With every step they took along the passage, they became more conscious of an odour, a poisonous smell, a *pestilential stink*, *which almost seemed to push them back again.'*

– Manzoni (1827/1983, p. 561)

Odor pleasantness has an important influence on human cognition, behavior, and emotions (Holland, Hendriks & Aarts, 2005). Discriminating between pleasant and unpleasant odors is crucial for regulating adaptive and reproductive behaviors in humans and in many other species (Auffarth, 2013; Haddad et al., 2010). Pleasant and unpleasant odors are usually detected at different speed (Bensafi, Rouby, Farget, Vigouroux & Holley, 2002). Avoidance of unpleasant odors tends to be rapid, as they are often associated to potential danger, whereas pleasant odors usually induce prolonged approaching behaviors (Boesveldt, Frasnelli, Gordon & Lundström, 2010; Knasko, 1995). In fact, like many other vertebrates, humans have the capacity to learn that certain odors signal something to elude, which is fundamental for avoiding environmental hazards (e.g., feces, vomit, and organic decay) (Stevenson, 2010). A similar facilitation in reacting to negative, fear-relevant stimuli extends to other sensory modalities, such as vision (e.g., Öhman, Flykt & Esteves, 2001), disclosing the human ability to rapidly detect information that is critical for survival, and to promptly adjust consequent behavior (Mineka & Öhman, 2002).

The processing of pleasant and unpleasant odors is known to modulate psychophysiological markers of arousal (Croy, Maboshe & Hummel, 2013; Miltner, Matjak, Braun, Diekmann & Brody, 1994), with unpleasant odors significantly increasing heart rate (Bensafi, Rouby, Farget, Bertrand, Vigouroux & Holley, 2002). Furthermore, brain circuits involved in approach and avoidance behaviors also underpin the discrimination between pleasant and unpleasant odors (Bensafi, Sobel & Khan, 2007; Zelano, Montag, Johnson, Khan & Sobel, 2007). More specifically, discrimination of odor pleasantness is associated with activations of the posterior medial and lateral portions of the orbitofrontal cortex (Grabenhorst, Rolls, Margot, da Silva & Velazco, 2007; Rolls, Kringelbach & De Araujo, 2003), an area critical for integrating sensory perception with hedonic experience and emotional processing (Kringelbach, 2005).

However, while previous works on odor valence have mainly focused on the speed of reaction to odors, the pattern of spatial orienting that follows such reactions still needs to be clarified, due to its critical importance for any approach and avoidance behaviors. In fact, humans typically respond to environmental stimuli according to their valence, by moving towards positive cues and moving away from negative ones (Seibt, Neumann, Nussinson & Strack, 2008; Strack & Deutsch, 2004). It is, therefore, reasonable that they might take advantage of similar spatial strategies when they encounter an odor. Nevertheless, whether odor pleasantness automatically modulates spatial orienting in humans is still unknown. Visuospatial attention represents an optimal model for addressing this issue, since attentional resources are continuously allocated to given spatial locations in order to approach, or avoid, relevant stimuli in the environment (e.g., Corbetta & Shulman, 2002; Yiend, 2010).

In the present study, we investigated whether odor pleasantness may bias visuospatial attention. Specifically, we explored whether attention shifts closer or further away from visual stimuli that have been previously associated with pleasant or unpleasant olfactory cues. Participants were first trained to associate a certain visual shape with a certain odor (e.g., pleasant or unpleasant). Critically, before and after the associative training, participants were required to bisect horizontal lines flanked by the same shapes. Line bisection is, indeed, a standard task employed to assess the allocation of visuospatial attention in both clinical and experimental settings, whereby participants are asked to estimate the subjective midpoint of the line. Healthy individuals typically show a slight but systematic leftward bias, known as pseudoneglect (Bowers & Heilman, 1980; see Jewell & McCourt, 2000, for a review), which is supposed to reflect an interplay between right-hemisphere dominance in spatial attention and reading habits (see Rinaldi, Di Luca, Henik & Girelli, 2014). Since the line bisection bias has been largely taken as an index of unilateral hemispheric activation, with leftward and rightward biases associated with relative larger activation of either the right or of the left hemisphere (Jewell & McCourt, 2000), in recent studies the bisection task has been exploited as a method for investigating approach and avoidance behaviors (Armaghani, Crucian & Heilman, 2014; Cattaneo, Lega, Boehringer, Gallucci, Girelli & Carbon, 2014; Hatin & Sykes Tottenham, 2016; Nash, Mcgregor & Inzlicht, 2010; but see Leggett, Thomas & Nicholls, 2015). On these grounds, here we aimed to explore whether the estimated midpoint of a line flanked by two different shapes would be influenced by the olfactory experience associated with each shape. We predicted that, if spatial attention is involved in approaching or avoiding odors according to their pleasantness, the subjective midpoint should be shifted away from the visual stimulus associated with the unpleasant odor, and shifted towards the visual stimulus associated with the pleasant odor.

