Scents boost preference for novel fruits

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Abstract

When faced with a novel food, multisensory information that includes appearance and smell is a very important cue for preference, categorization, and the decision of whether or not to eat it. We elucidated whether olfactory information leads to biased visual categorization of and preference for fruits, even when odors are presented subliminally. We employed morphed images of strawberries and tomatoes combined with their corresponding odorants as stimuli. Participants were asked to categorize the images into either of two categories, to evaluate their preference for each visual image, and to judge the presence/absence of the odor. Results demonstrated that visual categorization was not affected by the odor manipulation; however, preference for uncategorizable images increased when odors were presented regardless of the participant's awareness of the odor. Our findings suggest that visual preference for novel fruits is based on both conscious and unconscious olfactory processing regarding edibility.

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Introduction

Humans are omnivores. Omnivores can adapt to dynamic and diverse environments by eating highly diversified foods. In a natural environment, the availability of food sources alters depending on seasons and habitats. For example, brown bears primarily eat insects and herbs in the summer months but eat nuts in the autumn months to adapt to the season-based changes in food sources. However, one limitation to being an omnivore is the risk of accidental ingestion of harmful foods, especially when a food is novel. Food neophobia is an ingestion-avoidance response toward novel foods, and is considered to be characteristic of omnivores such as humans (Pliner & Salvy, 2006). Food neophobia is deemed to serve a protective function to prevent the ingestion of potentially harmful foods by evoking negative emotional reactions to unfamiliar foods. Humans use multisensory information, such as appearance and smell, to prevent themselves from ingesting potentially harmful foods.

Vision and olfaction interact with each other. So far, many previous studies have reported that olfactory processing is affected by visual information (e.g., DuBose, Cardello, & Maller, 1980; Garber, Hyatt & Starr 2000; Gottfried & Dolan, 2003; Morrot, Brochet, & Dubourdieu, 2001; Stillman, 1993; Zellner, Bartoli, & Eckard, 1991; Zellner & Kautz, 1990; for a review see Spence, Levitan, Shankar, & Zampini, 2010). Recently, it has also been found that olfactory information affects visual processing. For example, olfactory information corresponding to a visual object influences visual attention in space (Seo, Roidl, Müller, & Negoias, 2010) and time (Robinson, Mattingley, & Reinhard, 2013). Likewise, in a binocular rivalry situation, visual stimuli corresponding to odor information becomes perceptually dominant for a relatively longer time, based on the nostril-visual field correspondence (Zhou, Zhang, Chen, Wang, & Chen, 2012). Furthermore, a subliminally presented cleaner scent induces faster identification of cleaning-related words (Holland, Hendriks, & Aarts, 2005). Moreover, infants looked for a longer time at an object when an odor stimulus corresponding to the object was presented (Wada, Inada, Yang, Kunieda, Masuda, Kimura et al., 2012). These previous studies commonly suggest that the categorical consistency between visual and olfactory information is key to increasing the saliency of, preference for, or associated representations of visual objects. However, it is still unclear whether olfactory information induces a shift of visual categorization judgment, and whether enhancement of categorization caused by olfactory information bias is a necessary component of enhancement of visual preference caused by olfaction.

Here, we investigated whether olfactory information modulates categorization of visual objects, and whether the preference for visual objects that correspond to olfactory information stems from the categorization bias. In addition, we aimed to elucidate these issues by using perceptible and imperceptible odor stimuli because previous studies have shown that olfactory information modulates human cognition and behavior even when the odor stimuli are presented subliminally (Holland et al., 2005; Li, Moallem, Paller, & Gottfried, 2007; Seigneuric, Durand, Jiang, Baudouin, & Schaal, 2010). This experimental condition will help clarify at what stage in mental processing the visual-olfactory interaction occurs.

Visual stimuli with a multilevel categorical ambiguity are necessary in order to examine a visual categorization bias. Therefore, we employed 11-step morphed images generated by superimposing photos of a strawberry and a tomato (Yamada, Kawabe, & Ihaya, 2012). Yamada et al. found that observers disliked fruit images with ambiguous categorical information. Furthermore, they reported that participants with high food neophobia produced lower scores for eatability and preference for novel fruit than those with low food neophobia. They claimed that this aversive reaction was due to a mechanism for avoiding the risk of ingesting strange foods.

