Cross-modal and subliminal effects of smell and color

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In the present study, we examined whether the cross-modal effect can be obtained between odors and colors, which has been confirmed under olfactory recognizable conditions and also occurs under unrecognizable conditions. We used two flavors of red fruits such as strawberries and tomatoes for this purpose. We also aimed to compare whether similar cross-modal effects could be achieved by setting the flavors at recognizable (liminal) and unrecognizable (subliminal) concentrations in the experiment. One flavor at a normal concentration (0.1%, Liminal condition) and one at a concentration below the subliminal threshold (0.015%, Subliminal condition), were presented, and the color that resembled the smell most closely from among the 10 colors, was selected by participants. Except for the subliminal tomato condition, each odor was significantly associated with at least one color ($p<0.01$). Participants selected pink and red for liminal strawberry (0.1%) ($p < 0.05$), pink for subliminal strawberry (0.015%) ($p < 0.05$), and orange for liminal tomato (0.1%) ($p < 0.05$), but there was no color selected for subliminal tomato (0.015%) ($p > 0.05$). The results of this study suggest that the flavor of tomato produced a cross-modal effect in liminal conditions, but not in subliminal conditions. On the other hand, the results of the present study suggest that the flavor of strawberries produces a cross-modal effect even under subliminal conditions. This study showed that cross-modal effects might exist, even at unrecognizable levels of flavor.

Title: Cross-modal and subliminal effects of smell and color

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Abstract

In the present study, we examined whether the cross-modal effect can be obtained between odors and colors, which has been confirmed under olfactory recognizable conditions and also occurs under unrecognizable conditions. We used two flavors of red fruits such as strawberries and tomatoes for this purpose. We also aimed to compare whether similar cross-modal effects could be achieved by setting the flavors at recognizable (liminal) and unrecognizable (subliminal) concentrations in the experiment. One flavor at a normal concentration (0.1%, Liminal condition) and one at a concentration below the subliminal threshold (0.015%, Subliminal condition), were presented, and the color that resembled the smell most closely from among the 10 colors, was selected by participants. Except for the subliminal tomato condition, each odor was significantly associated with at least one color ($p<0.01$). Participants selected pink and red for liminal strawberry (0.1%) ($p < 0.05$), pink for subliminal strawberry (0.015%) ($p < 0.05$), and orange for liminal tomato (0.1%) ($p < 0.05$), but there was no color selected for subliminal tomato (0.015%) ($p > 0.05$). The results of this study suggest that the flavor of tomato produced a cross-modal effect in liminal conditions, but not in subliminal conditions. On the other hand, the results of the present study suggest that the flavor of strawberries produces a cross-modal effect even under subliminal conditions. This study showed that cross-modal effects might exist, even at unrecognizable levels of flavor.

Introduction

Understanding how humans process, integrate, and perceive external stimuli in the brain is very important. Many smells that we perceive in our daily lives can be easily expressed by the names of colors. For example, if asked to describe the smell of a lemon using color terms, people are more likely to use the word "yellow" than the word "blue" to describe it. Similarly, when people smell ripe strawberries at the market or elsewhere, they look for red fruits rather than orange fruits to find the source of the aroma. Such a phenomenon wherein perceptions that are supposed to be separate, such as taste and vision, or vision and smell, influence each other, is called a cross-modal phenomenon, and the effect it produces is called a cross-modal effect (Heatherly, Dien, Munafo & Luckett, 2019; Kemp & Gilbert, 1997; Luisa Demattè, Sanabria & Spence, 2006; Schifferstein & Howell, 2015; Schifferstein & Tanudjaja, 2004). Cross-modal effects such as those in everyday life, especially the cross-modal associations between vision and smell, are so numerous that a stable association between certain colors and smells has been demonstrated. Gottfried and Dolan (2003) showed that the presentation of visual stimuli with complex pictures may affect olfactory information processing. In addition, Morrot et al. (2001) showed an association between odor and color, as white wine artificially colored red with odorless dyes was determined to be red wine based on visual and olfactory information. In the study by Luisa Demattè, Sanabria and Spence (2006), it can be seen that caramel odors are significantly selected to be brown or yellow, cucumber odors are green, and strawberry odors are pink or red. These results are consistent with the general colors of foodstuffs, indicating that a significant relationship exists between odor and color.

