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Cross-modal integration between odors and abstract symbols

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ABSTRACT

This study aimed to investigate the cross-modal association of an "abstract symbol," designed for representation of an odor, with its corresponding odor. First, to explore the associations of abstract symbols with odors, participants were asked to match 8 odors with 19 different abstract symbols (Experiment 1). Next, we determined whether congruent symbols could modulate olfactory perception and olfactory event-related potentials (ERPs) (Experiment 2). One of two odors (phenylethanol (PEA) or 1-butanol) was presented with one of three conditions (congruent or incongruent symbol, no-symbol), and participants were asked to rate odor intensity and pleasantness during olfactory ERP recordings. Experiment 1 demonstrated that certain abstract symbols could be paired with specific odors. In Experiment 2 congruent symbol enhanced the intensity of PEA compared to no-symbol presentation. In addition, the respective congruent symbol increased the pleasantness of PEA and the unpleasantness of 1-butanol. Finally, compared to the incongruent symbol, the congruent symbol produced significantly higher amplitudes and shorter latencies in the N1 peak of olfactory ERPs. In conclusion, our findings demonstrated that abstract symbols may be associated with specific odors.

So far, in a line of studies investigating cross-modal integrations between vision and olfaction, verbal labels [2,5,7,13,25] and colors [6,8,10,17,24,28] have been used as visual stimuli. Based on those studies, it is assumed that a congruent verbal label of an odor enhances odor identification [7] or pleasantness [2,5,13,25], although the effect was not obtained always for all odors [2,25]. Similarly, an appropriate color not only facilitates odor identification [8] or discrimination [6], but also increases odor pleasantness [17].

Compared to verbal labels and colors, pictorial images [6,11,12,23] have received relatively few interests in this field. Sakai et al. [23] found that congruent pictures magnify odor intensity and pleasantness more strongly than incongruent ones. As another example, Gottfried and Dolan [11] demonstrated that participants detected odors more quickly and accurately in semantically congruent combinations of odors with pictures, compared to semantically incongruent combinations. However, considering that the different types of visual cues interact with olfactory cues differently [6], further studies are needed to understand integrations between visual images and odors.

In particular, to our knowledge, no study has been published in a peer-reviewed journal combining odor presentation with an "abstract image" such as an icon, symbol, or sign. Thus, the present study aimed to elucidate the cross-modal association of odors with "abstract symbols" intentionally created to reflect the specific odors. In Experiment 1, we explored whether certain abstract symbols could be connected with specific odors. As an extension of Experiment 1, we also wanted to investigate the associations of abstract symbols with odors using olfactory event-related potentials (ERPs), as well as psychophysical tests in the Experiment 2. Specifically, on the basis of aforementioned findings using verbal labels, colors, and pictorial images, we hypothesized that participants rate odors as being more intense and pleasant when the odors are presented with congruent symbols compared to the inverse situation, or when no-symbol is presented. Moreover, given the earlier findings of vision-olfaction integration [6,11] and the Stroop paradigm [29], we hypothesized that congruent combinations yield higher amplitudes and shorter latencies of ERP peaks (e.g., N1 and/or P2; see below), compared to incongruent or no-symbol condition.

First, in Experiment 1, a total of 120 participants (93 females and 27 males) with an age range from 19 to 55 years participated. All of these participants were recruited from a population of the Münster University of Applied Sciences. All participants confirmed that they had no clinical history of major diseases and that their

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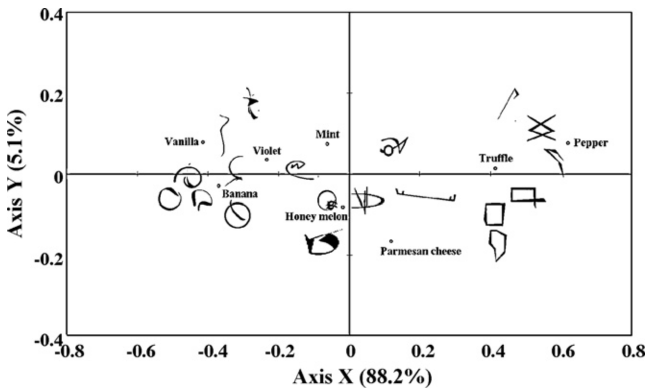

Fig. 1. The associations between abstract symbols and odors. The correspondence analysis revealed that certain abstract symbols could match with specific odors.

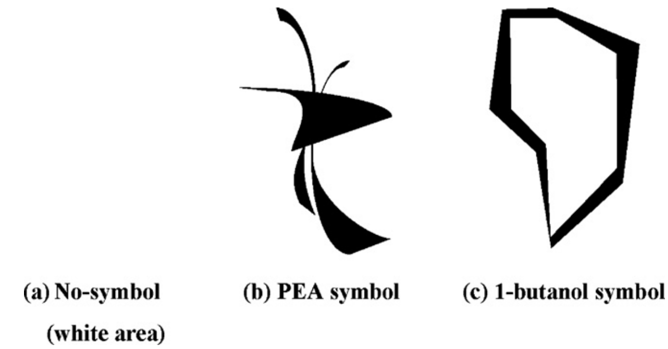

Fig. 2. Three different types of visual stimuli used in this study. In this study, three different types of visual stimuli were employed: (a) no-symbol (white area), (b) abstract symbol of phenylethanol (PEA) odor, and (c) abstract symbol of 1-butanol odor.

sense of smell was not impaired. The procedures were explained to all participants in great detail and informed consent was obtained for participation.