In their study, Yamada et al. (2012) manipulated only visual information using morphed images, but the effect of additional information from other modalities on visual categorization has been examined using a two-alternative forced choice (2AFC) for morphed images (de Gelder & Vroomen, 2000). In this paradigm, it can be assumed that the effect of other modalities becomes prominent for the most ambiguous stimulus, in which visual information is less reliable. In the present study, we presented the same visual stimuli used in Yamada et al. to participants, and simultaneously presented a strawberry or tomato odor in the background at a subliminal or supraliminal level. Participants were asked to categorize the images into one of two categories (strawberry or tomato). If visual categorization were biased by the background olfactory information, the point of subjective equality (PSE) of categorization would shift in the direction of the corresponding category. Conversely, if a visual preference enhancement occurred, as in previous studies, independently of categorization enhancement, categorization bias would not occur in the present experiment but a preference shift would be observed.

We also measured participants' preferences for the morphed images. If olfactory enhancement of visual preference were due to the enhancement of categorization by overlapping multisensory information, an increment of preference would occur in visual objects that were moderately hard to categorize but that corresponded to the olfactory category, but not in a visual object at the PSE, which would appear novel to participants. If odors of fruits without a strict categorical correspondence between vision and olfaction generally increased the "foodness" of the uncategorizable objects, we could expect that a preference increment of the morphed images at and around the PSE would occur.

Materials and Methods

Participants. Fifty-six graduate and undergraduate students attending Kyushu University participated in the experiment. The participants were unaware of the purpose of the experiment and all reported that they had normal olfaction and vision. The experiment was conducted according to the principles laid down in the Helsinki Declaration. Written informed consent was obtained from all participants after the nature and possible consequences of the study were explained to them. The ethical committees of Kyushu University and the National Food Research Institute approved the protocol. In a pre-experiment screening, three participants were excluded from the experiment because they disliked strawberries or tomatoes. In a post-experiment screening, another three participants were excluded because they explicitly perceived the odor in the subliminal condition or could not perceive the odor in the supraliminal condition. Ten participants were randomly assigned to each of the five conditions: subliminal-strawberry (2 males, mean age ± SEM = 21.5 ± 0.48 years), subliminal-tomato (2 males, 24.4 ± 1.53 years), supraliminal-strawberry (2 males, 24.3 ± 1.52 years), supraliminal-tomato (4 males, 22.2 ± 1.08 years), and odorless conditions (6 males, 22.8 ± 0.59 years), which are described below.

Apparatus and Stimuli. The stimuli were presented on a 19-in. CRT monitor (RDF193H; Mitsubishi, Japan) with a resolution of 1024 x 768 pixels, and a refresh rate of 100 Hz. The presentation of stimuli and the collection of data were controlled using a computer (Mac Pro; Apple, CA, USA). The visual stimuli were generated by Matlab with a Psychtoolbox extension (Brainard, 1997; Pelli, 1997).

Visual stimuli consisted of a fixation point, command cursors for rating, and images made up of morphed photographs of tomatoes and strawberries (Figure 1). Stimuli were presented at a viewing distance of 40 cm. The fixation point was composed of two concentric rings, one small and one large, with radii of 0.24° and 0.47° in visual angle, respectively. The luminance of each ring was 91.0 cd/m^2. The command cursors were white boxes surrounding each rating value (0.95 × 1.89°; 91.0 cd/m^2) and the selected box was filled in white. We employed color pictures (12.1° × 12.1°) of a tomato and a strawberry. We generated 11 equally stepped morphed images with tomato percentages ranging from 0% to 100%. Each stimulus was displayed on a gray background (43.5 cd/m^2).

Odor stimuli were water solutions of

strawberry and tomato odorants. These odorants were used in Wada et al. (2012) and, although the tomato odor was more difficult to categorize then the strawberry odor in the pilot experiment, the previous study has confirmed that most adults can successfully identify the olfactory categories of the odorants. In the subliminal condition of the present study, a 0.015% water solution was diffused by means of an aroma diffuser (CCP Co., Ltd., Tokyo, Japan). In the supraliminal condition, a 0.2% water solution was diffused. A divider plate was installed beside the computer. The diffuser was set behind the plate and out of sight of participants. Diffusion of the water solution began one to two hours before the experiment and continued until the end of the experiment.