Method

Participants

The study, ethically approved by the University of Milano-Bicocca, included 39 right-handed (Oldfield, 1971) students (*M* age = 24.9 ± 5.6 years; 30 females). None of the participants reported any stable or temporary deficit of olfaction or neurological disease. The presence of olfactory or visual deficits was assessed during the recruitment phase, by means of a short self-report questionnaire (see the Supplemental Appendix).

Apparatus and procedure

The experiment was run on an Acer Aspire 1350 (15-inch, refresh rate 60 Hz), with participants seated 60 cm from the screen. The experiment consisted of four sequential phases, outlined below (see Figure 1), that were repeated in two distinct daily-sessions, separated by an interval ranging between 4 and 7 days. In a first daily-session, participants were trained uniquely with the pleasant odor, whereas in a second daily-session they were trained uniquely with the unpleasant odor (i.e., order of presentation counterbalanced between participants). During the learning phase, odors were presented by means of a custom-built computer-controlled olfactometer. Specifically, the olfactometer is composed of three electro-valves activated via a parallel-port computer-controlled system, connected with a tank of compressed medical air (capacity 5 l at 300 Bar, N. ONU 1002, class 2, GASTEC-VESTA® S.r.l.). The inflow of compressed air was controlled by directing the airflow into one of the three valves, while leaving the others inactive (i.e., each valve can be on-off activated, 0-8 Bar). The airflow was set at a constant pressure of 0.2 Bar-l/min, through a manometer (0-10 Bar, Tecnocryo Harris Aria, En. 562).