A subliminal effect is a phenomenon that is said to be expressed by unconsciously stimulating the viewer (Yamada et al., 2014). An example of subliminal effect is the repeated insertion of unrecognizable sub-threshold (subliminal) speed and volume advertisements on TV and radio to increase viewers' desire to buy. By working under an unrecognizable threshold–that is, subliminally–it is possible to influence actions, choices, and thoughts. In the study by Holland et al. (2005), there was a significant difference in word selection for cleaning when a word recognition task was performed by presenting a citrus scent used by common cleaners under a subliminal threshold. In addition, Li et al. (2007) showed that the facial expression judgment task, when presented with pleasant, unpleasant, and in-between odors under subliminal thresholds, affected the social liking of human facial expressions. Previous studies have shown that olfactory information can modulate human cognition and behavior even when odor stimuli are presented under a subliminal threshold.

While both cross-modal and subliminal effects have been studied in various ways, but few studies have examined cross-modal effects under subliminal conditions, and there are many unknowns and a lack of knowledge in the field of multisensory integration as a whole (Stein & Stanford, 2008). In this sense, it is worth examining the cross-modal link between the visual and olfactory. Yamada et al. (2014) showed that odors under subliminal conditions increased preference for unfamiliar food images. This may be closely related to food neophobia (Pliner & Salvy, 2006), a feeding avoidance response to novel foods in studies involving food and nutrition. Participants with food neophobia have been shown to react and evaluate odors differently than those without (Randenbush, 1998), and odor control may reduce stress over unfamiliar foods. Food neophobia can have a negative impact on health in terms of nutrition, since rejecting novel foods is likely to narrow the range of foods available. In 7-year-old girls, food neophobia has been found to be negatively correlated with vegetable consumption (Galloway et al., 2003) and with fruit and vegetable consumption in preschool children (Cooke et al., 2004). Similar to previous studies, this study focused on food odors and examined the cross-modal effects of vision.

Tomatoes and strawberries as the olfactory stimuli since they are popular, red agricultural products in Japan. In addition, the aromatic components of tomatoes include cis-3-hexenal and trans-2-hexenal (Wang and Seymour, 2017). They are also called green leaf alcohol and aldehyde and are found mainly in green fruits such as cucumbers, and cabbage. The aromatic components of strawberries include alcohols, esters, and aldehydes, with furaneol as the main aromatic component (Schwab, 2013). Since strawberries have a specific aromatic component, it would be possible that the odor and color of strawberries are easily recognized in association with strawberries. Different reactions may be observed depending on the two red fruits, one with an odor that explicitly evokes an image (strawberries) and the other with an odor that evokes several fruits (tomatoes). In the present study, we hypothesized that olfactory information did connect to the visual information regardless of the subject's awareness of the odors and that the olfactory information is utilized only for the subliminal odors that evoke an image of the object.

In the present study, we examine whether two flavors, strawberry, and tomato, produce the same cross-modal effect as in previous studies. The purpose of this study was to compare whether the flavors were set at recognizable (liminal) and unrecognizable (subliminal) concentrations and whether the different cross-modal effect was obtained, to compare the difference in effect between strawberry and tomato flavors, and to examine the relationship between odor and color.

Methods

Participants

The study participants consisted of 39 healthy people, between 18 and 22 years of age and with normal or corrected-to-normal eyesight. They received an explanation regarding their written informed consent, which included a description of the risks of the experiment. The Ethics Committee of the Niigata University of Health and Welfare approved this study (Approval number: 18243-190705). All the participants were naïve regarding the study protocol. The research contents were explained verbally to all participants. Written informed consent was obtained from each participant after a full explanation of the nature of the study procedure and its non-invasiveness. The number of participants was calculated by G*Power (Faul et al., 2007) prior to the experiment (Effect size = 1.2, alpha = 0.005, df = 19) determined from the results of preliminary experiments.