As olfactory stimuli, 8 odors were used: banana, honey melon, mint, parmesan cheese, pepper, truffle, vanilla, and viola. All odors except parmesan cheese were artificial products (Symrise, Holzminden, Germany). Also, 19 abstract symbols were used as visual stimuli having different shapes, directions, and components (Olfatype®, Darmstadt, Germany; Fig. 1).

Participants were presented with 8 odors (kept in dark glass bottles), together with a list of 19 abstract symbols. After smelling each odor for 3–4 s, participants were instructed to answer the question: "*Does this odor fit to this symbol?*" via "yes" or "no" when viewing the 19 different symbols one by one. Multiple answers were allowed for each odor. All abstract symbols were applied in an irregular order.

The correspondence analyses using statistical software (XLSTAT, Addinsoft, NY, USA) demonstrated the pairs of abstract symbols with odors (Fig. 1). The first two dimensions (i.e., axes X and Y) accounted for 93.3% of total variance, and in particular, the first dimension (i.e., axis X) explained a large portion of total variance (88.2%). The odors generally regarded as being pleasant (e.g., vanilla, banana, violet, honey melon, and mint) were paired with circle- or curve-shaped symbols. Whereas, the odors judged generally as being unpleasant (e.g., parmesan cheese, truffle, and pepper) were paired with square- or angular-shaped symbols (Fig. 1).

In Experiment 2, a total of 100 healthy volunteers (54 females and 46 males) with an age range from 9 to 81 years participated in a preliminary odor-symbol association test. Subsequently, another 42 participants (28 females and 14 males) with an age range from 23 to 62 years took part in the psychophysical and electrophysiological tests. In order to exclude participants with olfactory loss and impaired cognitive function, the "Sniffin' Sticks" screening test (Burghart Instruments, Wedel, Germany; for details see [14]) and the "Mini-Mental-State Examination" (MMSE) [9] were used, respectively.

As olfactory stimuli two odors were used, 2-phenyethanol (PEA; Sigma–Aldrich, Steinheim, Germany) and 0.4% dilution of 1-butanol (Merck, Darmstadt, Germany) in 1,2-propanediol (Sigma–Aldrich, Steinheim, Germany). Moreover, as visual stimuli, two different abstract symbols were selected based on the results from Experiment 1. Specifically, as seen in Fig. 1, one abstract symbol (Fig. 2(b)) adjacent to the violet odor and the other symbol (Fig. 2(c)) close to the parmesan cheese odor were chosen as abstract symbol congruent with PEA (e.g., violet) or 1-butanol (e.g., parmesan cheese), respectively. Since it was difficult to control the odor of natural parmesan cheese via the olfactometer (see below) due to instability of parmesan cheese odor, the 1-butanol was used instead of natural parmesan cheese. Although the odor of 1-butanol is generally characterized as "chemical" or "malty," the odor of 1-butanol diluted was close to that of parmesan cheese. In addition, a white area (i.e., no-symbol) was used as a positive control in the psychophysical and electrophysiological tests.

Prior to the psychophysical and electrophysiological tests, to confirm the congruency of abstract symbols chosen with odors, the odor-symbol association test was conducted. In the test, one of two abstract symbols was separately presented on a monitor for six seconds. Three seconds after the onset of symbol presentation, participants were asked to sniff one of two odors for three seconds, and they were instructed to answer the question: "*How appropriate is this symbol to the presented odor?*" via a 9-point scale (1: extremely inappropriate to 9: extremely appropriate). The combination of symbols and odors (two symbols x two odors) was presented in irregular order across participants.

During the psychophysical and electrophysiological tests, one of two abstract symbols or no-symbol (i.e., white area) was presented on the computer monitor for four seconds. Subsequently, three seconds after the onset of visual presentation, one of two odors was presented for 250 ms to the right nostril of participants. The odors were delivered via a dynamic air-dilution olfactometer (OM2b; Burghart, Wedel, Germany). The olfactory stimuli were embedded in a constantly flowing air stream of 7.0 L/min, with controlled temperature (36 °C) and humidity (80% relative humidity). All participants were instructed to perform the velopharyngeal closure breathing technique [15] to prevent nasal air flow during the experiment. They also received white noise (approximately 50 dB SPL) via headphones to dampen environmental sounds (e.g., valve switching sound of olfactometer).

There were six different combinations between visual and olfactory stimuli (three different abstract symbols (Fig. 2) × two different odors). The combinations were randomized across participants. Each condition was repeated 16 times. Thus, total number of stimuli presentations were 96 (6 conditions × 16 repetitions). To minimize olfactory desensitization, 27–33 s were allowed between odor presentations.

According to the experimental design, after receiving the visual and olfactory stimuli together, participants were instructed to immediately rate odor intensity and pleasantness. The participants rated the odor intensity on a visual analogue scale (VAS) ranging between 0 (extremely weak) and 100 (extremely strong). Also, they rated odor pleasantness on a VAS ranging from 0 (extremely unpleasant) to 100 (extremely pleasant). Instructions and scales were presented on a monitor using software (E-Prime 2.0). Prior to the experiment participants had no information what odors they would smell or what symbols they would see.

Olfactory ERPs were recorded from three electrode sites of the international 10–20 system, Fz (frontal), Cz (central), and Pz (pari-