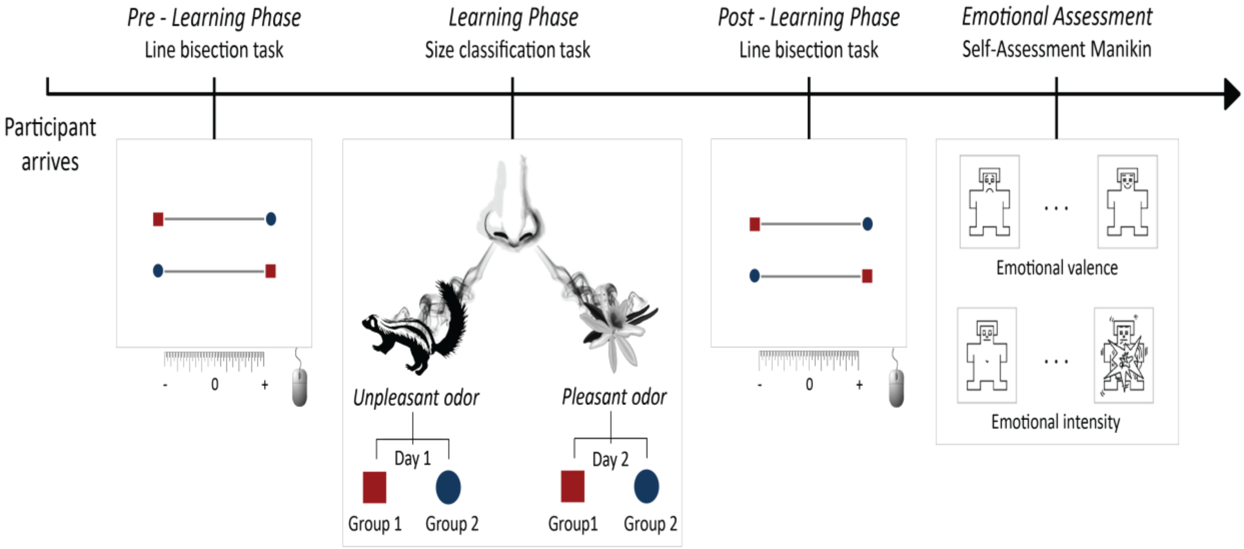

Figure 1. Outline of study design. The experiment consisted of four sequential phases, repeated in two different daily-sessions. In the first session, participants first completed a computerized line bisection task, in which they had to estimate the midpoint of a line, flanked by different shapes (*Pre-learning phase*). Subsequently, they performed a size-classification task with geometrical shapes (e.g., red square) (*Learning phase*); critically, during this task, the geometrical shape was presented together with a given odor (e.g., pleasant odor), so that participants were trained to specific shape/odor associations. After completing the size-classification task, participants performed once again the line bisection task (*Post-learning phase*). Finally, emotional level of pleasure and arousal was assessed by means of the Self-Assessment Manikin (*Emotional assessment*). Participants were exposed to the pleasant and unpleasant odors in two different daily sessions. Specifically, the same participants trained, for example, with the red square/pleasant odor association on the first daily-session, completed a second daily-session in which they were trained to associate the red square with the unpleasant odor. Half of participants (*N*=20) were trained to associate the odors (pleasant/unpleasant) with the red square, whereas the other half (*N*=19), with the blue circle.

Pre-learning phase. Participants performed a computerized line bisection task. Each trial was composed by a black line. The line was flanked by two visual shapes, placed at a distance of 7 pixels from each end of the line. A red square (side: 60 pixels) and a blue circle (diameter: 60 pixels) were used as flankers. In particular, two different flanker displays were presented: *a)* lines with the red square located at the left end and the blue circle at the right, and *b)* lines with the blue circle located at the left end and the red square at the right (see Fig. 1).

In order to increase stimulus variability line length and line position were systematically varied: two different line lengths (333 pixel and 499 pixel) appeared at eight different spatial positions on the screen. Specifically, lines were always displaced 50 pixels to the left or to the right of the center and could appear in four different vertical positions (from the center, displaced 50 or 100 pixels up or down). Long and short lines appeared an equal number of times in each of the eight possible positions. Since line length and line position were not designed as experimental manipulations, they were not analyzed.

The pre-learning phase started with 5 practice trials and consisted of 32 trials. Before starting the experiment, participants were instructed to indicate the line midpoint using the computer mouse. The mouse cursor was a vertical arrow that moved along the horizontal axis only, appearing for an equal number of times at the left or at the right extreme of the line, four pixels below the stimulus, on trial onset. Participants indicated the line midpoint by clicking the mouse with the right hand.

Learning phase. In the learning phase participants performed a size-classification task. Participants were first presented simultaneously with two shapes, one big (180 pixels wide) and one small (90 pixels wide), to be used as references. At the beginning of each trial, a fixation point was presented at the center of the screen for a variable time (250, 350, 450 ms), in order to avoid automatic responses. The fixation point was followed by a visual shape (i.e., the target stimulus), that remained on the screen until the participant's response, and ended with a blank screen lasting for 1000 ms before the next trial. Participants classified the target stimulus as small or large by pressing the (Q) or (P) keys of a vertically aligned keyboard, in order to avoid any right/left directional interference. For the first group of participants (*N*=20) the target stimulus consisted of a big (side: 180 pixels) or a small (side: 90 pixels) red square, while for the other group of participants (*N*=19) it consisted of a big (diameter: 180 pixels) or a small (diameter: 90 pixels) blue circle[1]. Simultaneous with the onset of the fixation point, an olfactory stimulus was presented, that lasted until the presentation of the next fixation point. The olfactory stimuli were provided by Agieffe International® (Milan, Italy) and were presented birhinally to avoid any effect of hemispheric dominance. In particular, vanilla odor was used as pleasant stimulus (commercial name, *vanilla*, 25% pure essential oil), whereas civet odor

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[1] This design was chosen in order to compensate for the crossmodal association between visual shapes, colors, and odor pleasantness (Dematte, Sanabria & Spence, 2006; Deroy, Crisinel & Spence, 2013). That is, whereas unpleasant odors are usually associated with more angular and sharper shapes, pleasant odors are generally associated with more circular ones (Hanson-Vaux, Crisinel & Spence, 2013). Moreover, although the association between hue color and odor pleasantness is still not clear (see for a review, Deroy et al., 2013), hue has been demonstrated to influence cognitive task performances, with red that activates mainly an avoidance attitude, whereas blue an approach attitude (Mehta & Zhu, 2009). Thus, the present experimental design allowed us to mainly focus on the effect of odor pleasantness *per se*, rather than on its possible interaction with other visual features.

(commercial name, *zibet*, condensed at a level of 10%) was used as unpleasant stimulus. These alcohol free and water-soluble odors were diluted at a concentration of 10% in water. Pleasant and unpleasant odors were administered in two separate sessions, in a counterbalanced order across participants. Hence, the first group of participants was trained to associate the red square with the both pleasant (e.g., Day 1) and the unpleasant odor (e.g., Day 2; order counterbalanced across participants). Similarly, the second group of participants was trained to associate the blue circle with the pleasant and the unpleasant odors in two different daily-sessions. In order to limit the occurrence of habituation on presentation of frequent unpleasant stimuli and, consequentially, reduce their emotional salience (Croy et al., 2013), olfactory cues were presented once every two target stimuli. A total of 36 trials were presented in this phase (18 for each stimulus size).