Protocol

Upon their arrival at the laboratory, participants were asked to sit in front of a computer in a small room for 15 minutes, to create a resting state. They were assured that their responses would remain completely anonymous as ID numbers were used to manage the data. They were then given instructions regarding the tasks conducted in the experiment. The experimenter then left the room to ensure the participants' anonymity during the experiment. The participants performed the tasks while facing the computer. All tasks were performed using a computer program written in PsychoPy (Peirce 2007; Peirce 2009; Peirce et al. 2019). The stimuli were presented on a 17" (inch) CRT monitor (LCS 172VXL; NEC, Japan) with a resolution of 1024 × 768 pixels and a refresh rate of 100 Hz. Stimulus presentation and data collection were controlled using a computer (M8-D, NEC, Japan). Stimuli were presented at a viewing distance of 40 cm. The luminance of the fixation point was 91.0 cd/m^2. The command cursors were the white boxes surrounding each rating value (0.95. × 1.89 °; 91.0 cd/m^2); selected boxes were filled in with white color.

The participants were tested under two conditions: 1) flavors with liminal concentration and 2) flavors with subliminal concentration. Two flavors were used: strawberries (T & M Co., Ltd.) and tomatoes (Yokoyama Flavoring Co., Ltd.). Each flavor was diluted with ion-exchanged water to achieve liminal (0.1%) and subliminal concentrations (0.015%) (Yamada et al., 2014) to create four different samples. The four flavors were correctly identified by the participants as liminal and subliminal after all experiments. Odorless air was released with an aroma diffuser (Muji Supersonic Wave Aroma Diffuser; Rhohin Keikaku Co., Ltd.) from 1-2 h before the experiment and continued until the end of the experiment. In addition, a drop of the sample was placed on an aroma-testing paper and the paper was placed 3 cm away from the subject's nose for 4 s. The participants were wearing blindfolds and ear-muffs, during the experiment as in a previous study (Yamada et al., 2014).

All ten colors (red, yellow, blue, green, orange, pink, brown, turquoise, purple, and gray) were displayed on the monitor, and the color that felt closest to their mood was selected by participants, as in a previous study (Dematte et al. 2006). Participants came to the laboratory eight times to be tested. The time between each visit was set to be open for at least 24 h. The same procedure was repeated twice for four different samples. The order of the ten colors displayed on the monitor for 15 s and the order of smelling the samples were randomized. The participants were not informed of the flavor of the odor used for the samples. The RGB values for the 10 colors were as follows: red (231, 0, 0), yellow (248, 248, 0), blue (0, 48, 255), green (0, 85, 0), orange (255, 85, 12), pink (255, 0, 193), brown (98, 48, 0), turquoise (0, 229, 189), purple (99, 13, 253), and ash (56, 56, 56) (Figure 1). Participants' judgments were saved in csv files. The colors, and odor types selected by the participants were statistically evaluated by residue analysis using the chi-square test (McHugh, 2013) for the colors associated with each odor type.

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 interview after all the experimental blocks 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 liminal conditions.

Statistical Analysis

We used a nonparametric χ^2 statistic to test whether the observed color associations for each of the odors deviated from an equal distribution. Given that we were interested in possible associations between particular odors and specific colors, we conducted post-hoc $\chi 2$ comparison using residual analysis (Bonferroni corrected, $\alpha = 0.005$ (0.05/10 colors)) between the participant's responses to the colors for each odor.

Results

The mean age of the participants was 19.7 ± 0.8 years. The chi-square test was used to compare the frequency of each odor with the color selected by the subjects, statistical analyses were performed, and the results were evaluated by residue analysis (Table 1). The results of the $\chi 2$ analysis showed that subjects' color responses to a given odor were not equally distributed among the 10 color options (i.e., they responded to a particular color on significantly more than 10% of trials) (upper row of Table 1, Liminal Strawberry; $p < 2.72 \times 10\text{-}11$, Subliminal Strawberry; $p < 1.30 \times 10\text{-}5$, Liminal Tomato; $p < 8.80 \times 10\text{-}3$). Most of the odors used in the experiment were significantly ($p < 0.005$) associated with at least one color (see a lower row of Table 1 for the respective p values). As in Tables 1 and 2, the colors significantly selected for the liminal (0.1% concentration) strawberry flavor were pink (50.0%) and red (23.7%). The color of the subliminal (0.015% concentration) strawberry was pink (42.1%). The most significantly selected color for the liminal (0.1% concentration) tomato flavor was orange (31.6%). No significant difference was observed for any color in the subliminal (0.015% concentration) tomato flavor.