Procedure. The experiment was conducted in a darkened room. Each participant's visual field was fixed using a chinrest. The experiment consisted of two task blocks: a categorization task and an evaluation task. The order of the blocks was counterbalanced across the participants.

Participants initiated each trial by pressing the spacebar on a computer keyboard. The fixation point was presented throughout the experiment whenever there was no image on-screen. For each trial in the categorization task, after a delay of a random duration between 800 and 1200 ms, a morphed image was presented and remained on the screen until a response was made. The participant's task was to categorize the morphed image as either of two categories (i.e., strawberry or tomato) by pressing assigned keys as quickly as possible while maintaining accuracy. Each participant performed 220 trials (20 repetitions of 11 images). The trial order was randomized for each participant.

For each trial in the evaluation task, after a delay of 500 ms a morphed image was presented and remained on the screen until an evaluation was made. The participants were asked to evaluate their preference for each image using a 7-point scale ranging from -3 (*strongly not prefer*) to 3 (*strongly prefer*) using selection keys and a decision key. Rapid responses were not encouraged. Each participant performed 11 trials (1 series of 11 images). The trial order was randomized for each participant.

After the experimental blocks, participants were asked whether they were aware of the odor and of the influence of the odor on their performance (Holland et al., 2005). The post-experimental interview showed that none of the participants were aware of the odor in the subliminal conditions and all the participants were aware of and identified the odor in the supraliminal conditions.

Figure 1. Examples of visual stimuli used in this study.

Results

Categorization

The results of the categorization task are shown in Figure 2. The proportion of the trials in which the image was judged as a tomato was the subject of the analysis here. A two-way mixed between-within participants analysis of variance (ANOVA) performed on "proportion of tomato" with odor type (subliminal-strawberry, subliminal-tomato, supraliminal-strawberry, supraliminal-tomato, and odorless) as a between-participants factor and tomato percentage as a within-participant factor revealed a significant main effect of tomato percentage, $F(10, 450) = 861.91$, $p < .0001$, $p_{rep} = .997$, $\eta_p^2 = .95$ (Figure 2a). Neither a main effect of the odor type, $F(4, 45) = 0.38$, $p = .8253$, $p_{rep} = .562$, $\eta_p^2 = .03$, nor the interaction, $F(40, 450) = 0.83$, $p = .7636$, $p_{rep} = .584$, $\eta_p^2 = .07$, was significant. Furthermore, we calculated the PSE (Mean ± SEM = 63.6 ± 0.95%) for each participant by fitting a cumulative Gaussian function to proportion of tomato as a function of the tomato percentage (Figure 2b). The mean R^2 was .986, suggesting a high goodness of fit. A one-way between-participants ANOVA on PSE with the odor type as a factor showed no significant main effect, $F(4, 45) = 0.30$, $p = .8741$, $p_{rep} = .545$, $\eta_p^2 = .03$.

We also analyzed reaction time data for the categorization task (Figure 2c). A two-way mixed between-within participants ANOVA performed on log-transformed "reaction time" with odor type as a between-participants factor and tomato percentage as a within-participant factor revealed a significant main effect of tomato percentage, $F(10, 450) = 32.66$, $p < .0001$, $p_{rep} = .997$, $\eta_p^2 = .42$. Neither a main effect of odor type, $F(4, 45) = 1.36$, $p = .2621$, $p_{rep} = .786$, $\eta_p^2 = .11$, nor the interaction, $F(40, 450) = 0.74$, $p = .8756$, $p_{rep} = .544$, $\eta_p^2 = .06$, was significant.

