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Research report

Odors enhance visual attention to congruent objects☆

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ABSTRACT

Although it is well known that visual stimuli affect olfactory performance, little is known about the reverse case: the influence of odor on visual performance. This study aimed to determine whether odors can enhance attention towards visually presented objects congruent with the odors. Sixty healthy participants were presented with four odors (orange, lavender, coffee, and liquorice) before and during the presentation of photographic slides containing one congruent and three incongruent objects with the presented odors. The participants' visual attention was assessed as the total number and time of eye fixations by using an eye tracking system. When the participants smelled an odor, they looked more frequently and longer at a corresponding object as compared to the odorless condition. In conclusion, our findings demonstrate for the first time an olfactory priming effect on visual selective attention: odor can increase attention towards a congruent visual object as compared to a non-odor condition.

Introduction

In humans, it has been well established that visual cues affect olfactory performance. For example, verbal labeling of odors cannot only facilitate odor identification (Distel & Hudson, 2001; Jehl, Royet, & Holley, 1997), but also influence odor memory (Jehl et al., 1997, for a review, see Larsson, 1997) and pleasantness (Bensafi, Rinck, Schaal, & Rouby, 2007; de Araujo, Rolls, Velazco, Margot, & Cayeux, 2005; Herz & von Clef, 2001; Seo, Buschhüter, & Hummel, 2008). Effects of color on olfactory perception and hedonic ratings have been also described (Kemp & Gilbert, 1997; Österbauer et al., 2005; Schifferstein & Tanudjaja, 2004; Zellner, Bartoli, & Eckard, 1991). Specifically, Zellner et al. (1991) demonstrated that, when an odor was matched appropriately with color, participants rated the odor as being more pleasant as compared to an inappropriate combination of odor with color. Moreover, visual features such as shape or picture have been employed as visual cues in cross-modal studies between olfaction and vision (Demattè, Sanabria, & Spence, 2009; Gottfried & Dolan, 2003; Sakai, Imada, Saito, Kobayakawa, & Deguchi, 2005). For instance, Sakai et al. (2005) showed that watching congruent pictures increased odor intensity and pleasantness compared to incongruent matching.

In contrast, little is known about the influence of olfactory cues on visual performance in humans. Several studies have demonstrated that olfactory cues can modulate participants' behavior towards visual stimuli (Castiello, Zucco, Parma, Ansuini, & Tirindelli, 2006; Demattè, Österbauer, & Spence, 2007; Knasko, 1995; Lorig, Mayer, Moore, & Warrenburg, 1993; Michael, Jacquot, Millot, & Brand, 2003; Millot, Brand, & Morand, 2002; Tubaldi, Ansuini, Demattè, Tirindelli, & Castiello, 2008; Tubaldi, Ansuini, Tirindelli, & Castiello, 2008). Specifically, participants exposed to ambient scent, irrespectively of its hedonic valence, responded to visual stimuli more rapidly in a simple sensory-motor task, compared to those who experienced an unscented condition (Millot et al., 2002). In addition, Grigor (1995) and Grigor, Van Toller, Behan, and Richardson (1999) demonstrated an olfactory priming effect on visual event related potentials (ERPs) by using a series of photographs of foods or non-food objects congruent or incongruent with previously presented odors of common foods (Grigor, 1995) or non-food (Grigor et al., 1999). More specifically, in visual ERPs, the amplitude of the N400 peak (negative peak with a latency of ~400 ms after stimulus onset) was higher when participants received visual stimuli non-matched to formerly presented odor (i.e. non-primed condition) as compared to that of matched visual stimuli (i.e. olfactory primed condition) in both food and non-food related odors used as primer. Similar results appeared in other visual ERP studies investigating an olfactory priming effect (Castle, Van Toller, & Milligan, 2000; Sarfarazi, Cave, Richardson, Behan, & Sedgwick, 1999). Additionally, Castle et al. (2000) showed an olfactory priming effect for unpleasant odors but

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not for pleasant ones (see also Demattè et al., 2007). More recently, a series of documents demonstrated that olfactory cue plays an important role in planning and controlling reach-to-grasp tasks towards visual objects (Castiello et al., 2006; Tubaldi, Ansuini, Demattè, et al., 2008; Tubaldi, Ansuini, Tirindelli, et al., 2008). Specifically, after receiving an odor associated with a large (i.e. apple and orange) or a small sized object (i.e. almond and strawberry), participants were asked to reach and grasp either a small or a large object. When the type of grasp formed by the earlier delivered odor was congruent with the subsequent visual target, the kinematics of hand shaping was magnified, whereas the facilitation effect of hand shaping was decreased in incongruent condition between the type of hand shaping and following visual object (Tubaldi, Ansuini, Tirindelli, & Castiello, 2008).