Discussion

The analysis of the data reported here reveals that the flavors of foods, whether liminal or subliminal, produce a cross-modal effect and evoke common colors. In particular, our results show that a characteristic flavor, such as the flavor of strawberries, whether liminal or subliminal, evokes a similar color to that of the food. The pink color was significantly selected for the liminal (0.1% concentration) and subliminal (0.015% concentration) strawberry flavors.

This suggests that our finding that subliminal flavors can evoke a cross-modal effect is consistent with the results of Yamada et al. (2014). They found that visual choices were influenced by both conscious and unconscious olfactory processing. Similarly, previous studies have repeatedly reported that cognitive processing operates unconsciously (Tsuchiya & Adolphs, 2007). The effect of odors on visual processing has also been found in a subliminal odor presentation experiment (Holland et al., 2005). In addition, Demattè et al. (2006) reported that liminal strawberry flavor evokes a cross-modal association between odor and color. A precious result of the present study was that a cross-modal effect between odor and color was obtained in strawberries both under liminal and subliminal conditions, but in the case of tomatoes, which share common odors with other agricultural products such as cucumbers, cross-modal effect between color and odor was obtained under liminal conditions, but no such effect could not be obtained under subliminal conditions. The results that cross-modal effect occurs even in the subliminal stimuli identified in the present study were consistent with the findings of the neurophysiological previous study (Barutchu, Spence, & Hymphereys, 2018).

Strawberries are generally red and pink in color, although there are differences between varieties. The fact that there was a significant difference in the red and pink colors between strawberries in the experiment suggests that strawberries are generally perceived as red and pink. In the experiment, pink was selected more frequently than red. This was also found in the study by Demattè et al. (2006), where pink was selected significantly more often than red when people smelt strawberries. One possible explanation for the significant selection of pink over red is that many foods marketed as strawberry-flavored may use more pink than red in their packaging design or in the color of the food itself. In addition, many products that claim to have a strawberry flavor also use a lot of pink in their packaging. Thus, the strong association between strawberries and the color of the packaging and food products associated with the flavor and aroma of strawberries in everyday life may have influenced the results of this experiment.

A significant difference was observed in the pink color in the subliminal (0.015% concentration) strawberry odor. This suggests that a cross-modal effect was obtained between strawberry odor and pink color, even at the subliminal concentration. However, the red color that was significantly chosen for the liminal strawberry flavor was not significantly chosen for the subliminal strawberry flavor. This might be because the cross-modal effect was not as strong for the subliminal strawberry flavor as it was for the liminal strawberry flavors. In addition, there were no significantly selected colors for subliminal (0.015% concentration) tomato flavors, suggesting that tomato flavors cannot achieve the same cross-modal effects at subliminal and liminal concentrations. Yamada et al. (2014) reported that subliminal tomatoes were more difficult to judge than subliminal strawberries. Therefore, it is possible that the subliminal tomato flavor was more difficult to judge than the subliminal strawberry flavor in the current study, which may have led to variations in the participants’ color choices.

It is well known that multisensory integration is stronger when the information reaching multiple sensory receptors comes from the same, rather than a different, spatial region in the brain (Stein & Meredith, 1993; Meredith, Keniston, Prickett, Bahwa, Cojany, Clemo, Allman, 2020). In our experiment, the odors reached the olfactory cortex of the participants and were transmitted to the hippocampus, which recalled the odors of the past. At the same time, the hippocampus contains memories of food that are strongly bound to the odor, so it is easy to imagine that participants will recall the food and its colors from the odor. In contrast, in our experiment, the color significantly selected for the liminal (0.1% concentration) tomato flavor was orange. Because most of the tomatoes in general circulation are red, we expected to see a significant difference in the red color in this experiment, but the actual result was orange. Many tomatoes are red, but there are yellow and orange varieties as well; therefore, the significant difference may be due to the orange color, which is a warm color similar to red. It is possible that the subject's perception of the odor of tomatoes may depend on their accumulated experience. In our experiment, participants typically reported that in the liminal strawberry odor trial, they could clearly smell the strawberries, but could not tell at all in other trials (liminal tomato, subliminal tomato, and subliminal strawberries) because of the random repetition of stimuli. Therefore, it is possible that the choice of color of the liminal tomato odor itself was made unconsciously, and that this may have made the choice of tomato color less vivid. At this moment, we have not found any previous studies that can justify the choice of orange to tomato flavor. However, it was unlikely that the participants have a particularly biased opinion about the color of tomatoes. Future studies will justify the reasons for these results.