Evaluation

The results of the evaluation task are shown in Figure 3. A two-way mixed ANOVA on preference score was also performed and showed main effects of odor type, $F(4, 45) = 3.75$, $p = .0102$, $p_{rep} = .965$, $\eta_p^2 = .25$, and that tomato percentage, $F(10, 450) = 75.89$, $p < .0001$, $p_{rep} = .997$, $\eta_p^2 = .63$, and the interaction, $F(40, 450) = 1.80$, $p = .0027$, $p_{rep} = .983$, $\eta_p^2 = .14$, were significant. Post-hoc tests showed significant simple-main effects in the 40%, 50%, 70%, and 90% conditions, $F(4, 495) = 5.62$, $p = .0002$, $F(4, 495) = 3.84$, $p = .0044$, $F(4, 495) = 6.13$, $p = .0001$, $F(4, 495) = 5.41$, $p = .0003$, respectively. Multiple comparisons using the Ryan-Einot-Gabriel-Welsch multiple range test (Ryan, 1960) revealed that the preference score for the odorless condition was significantly lower than that for the other four conditions in the 40% morphing image. In the 50% image, the preference score for the odorless condition was significantly lower than that for the subliminal-strawberry condition. In the 70% image, the preference scores for the subliminal- and supraliminal-tomato conditions were significantly higher than those for the subliminal-strawberry and odorless conditions. Lastly, in the 90% image the preference scores for the subliminal- and supraliminal-tomato conditions were significantly higher than those for the odorless condition, and the preference score for the subliminal-tomato condition was significantly higher than that for the subliminal strawberry condition.