Post-learning phase. The post-learning phase was a line bisection task, identical to the pre-learning phase.

Emotional assessment. The participants' olfactory experience, in terms of pleasure and arousal, was assessed using the 9-point scale of the Self-Assessment Manikin (SAM; Bradely & Lang, 1994).

Data analysis

First, an analysis on reaction times (RTs) to the target stimulus in the learning phase was performed. More specifically, the mean RT to the stimuli presented without any olfactory cues was subtracted from the mean RT to the stimuli presented simultaneously with the olfactory cues (i.e., ΔRTs). Thus, a negative Δ indicates faster responses to targets presented simultaneously with odors than targets presented alone, whereas a positive Δ indicates slower responses (see the Supplemental Materials for additional analyses on the non-subtracted RTs).

Second, the bias in line bisection was computed, by subtracting the veridical midpoint from the participants' estimated midpoint. These values were then converted to signed percentage scores, by dividing the true half-length of the interval from the response bias and multiplying the quotient by 100. This procedure yielded a positive score if the participant's response was to the right of the veridical midpoint and a negative score if the response was to the left of it. Since the trained flanker (i.e., red square for the first group, blue circle for the second group) was placed at the left or right line end in the different line conditions, we converted all the response biases so that the trained flanker was arbitrarily considered as to be always placed at the left end. Finally, in order to explore any systematic visuospatial attentional shift after the training, the mean bisection bias in the pre-learning phase was subtracted from that of the post-learning phase (i.e., ΔSpatial bias). Consequently, a negative Δ indicates that the subjective midpoint was shifted toward the trained flanker, whereas a positive Δ that it was shifted away from the trained flanker (see the Supplemental Materials for additional analyses on the non-subtracted visuospatial responses).

Finally, we performed an analysis on the 9-point scale of the SAM, for the pleasure (1=negative; 9=positive) and arousal (1=low; 9=high) assessment. Furthermore, we also explored the relationship between the visuospatial and the emotional response.

Results

Response time. Only correct responses to target stimuli within 1500 ms in the learning phase were considered in the analyses (98%). A paired samples *t*-test revealed that ΔRTs to targets presented with the pleasant odor was significantly different from those presented with the unpleasant odor, *t*(38)=10.67, *p*<.001, Cohen's *d*=1.709. Subsequently, in order to explore whether the ΔRTs to targets presented simultaneously with odors were significantly different than those to targets presented alone, a *t*-test for the ΔRTs average of each odor against the value of zero was carried out. Results showed a significant positive ΔRTs (*M*=23.94*, SD*=46.27) with the pleasant odor (i.e., slower responses when odor was presented), *t*(38)=3.23, *p*=.003, Cohen's *d*=.517. Contrarily, results showed a significant negative ΔRTs (*M*=-75.57*, SD*=41.01) with the unpleasant odor (i.e., faster responses when odor was presented), *t*(38)=11.51, *p*<.001, Cohen's *d*=1.843 (Figure 2a) (see the Supplemental Materials for additional results on RTs).

Visuospatial response. Data with more than 2 SD above the mean were removed from the analyses (4.6%). A first preliminary analysis was carried out to compare the bisection bias in the pre-learning phase of the two sessions. Accordingly, a *t*-test was performed for each of the two different flanker conditions between pre- and post-learning performances in each group. Results showed no significant difference, indicating that participants' visuospatial performance was stable across daily-sessions (all *ps*>.05).

A paired samples *t*-test on the ΔSpatial bias revealed that the subjective midpoint was located differently depending on whether the trained flanker was associated to a pleasant or to an unpleasant odor, *t*(38)=5.96, *p*<.001, Cohen's *d*=.954. Subsequently a *t*-test for the ΔSpatial bias against the value of zero was computed, in order to detect whether the learning phase significantly modulated visuospatial performance. The *t*-test against the value of zero showed that the subjective midpoint was shifted toward the trained flanker associated with the pleasant odor (*M*=-1.09*, SD*=1.06), *t*(38)=6.44, *p*<.001, Cohen's *d*=1.031. Contrarily, the subjective midpoint was shifted away from the trained flanker associated with the unpleasant odor (*M*=.72*, SD* = 1.72), *t*(38)=2.61, *p*=.013, Cohen's *d*=.418 (Figure 2b) (see the Supplemental Materials for additional results on visuospatial responses).