The aromatic components of tomatoes include cis-3-hexenal and trans-2-hexenal (Wang and Seymour, 2017). They are also called green leaf alcohol and aldehyde, and are found in cucumbers, cabbage, and tomatoes. Cis-3-hexenal and trans-2-hexenal are not tomato-specific odorants, but are common to all fruits, which may be the reason for the variation in selection other than warm colors in this study. The aromatic components of strawberries include alcohols, esters, and aldehydes, with furaneol as the main aromatic component (Schwab, 2013). Since strawberries have a specific aromatic component, it is possible that the odor and color of strawberries are easily recognized in association with strawberries, whereas tomatoes lack a specific aromatic component, which may have made it difficult for tomatoes to be recognized in association with their odor and color. These findings suggest that the cross-modal effect under subliminal conditions is flavor specific.

Conclusion

Significant differences appeared in the color associated with the foodstuff itself in both liminal (0.1% concentration) strawberry and tomato flavors, suggesting that a cross-modal effect of odor and color was achieved.

Disclosure of interest

The authors report no conflict of interest.

Data availability statement

The data supporting the findings of this study are available from the corresponding author, KS, upon reasonable request.

Author Contributions

Naoto Sato: Writing – Analysis, Review and Editing, Writing. Ayaka Sasaki: Investigation, Resources, and Writing – Original draft. Mana Miyamoto: Resources, Review and Editing, and Writing. Risa Santa: Resources, Review and Editing, Writing. Kenichi Shibuya: Analysis, Review and Editing, Writing, Supervision.

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Figure legend

Figure 1 illustrates the task used in the experiment. Participants should judge which of the given colors on the screen can best match the odor they smell, by clicking the corresponding color square directly when they decide to choose. Participants responded with the mouse.

Table 1(on next page)

Table 1. The p-values and effect sizes for redidue analysis

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	Strawberry		Tomato	
	Liminal	Subliminal	Liminal	Subliminal
χ^2	90.5	56.6	36.6	11.0
df	19	19	19	19
p	2.72×10^{-11}	1.30×10^{-5}	8.80×10^{-3}	0.924
Effect size w	1.52	1.21	0.97	0.53
Red	0.001 *	0.311	0.262	0.311
Yellow	0.037	0.262	0.262	0.957
Blue	0.037	0.122	0.037	0.311
Green	0.037	0.037	0.311	0.957
Orange	0.311	0.557	0.000 *	0.557
Pink	0.000 *	0.000 *	0.631	0.957
Brown	0.311	0.311	0.311	0.311
Turquoise	0.037	0.122	0.122	0.311
Purple	0.262	0.631	0.262	0.557
Gray	0.037	0.311	0.037	0.007

Results of χ2 analysis for each of the odors are reported in the upper and lower rows. Significant p-values in the upper and lower rows mean that participants' color responses to a given odor were not equally distributed among the 10 color options (i.e., they responded to a particular color on significantly more than 10% of the trials). The lower rows show the results of the post hoc comparisons (Bonferroni corrected, $\alpha = 0.005$ (0.05/10 colors) used to detect responses to a particular color, along with the percentage of each color choice.

Table 2(on next page)

Table 2. Odors and related colors

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Odors	Related Colors
Strawberry (0.1%)	Pink (50.0%), Red (23.7 %)
Strawberry (0.015%)	Pink (42.1%)
Tomato (0.1%)	Orange (31.6 %)
Tomato (0.015%)	None

Figure 1

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