Discussion

The results indicate that the olfactory

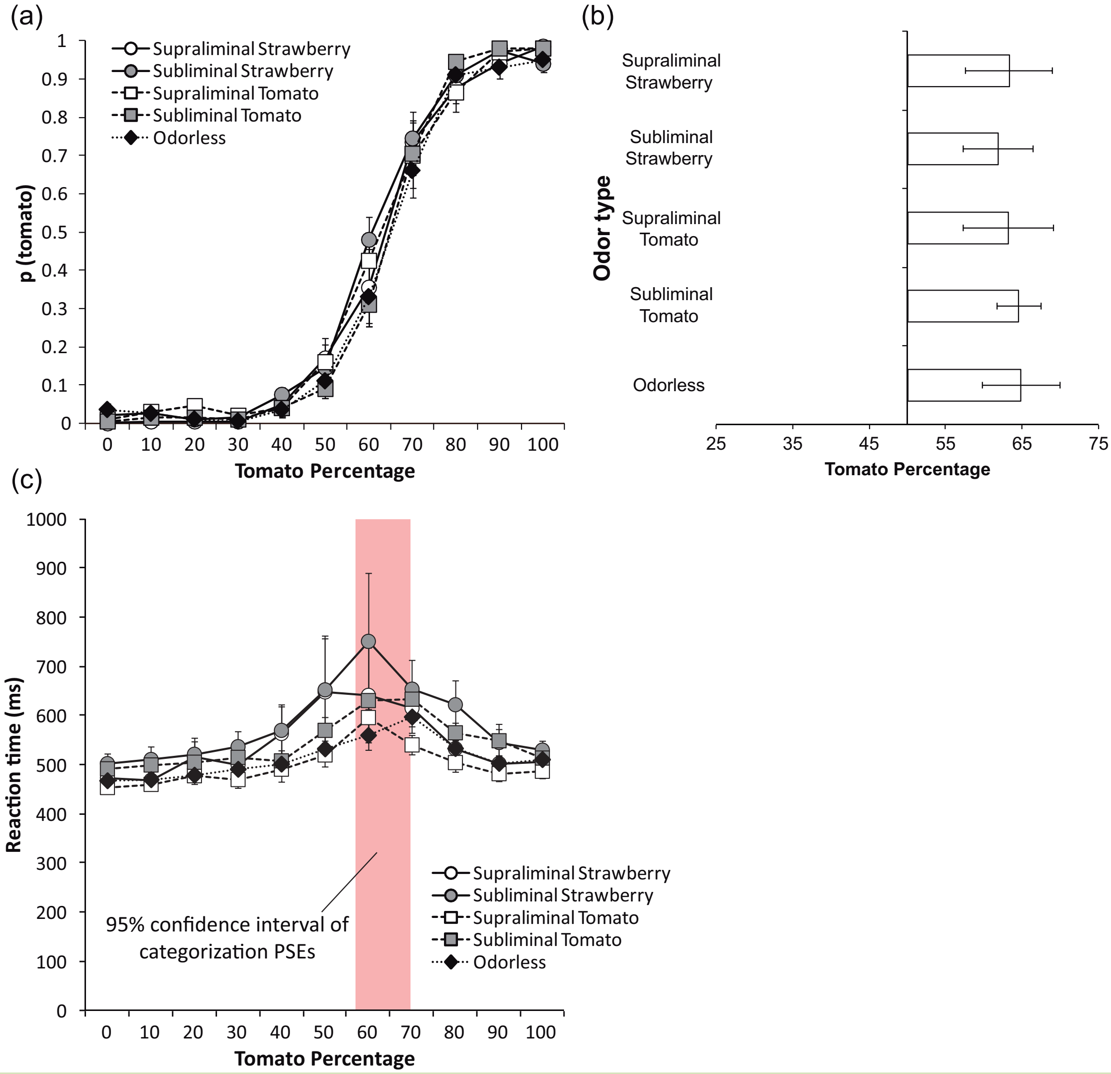

Figure 2. Results of the categorization task. (a) Proportions of tomato responses as a function of tomato percentages for each odor type. Error bars denote the standard errors of the mean. (b) Mean PSEs in each odor type. Error bars denote 95% confidence intervals. (c) Mean reaction time as a function of tomato percentages for each odor type. Error bars denote the standard errors of the mean. The colored zone in the graph indicates a 95% confidence interval for PSEs between the upper limit of a condition showing the maximum value and the lower limit of a condition showing the minimum value.

information did not affect visual categorization, whereas odors of fruits enhanced visual preference for novel fruit generated by the morphing of strawberry and tomato. This fact suggests that olfactory bias for visual preference is not caused by olfactory enhancement of visual categorization, but rather by olfactory information from a familiar smell which relays a message related to edibility or "foodness," which might reduce neophobia towards a food with a novel appearance even if odors are presented at a subliminal level. Given previous findings that have shown the effects of olfactory information on visual processing (e.g., Holland et al., 2005), it seems possible that visual categorization would be biased by background olfactory information, that is, the PSE of categorization would shift in the direction of the corresponding category. However, our study implies that this hypothesis is not true.

There is also the possibility that the lack of significant effect of olfactory information on visual categorization might be due to the repetitive presentation of the images. Over the experimental session, participants may realize or assume the purpose of the experiment or they may become familiar with the images, thereby resulting in a ceiling effect during the task. This may reduce the effect of congruent odors on the visual categorization task in the present study. However, a previous study that used multimodal stimuli and employed a 2AFC task similar to the present study also presented visual stimuli repeatedly (de Gelder et al., 2000). The researchers observed obvious multimodal effects even when they presented each image six times. This fact suggests that multimodal interactions could be detected during a 2AFC task with repetitive presentation of visual images, at least in their study. The present study presented each image 20 times: This may seem highly repetitive, and raises the question of whether the number of repetitions matters. We used categorization data from only the first five repetitions (smaller than the number of repetition in de Gelder et al.) and submitted it to a two-way mixed ANOVA similar to the one used in the main analysis. The results showed no significant interaction between odor types and tomato percentage, $F(40, 450) = 0.79$, $p = .8254$, $p_{rep} = .562$, $\eta_p^2 = .07$, as in the main results. Thus, it is plausible that repetitive presentation was not critical in the present study and that olfactory information had little or no effect on visual categorization.

Olfactory information, however, did affect preference for the fruits regardless of the subjects' awareness of the odors. Specifically, the strawberry odor boosted preference for morphed images that were categorized as strawberries. Likewise, the tomato odor increased preference