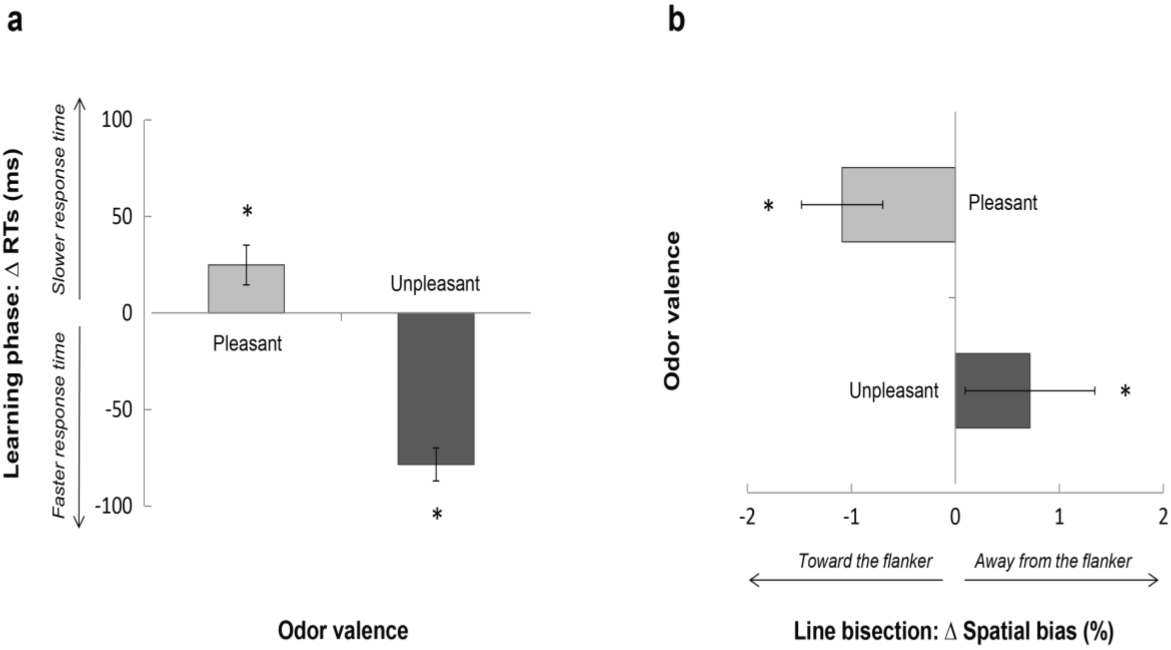

Figure 2. Impact of odor pleasantness on response time (a) and on visuospatial response (b). For the response time, the mean RT to the stimuli presented without any olfactory cues was subtracted from the means RT of the stimuli presented simultaneously with the olfactory cues, to get an index of participants' response time to odor pleasantness (i.e., ΔRTs). Negative ΔRTs indicates faster responses to targets presented simultaneously with odors than targets presented alone and *vice versa* for positive values. Results showed that unpleasant odor elicited faster responses, while pleasant odor elicited slower responses (a). For the visuospatial response, the mean bisection bias in the pre-learning phase was subtracted from that of the post-learning phase (i.e., ΔSpatial bias) to detect any systematic visuospatial attentional shift after the training. Thus, while a negative Δ indicates that the subjective midpoint was shifted toward the trained flanker, a positive Δ indicates that it was moved away from the trained flanker (see the Methods section). Results revealed that participants' estimated midpoint was shifted toward the flanker associated with a pleasant odor, whereas it was shifted away from the flanker associated with an unpleasant odor (b). Error bars, ± s.e.m. **p* < .05.

Emotional response. A paired samples *t*-test on the 9-point scale of the SAM ratings of pleasure showed that the pleasant odor was associated with a more positive rating (*M*=7.1, *SD*=1.1) than the unpleasant odor (*M*=5, *SD*=1.2), *t* (38)=7.28, *p*<.001, Cohen's *d*=1.165.

Subsequently, a paired samples *t*-test on SAM ratings of arousal showed that the unpleasant odor was associated with a more arousing rating (*M*=3.5, *SD*=1.6) than the pleasant odor (*M*=2.5, *SD*=1.4), *t*(38)= 4.22, *p*<.001, Cohen's *d*=.676.