Taken together, although several studies have demonstrated influences of olfactory cue on visual and visuo-motor tasks, it has been assumed that visual cue dominantly modulates olfactory performance in olfactory–visual integration (Thesen, Vibell, Calvert, & Österbauer, 2004). However, in animals, it has been often observed that olfactory cue contributes to use visual cue especially during food foraging and spatial navigation (Chow & Frye, 2008; Duistermars & Frye, 2008; Frey, Tarsitano, & Dickinson, 2003; Maaswinkel & Li, 2003; Reinhard, Srinivasan, & Zhang, 2004; Rossier & Schenk, 2003). For example, in zebrafish, visual sensitivity was increased by the addition of amino acids as olfactory stimuli to the aquarium, while such a result was not obtained after ablation of the olfactory bulb (Maaswinkel & Li, 2003). Moreover, Reinhard et al. (2004) found that the honey bees, *Apis mellifera*, can find food sources by learning visual information and its stimulator, olfactory cue. More specifically, the honey bees were trained to visit two different scented sugar feeders (e.g. rose and lemon scents) positioned at two different locations for 2 days. Afterwards, when the experimenter injected each of both scents towards the bees' hive, the bees visited the sugar jar corresponding to the scent significantly often than the other one, although the sugar feeder was not scented any longer. The authors proposed that experienced scent can stimulate specific visual cues and memories (e.g. route, direction) associated with the sugar jar previously visited. In addition, Rossier and Schenk (2003) demonstrated that rats use age-specific strategies using olfactory and/or visual information for place navigation through ontogeny. Specifically, 24-day-old rats relied mainly on olfactory cues to find the escape hole, whereas 12-month-old rats use visual cue dominantly. Also, olfactory cue facilitated to use visual information by 48-day-old rats. It is also known that human infants are dependent on olfactory cue over ontogeny, and they are able to discriminate odor quality using head-turning response (for a review see Schaal, 1988).

Here, we attempted for the first time to determine whether an odor can increase participants' attention towards its congruent object. To date, one study dealing with odor and visual attention (i.e. looking at visual stimulus) has been reported. Knasko (1995) showed that participants looked significantly longer at photographic slides in the presence of a pleasant odor such as baby powder or chocolate than in an odorless condition; however, this study failed to elicit an effect of congruency upon viewing time. Whereas Knasko's study focused on how long participants chose to view slides which were congruent, incongruent, or non-related to ambient odors (baby powder or chocolate), our study additionally aimed to explore where participants' eye fixed among four objects (one of matched and three of non-matched objects) shown within one photographic slide by using an eye tracker apparatus, a non-invasive device for measuring eye movement.

In general, eye movements are assumed to be related to perceptual and cognitive processing, specifically, to reflect attention on visual stimuli (Lykins, Meana, & Kambe, 2006; Rayner, Miller, & Rotello, 2008; Rayner, Rotello, Stewart, Keir, & Duffy, 2001; Wedel, Pieters, & Liechty, 2008; for a review see Hayhoe & Ballard, 2005; Rayner, 1998). Thus, the eye tracker method, regarded as a reliable and valid approach for measuring attention, has been employed in various academic and industry fields (Rayner, 1995). Specifically, the eye tracker method has been used to investigate cross-modal interactions of visuo-motor tasks (Land & Lee, 1994, for a review see Hayhoe & Ballard, 2005) and of audio–visual tasks (Baumann & Greenlee, 2007); however, to our knowledge, no cross-modal study between vision and olfaction was performed by means of this apparatus. Here, the eye tracker method could enable us to observe participants' selective attention towards the object congruent with earlier presented odor.

Therefore, the aim of this study was to examine whether an odor can enhance participants' visual attention towards its congruent object in terms of frequency and duration of eye fixation. Given that an olfactory cue could trigger visual performance (Chow & Frye, 2008; Duistermars & Frye, 2008; Frey et al., 2003; Maaswinkel & Li, 2003; Reinhard et al., 2004; Rossier & Schenk, 2003) and influence human behavior towards a visual stimulus (Castiello et al., 2006; Demattè et al., 2007; Knasko, 1995; Michael et al., 2003; Millot et al., 2002; Tubaldi, Ansuini, Demattè, et al., 2008; Tubaldi, Ansuini, Tirindelli, et al., 2008), we hypothesized that an olfactory cue enhances visual selective attention towards its corresponding object. Specifically, participants looked more often and longer at the object congruent with previously presented odor as compared to the odorless condition.

Materials and methods

Participants

A total of 60 healthy right handed volunteers (40 women and 20 men) with an age range from 19 to 44 years (mean ± standard deviation (SD) = 24.4 ± 4.6 years) participated in this study. Handedness was determined using a translated version of the Edinburgh Inventory (Oldfield, 1971). Participants were recruited via leaflet. All participants confirmed that they were in good health and had normal smell and vision. The experiment was explained to all participants in great detail and informed consent was obtained for participation. In order to exclude participants with impaired olfaction, color-blindness, or impaired cognitive function, the "Sniffin' Sticks" screening test (Burghart Instruments, Wedel, Germany; for details see Hummel, Konnerth, Rosenheim, & Kobal, 2001), the Ishihara color test (Ishihara, 1986), and the "Mini-Mental-State Examination" (MMSE) (Folstein, Folstein, & McHugh, 1975) were used, respectively.

The participants were divided into two groups, non-odor group (19 women and 11 men, mean age ± SD = 24.4 ± 4.6 years) and odor group (21 women and 9 men, mean age ± SD = 24.5 ± 4.7 years) due to the order of their appearance. Additionally, sex ratio was counterbalanced between both groups. The groups did not differ from each other in terms of mean age ($t(58) = -0.11$, $p = .91$) and sex ratio ($\chi^2(1, N = 60) = 0.30$, $p = .58$).

Stimuli and presentation

Four odors (orange, PG 92122; liquorice, RC 110/15, both from Fragrance Resources GmbH, Hamburg, Germany; coffee, P0613905; lavender, P0123527, both from FREY+LAU GmbH, Henstedt-Ulzburg, Germany) were used as olfactory primers. All odors were delivered by using a computer-controlled air-dilution olfactometer (OM6b, Burghart, Wedel, Germany). Olfactory stimuli (10% (v/v)) diluted by humidified air were embedded in a constantly flowing air stream (7.0 L/min), with controlled temperature (36 °C) and humidity (80% relative humidity). Intensities of all odors were equally controlled: e.g. 4–5 points in a scale ranging