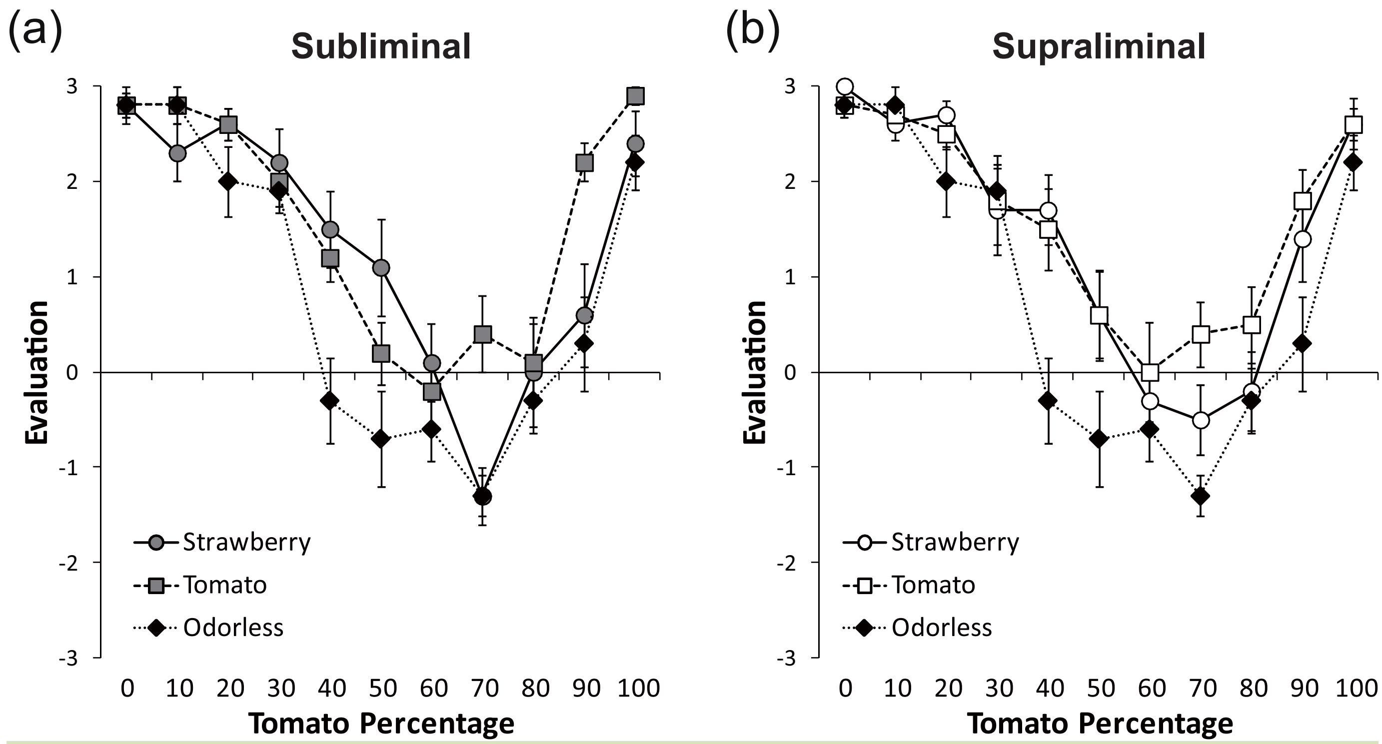

Figure 3. Results of the evaluation task. The results of (a) subliminal and (b) supraliminal conditions are shown separately for visibility. Error bars denote the standard errors of the mean.

for morphed images around the PSE. That is, olfactory information increased preference only for uncategorizable images, not for all images, suggesting that olfactory information is utilized only for evaluation of uncategorizable fruits. However, it must be noted that categorizable images (e.g., 0% and 100%) were evaluated with almost maximum scores, and hence it was also possible that the results were due to a ceiling effect: Further experimentation with more appropriate categories or rating methods are deemed necessary to resolve this issue.

In addition, the tomato odor also increased preference for images with high strawberry percentages (e.g., 40%). This may be because of the scarcity of a categorical uniformity of the tomato odor (Wada et al., 2012). In daily life, we experience the tomato odor via a broad range of dishes, in which the appearance of tomatoes is substantially changed, and thus the tomato odor increases preference not only for tomato-like foods, but also for uncategorizable foods. On the other hand, the strawberry odor may be relatively uniformly categorized into strawberry, because strawberries are often eaten as is. Note, however, that the previous study explicitly tested this issue. In their pilot study, Wada et al. asked 31 adults to freely sniff the two odorants, which are the same as the ones used in the present study, and to freely name them. The researchers found that the tomato odor was difficult for participants to categorize relative to the strawberry odor, but that the categorization performance for the tomato odor was significantly correct nonetheless. Thus, it is still unclear whether vague, difficult to categorize fruit or food odors could induce the preference effects found in the present study. It would be interesting to explore whether a fruit odor unrelated to the visual category (e.g., banana odor with tomato visual) or a very vague but clearly food-like odor could produce the preference effect.