Correlation between visuospatial and emotional response. A Pearson correlation analysis was conducted to analyze the relationship between the SAM ratings of pleasure and the ΔSpatial bias. Results showed that participants who rated the odor as more unpleasant shifted the midpoint more away from the trained flanker, *r*=-.355, *p*=.027. Conversely, no relationship was found for the pleasant odor, *r*=.077, *p*=.641. Finally, no significant correlation characterized the SAM ratings of arousal and the ΔSpatial (pleasant odor: *r*=-.136, *p*=.408; unpleasant odor: *r*=.102, *p*=.538).

Discussion

The present study explored whether odor pleasantness may influence the allocation of attentional resources in the surrounding space. In particular, since approach and avoidance behaviors often involve a spatial dimension, we investigated whether odors, which typically feature objects that are likely to be approached or avoided, may induce selective shifts of visuospatial attention. Overall, we found that the unpleasant odor was detected faster than the pleasant odor in the learning phase, in line with previous studies showing that pleasant and unpleasant odors induce regulatory reactions at different speed (Bensafi, Rouby, Farget, Vigouroux & Holley, 2002; Boesveldt et al., 2010). Notably, results revealed that participants' visuospatial attention clearly deviated according to odor pleasantness. In particular, the subjective midpoint of the line bisection task was shifted away from the visual stimulus associated with the unpleasant odor and towards the visual stimulus associated with the pleasant odor.

Different studies have demonstrated that line bisection performance is modulated by the concurrent presentation of irrelevant lateralized flankers (e.g., Cattaneo et al., 2014; de Hevia, Girelli & Vallar, 2006). For instance, flanker numbers influence the line bisection performance, with a tendency to direct the subjective midpoint toward the larger digit as to balance the numerical disparity between flankers (de Hevia et al., 2006). This means that flanker numbers might act as meaningful bilateral cues. With a similar mechanism, in the present study participants may have classified the shapes as pleasant or unpleasant and, accordingly, placed the subjective midpoint towards the pleasant stimulus as to balance the emotional disparity.

The line bisection task has been recently exploited also to measure attentional asymmetries linked to motivational states (Nash et al., 2010). In particular, two previous studies explored whether emotional faces placed at the end of the line might alter the allocation of visuospatial attention (Armaghani et al., 2014; Cattaneo et al., 2014). Results of the above studies were partially consistent with the 'valence model', that argues for a left and a right hemispheric lateralisation of approach and avoidance behaviors, respectively (Davidson, 2003). In fact, while a first study by Armaghani et al. (2014) reported a more pronounced leftward bias with lines flanked by two sad faces (i.e., avodiance), a second study by Cattaneo et al. (2014) reported a rightward bias with lines flanked by two happy faces (i.e., approach). These results were not fully corroborated by a subsequent study using a landmark task, whereby participants were required to perform forced-choice decisions regarding a pre-bisected line, preceded by angry/happy faces (Legget et al., 2016). In discussing our results in light of this evidence, however, we note that the present data did not show any lateralised behaviour induced by the emotional content of the learning phase. This may be explained by the fact that, whereas in the previous studies (Armaghani et al., 2014; Cattaneo et al., 2014) lines were flanked by identical emotional faces (i.e., two happy or two sad faces), here only one flanker was trained to be associated with a particular emotional content. Further, whereas Leggett et al. (2016) used a landmark task, which has clearly a lower motor component than the line bisection task (e.g., Weiss et al., 2000; Weiss, Marshall, Zilles & Fink, 2003), in our bisection task participants had to manually and actively indicate the midpoint of the line. In addition to this, whereas Leggett et al. (2016) presented emotionally valenced stimuli (e.g., angry/happy faces) as a probe before each trial, in our study the trained stimuli were presented as flankers with the lines. This might explain why in our study approach and avoidance were not lateralized following hemispheric prevalence for a given emotion, but emerged as flexible allocation of visuospatial resources. Specifically, our findings are consistent with previous reports in which approach behaviors decrease the distance between the individual and the target object, whereas avoidance behaviors increase it (Strack & Deutsch, 2004). Similarly, in the present study, the learned association between central visual cues and olfactory information biased bisection performance by shifting the subjective midpoint (i.e., spatial attention) away from the stimulus associated with the unpleasant odor and towards the one associated with the pleasant odor.

Notably, we found that participants who rated the olfactory experience as more negative also shifted their attentional midpoint more away from the stimulus trained with the unpleasant odor, without any correlation with arousal ratings. This may suggest that negative emotional valence induced by the unpleasant odor significantly affects the allocation of visuospatial attention. The extent to which the reported effects were determined by an implicit or explicit mechanism cannot be inferred by the present study. Yet, the association with olfactory information modulated the allocation of spatial attention without participants paying voluntary attention to their emotional valence. Indeed, the learning phase was completely irrelevant to the bisection task and there was no explicit reference to the emotional content. Furthermore, whereas in some previous studies the bisection task was followed by a memory test explicitly assessing the processing of the flankers (see Claunch et al., 2012; see also Lichtenstein-Vidne, Henik & Safadi, 2012), here participants were not explicitly required to pay attention to the flankers. This suggests that any effect of odor pleasantness on bisection performance is likely to result from implicit, rather than explicit, mechanisms. These results are thus in line with previous findings showing that attentional resources can be shifted by irrelevant emotional stimuli (e.g., Cattaneo et al., 2014; Hodsoll, Viding & Lavie, 2011; Tamietto et al., 2005), although the exact mechanism through which the shift of visuospatial attention occurs (e.g., olfactory priming; see Smeets & Dijksterhuis, 2014) still remains to be clarified.

Capture of selective attention induced by emotional stimuli has been widely reported in the literature, by means of the visual search (Brosch & Sharma, 2005; Öhman et al., 2001) and of the cueing tasks (MacLeod, Mathews, & Tata, 1986; Mogg & Bradley, 1999). Specifically, in the cueing task, participants have to respond to a target that replaces one of two simultaneously presented cues (i.e., one with an emotional connotation and one neutral) (see for a review Yiend, 2010). Results typically show a response facilitation if the target replaces the emotional cue, rather than the neutral cue, at the target location (Lipp & Derakshan, 2005; Mogg & Bradley, 1999; Phelps, Ling, & Carrasco, 2006). This facilitation holds for both negative and positive stimuli, and it is accompanied by specific brain-activation patterns (e.g., Brosch, Sander, Pourtois & Scherer, 2008). It is important to note, however, that studies on the time course of the capture of selective attention have unveiled a vigilance pattern toward threatening stimuli only at short cue duration (Cooper & Langton, 2006; Holmes, Green, & Vuillemier, 2005). Accordingly, some models of attention to threat (e.g., Mogg & Bradley, 1998) emphasize the possible adaptive role of both initial attention to threatening information and strategic attentional avoidance (Koster, Verschuere, Crombez & Van Damme, 2005). Initial attention to threatening stimuli, indeed, may favor fast responses to danger (Öhman et al., 2001). Yet, especially in the case of a threatening stimulus that does not necessitate prompt responding, attentional avoidance may represent a valid strategy to maintain goal-directed behavior (Mogg & Bradley, 1998) or to regulate mood (Ellenbogen, Schwartzman, Stewart, & Walker, 2002). In this sense, emotional content may engage attention in the early stages, whereas active avoidance would necessitate additional time (Nummenmaa, Hyönä, & Calvo, 2006; but see McSorley & van Reekum, 2013). A similar rationale may apply as well to the present findings, especially in the case of the unpleasant odor. In our experimental paradigm, in fact, participants were first exposed to the crossmodal associative training and, only subsequently, they had to perform a line bisection task, in which lines were flanked by the trained visual shapes. In this sense, an initial facilitation in processing olfactory unpleasant stimuli may be reflected by the fast responses during the learning phase, whereas a voluntary and strategic avoidance behavior may have emerged later in time, during the visuospatial task. This possibility remains, however, rather speculative, as no study has so far address the time course of selective attention to odor pleasantness by means of a cueing task. Future studies are therefore needed to investigate the time course of spatial attentional engagement with olfactory stimulation.

Beyond advancing our understanding of the effects of odors on human behavior, the present research provides original theoretical insights for a more comprehensive evolutionary view of olfaction (Rutherford & Lindell, 2011). Indeed, our findings show that odor pleasantness moves human attention away from the unpleasant source (i.e., increase in distance) or close to the pleasant source (i.e., decrease in distance). Adopting such a spatial strategy in real-world situations might allow a more efficient exploration of our environment. From an evolutionary perspective, this might be critical in regulating food-seeking and even mate-seeking behaviors: edible food or a fertile mate usually smell pleasant, whereas a poison or a predator smell unpleasant (Yeshurun & Sobel, 2010). Intriguingly, the present findings show that spatial bias can be induced by learned contingent odor-object associations in a very short time. Accordingly, odor pleasantness may quickly create strong spatial boundaries around objects, possibly influencing spatial decision making in perceptual and social contexts (e.g., Spangenberg, Crowley & Henderson, 1996).