The present results provide evidence that allows the inference of an internal mechanism regarding food preference. Previous studies have claimed that negative responses for uncategorizable objects are based on a stranger-avoidance mechanism (Yamada et al., 2012; Yamada, Kawabe, & Ihaya, 2013). This explanation is based on the assumption that the cognitive system elicits negative reactions to an uncategorizable, unknown object in order to avoid negative repercussions. Totally uncategorizable objects are rarely found in nature, so this strategy is plausible for omnivores to adapt to a dynamic and diverse environment (e.g., it prevents “over-avoidance”). In food research, it might closely relate to food neophobia (Pliner & Salvy, 2006). The present experiment has replicated stranger-avoidance reactions to uncategorizable objects. More importantly, the findings suggest that stranger-avoidance reactions could be diminished with additional information. It is unlikely that specific categorical information involved in the strawberry and tomato odors helped to reduce the visual strangeness of the objects, because these odors did not affect the performance of visual categorization at all. Conversely, it is possible that the odors added the categorical information of “food”, thereby increasing the perceived edibility of (and thus preference for) the objects. Furthermore, the results of the subliminal conditions suggest that this process also works unconsciously. It has been repeatedly reported that emotional processing operates unconsciously (Ghuman & Bar, 2006; Murphy & Zajonc, 1993; Sweeny, Grabowecky, Suzuki, & Paller, 2009; Yamada & Kawabe, 2011; for a review see Tsuchiya & Adolphs, 2007). The effect of odors on visual processing has also been found in a subliminal odor presentation experiment (Holland et al., 2005). Consistent with these previous findings, the present study suggests that human food preferences are based on an unconscious process as well as a conscious process of integrating categorical information from multiple modalities.

Another possible explanation is based on processing fluency. One can argue that food information from multiple modalities (i.e., vision and olfaction) can induce more positive affective responses than that from a single modality (i.e., vision only). A previous study suggested that more information gives observers more pleasure (Biederman & Vessel, 2006). Higher processing fluency for the fruits may be yielded by more information from multiple modalities (e.g., Zhou et al., 2012), thereby eliciting more positive responses (Reber, Winkielman, & Schwarz, 1998). Is this the case? To clarify this issue, we analysed reaction time data for the categorization task. The fluency-based explanation predicts that reaction time for categorization would be reduced when the visual and olfactory categories were congruent. However, there was neither a main effect of odor type nor significant interaction between odor type and tomato percentage. These results are very important because the evidence suggests that a fluency-based explanation of the present findings is unlikely. That is, the odors did not affect processing fluency. However, a categorization-based mechanism would be plausible.

Furthermore, one might argue that the present findings were a by-product of an artifact in which participants intentionally biased their responses so as to increase evaluation for images categorically similar to background odors. However, this possibility is not plausible because the effect of odors was also found in the subliminal conditions. In these conditions, participants could not detect the odors, and hence they could not intentionally bias their responses toward the category of the background odor. Moreover, this intention-based hypothesis cannot explain why the effect of odors was found only in the evaluation task. The intention-based hypothesis predicts that the effect of odors also occurs in the categorization task. However, the background odors did not affect participants' categorization performance at all. In addition, in the post-experimental interview, no participants answered that their task performance was affected by odors during the experiment. Therefore, the possibility of that kind of artifact was successfully ruled out.

Conclusion

In summary, the present study aimed to clarify the effect of subliminal and supraliminal odors of strawberry and tomato on visual categorization and evaluation of fruits. We found that the odors did not affect categorization but affected preference for fruit images regardless of the participants' awareness of the odors. A categorization-based mechanism was proposed as underpinning the present findings. Here, we have provided compelling evidence that additional information both subliminally and supraliminally provided through modalities other than the task-related modality influences object evaluation.

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