In interpreting our results, a few aspects need to be carefully considered. First, following previous studies (e.g., Bensafi, Rouby, Farget, Vigouroux & Holley, 2002) we explored the effect of odor pleasantness by means of only two odors, whereas other reports tested crossmodal associations with several odors (Boesveldt et al., 2010; see Deroy et al., 2013). Consequently, although the two odors adopted here were selected as samples of pleasant or unpleasant, future research is needed to assess whether the effect of odor pleasantness on visuospatial attention can be generalized. A larger sample of odors will also ensure to make more comparable, across the group of participants, the valence of the pleasant and unpleasant odors, as well as their intensity (see Yeshurun & Sobel, 2010). Currently, the civet odor was not perceived as unpleasant in absolute terms. Rather, it was perceived as less unpleasant than how the vanilla was perceived as pleasant, thus possibly reducing the difference between the two.

This pattern may be likely explained in terms of “affective habituation”, an expression indicating how repeated exposure can shift odor pleasantness ratings toward neutrality (Cain & Johnson, 1978). Repeated exposure to odors, indeed, can affect both their perceived intensity (Dalton, 1996; Frank, Dulay & Gesteland, 2003) and pleasantness (Cain & Johnson, 1978; Ferdenzi, Poncelet, Rouby & Bensafi, 2014). Yet, affective habituation can occur differently for pleasant and unpleasant odors. For instance, it has been shown that unpleasantness ratings decrease for unpleasant odors with repeated presentation, whereas this does not necessarily occur for pleasant odors (Croy et al., 2013; cf. Ferdenzi et al., 2014). This may apply as well to the present findings. Unfortunately, in our study, pleasantness was evaluated only at the end of the experimental block, and hence it is hard to infer whether the pattern of results yielded by the emotional assessment reflects the fact that participants’ judgment decreased with repeated exposure. A more cautious preliminary test on odor pleasantness should be employed by future studies, with the aim to select more equal olfactory stimuli, possibly at the subjective level. Further, it is worth noting that in the present work we exposed participants to short experimental sessions in order to avoid habituation, which may reduce the emotional saliency (Cain & Johnson, 1978; Croy at al., 2013). Nonetheless, the short exposure period was enough to show an effect on the allocation of attentional resources in space.

Second, most participants recruited in our study were females (e.g., 30 out of 39). As such, a potential gender bias may be considered and represents a potential field of exploration for future research. In the case of olfactory perception, indeed, well-known gender differences include a female advantage in identifying (Ferdenzi et al., 2013), recognizing (Brand & Millot, 2001) and remembering odors (Öberg, Larsson & Bäckman, 2002). In addition to this, greater affective reactivity to odors, as also reflected in electrophysiological responses, characterizes women relative to men (Olofsson & Nordin 2004; Pause et al., 2010). It remains an open question, therefore, whether the reported effects of odor pleasantness on visuospatial attention occurs similarly in females and men.

Third, the present study did not assess a primary propriety of odorants, that is odor intensity. Perceived odor intensity depends both on odor concentration and on the duration of the odor exposure or adaptation (Yeshurun & Sobel, 2010). For this very reason, in our study the odors were delivered with a constant pressure and with a fixed exposure time to participants. More critically, odor pleasantness is known to be partially dependent on odor intensity (Doty, 1975; Yeshurun & Sobel, 2010). Further research is, thus, needed to investigate whether perceived odor intensity could further modulate the reported findings. In fact, despite intensity and pleasantness draw upon dissociable neural representations, they can interact in different and complex ways (Anderson et al., 2003; Henion, 1971; Zatorre, Jones-Gotman, & Rouby, 2000). Accordingly, it is possible that an increase in perceived intensity may be related to a more pronounced visuospatial bias, with this effect that may vary as a function of odor pleasantness. This possibility might be achieved by presenting different concentrations of odors (e.g., odor intensity scaling) and exploring whether weak or strong odor intensity may differently impact on the allocation of visuospatial attention.

To conclude, Don Abbondio and Perpetua felt themselves pushed back by the poisonous smell, while entering in their plague-stricken house. We ourselves encounter unpleasant odors in many everyday life situations and feel such a repulsion, with pleasant odors acting in the opposite way. Here we show that these feelings go beyond their literal meaning: unpleasant odors actually shift away the allocation of spatial attention from the unpleasant source, whereas pleasant sources attract it (see Pool, Brosch, Delplanque & Sander, 2014). This means that odor pleasantness, the primary trait adopted by people to classify and describe odorants (Yeshurun & Sobel, 2010), is a key dimension for the regulation of spatial attention.

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