Flavor-Induced Attentional Bias Toward Associated Colors in Visual Search

Authors: Peng Yubin, Wan Xiaoang, Wan Xiaoang

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Abstract

People often associate specific colors with flavors to form color-flavor associations, and color cues can influence flavor perception, which reflects the cross-modal influence of visual information on gustatory information processing. The present study investigated whether gustatory information can also affect visual search through two behavioral experiments. The experimental task required participants to perform visual search for shape targets after tasting beverages, while manipulating the predictive nature of gustatory stimuli as well as the association between target color and flavor. The results of Experiment 1 demonstrated that when the target color cued by the flavor cue was the color associated with that flavor, visual search could be facilitated. However, if the color associated with that flavor appeared on distractors, the flavor cue could not facilitate visual search. Subsequently, in Experiment 2 we eliminated the confound of semantic priming and also found results consistent with Experiment 1. The findings of this study indicate that flavor cues trigger an attentional bias toward associated colors, confirming the cross-modal influence of gustatory stimuli on visual attention, providing new experimental evidence for color-flavor interactions, and revealing possible mechanisms underlying cross-modal influences.

Full Text

Flavors Bias Attention Toward Associated Colors in Visual Search

PENG Yubin, WAN Xiaoang
(Department of Psychology, Tsinghua University, Beijing 100084, China)

Abstract

People frequently associate specific colors with particular flavors, forming color-flavor associations that demonstrate how visual information can exert crossmodal influence on gustatory processing. The present study investigated whether this influence is bidirectional by examining whether gustatory information, in turn, affects visual search. Two behavioral experiments required participants to taste beverages before performing a visual search task for shape targets, while we manipulated both the predictive nature of the taste stimuli and the association between target colors and flavors.

In Experiment 1, participants searched for shape targets more rapidly when the flavor cue predicted that the target would appear in the associated color. However, this facilitative effect disappeared when the flavor-associated color appeared in a distractor rather than the target. Experiment 2 replicated these results while controlling for potential semantic priming effects by withholding flavor labels. These findings demonstrate that flavor cues trigger an attentional bias toward associated colors, confirming crossmodal influence from gustatory to visual modalities. This work provides novel experimental evidence for color-flavor interactions, reveals underlying mechanisms of crossmodal influence, and offers insights for understanding other forms of intersensory crosstalk.

Keywords: color-flavor associations, crossmodal influence, flavor, attentional bias
Classification: B842

1. Introduction

We inhabit a multisensory world where we not only integrate information from multiple sensory channels but also tend to link features or stimuli across modalities, forming crossmodal correspondences (Spence, 2011). A prominent example involves the systematic associations people form between colors and flavors (Delwiche, 2004). Individuals can associate the color of a food or beverage with its flavor (Delwiche, 2012), and through repeated exposure to product packaging, they may also form associations between package colors and flavor labels (Velasco et al., 2014). Based on these color–flavor associations, people generate flavor expectations upon seeing a food or beverage' s color (Shankar et al., 2009), illustrating the crossmodal influence of visual information on gustatory processing.

Crossmodal influence refers to how information in one sensory modality affects the processing of information in another. Importantly, the existence of crossmodal correspondences does not guarantee that crossmodal influence will occur, and the two phenomena differ in at least two key respects (Spence, 2019). First, crossmodal correspondences represent a "relative" process that depends on the relative attributes of stimuli across two modalities (Brunetti et al., 2018). For instance, in studies of audiovisual correspondences, participants match the relatively lower-pitched of two sounds with the relatively larger of two objects (Parise & Spence, 2013). Both pitch and size are defined relationally, with no one-to-one mapping between specific pitches and absolute object sizes. In contrast, crossmodal influence is a more "absolute" process that depends on the absolute properties of sensory information. In studies of visual-to-gustatory influence, participants' judgments of taste stimuli are affected by certain specific colors but not others (Shermer & Levitan, 2014), independent of comparisons between two colors or two flavors. Second, crossmodal correspondences are bidirectional, with the association strength between stimulus A and stimulus B being roughly equivalent to that between stimulus B and stimulus A (Deroy & Spence, 2013; Parise, 2016). Crossmodal influence, however, is typically unidirectional and asymmetrical: information in one sensory channel can influence processing in another, but the reverse influence is either absent or substantially weaker (Spence, 2019).

Extensive research has demonstrated that visual information can influence flavor expectations, perception, and judgments (Spence, 2011). Although people frequently rely on color cues to identify food and beverage flavors (Zampini et al., 2007), they struggle to correctly identify a beverage' s flavor when its color violates their established color–flavor associations (DuBose et al., 1980). Surprisingly few studies have examined how flavors might modulate color processing, and existing evidence suggests that such effects are weak or non-significant (Qi et al., 2020). For example, color cues can alter flavor perception during beverage tasting, but flavor cues do not significantly affect color perception (Stäger et al., 2021). This asymmetry may arise because visual information is dominant (Posner et al., 1976), making it easy for color to influence flavor processing but difficult for flavor to affect color processing. Additionally, presenting and manipulating flavor stimuli is more challenging than presenting colors (Saluja & Stevenson, 2018), which has hindered research on gustatory-to-visual influence.

In daily life, people typically see food or beverages before tasting them, and among visual cues, color is particularly salient, leading to a sequence where color information precedes flavor information (Wadhera & Capaldi-Phillips, 2014). However, packaged foods and beverages often carry flavor labels, allowing consumers to obtain flavor information before actual tasting. Recent visual search studies have examined how flavor labels influence color expectations. When searching for flavored potato chip packages, participants generate color expectations based on learned package color–flavor associations (Velasco et al., 2014) and prioritize color in their search (Velasco et al., 2015). When the target flavor is paired with a color that violates these associations, the color expectation is disconfirmed, forcing participants to revert to text-based search and resulting in slower visual search responses (Huang et al., 2019, 2021). These findings demonstrate that flavor labels can generate color expectations that guide visual search. However, because flavor labels are presented visually rather than as actual taste stimuli, the question remains how genuine gustatory information influences visual search.

Previous research has investigated how other sensory modalities affect visual search. When auditory or tactile information is presented synchronously with visual information in space or time, it can influence visual search (Iordanescu et al., 2008; Ngo & Spence, 2010; Van der Burg et al., 2010). Auditory cues facilitate visual search when they are semantically related to visual targets (Knoeferle et al., 2016), and both auditory and tactile stimuli can facilitate search for associated visual stimuli through crossmodal correspondences (Klapetek et al., 2012; Orchard-Mills et al., 2013). However, the underlying mechanisms remain controversial. Van der Burg et al. (2008) proposed that auditory facilitation of visual search results from bottom-up guidance, where temporally synchronous auditory cues integrate with visual targets, increasing their salience and causing them to "pop out" from distractors. In contrast, Orchard-Mills et al. (2013) argued for top-down guidance, showing that tactile cues preceding visual search facilitate search for associated visual features only when the tactile information is predictive of the target (i.e., when tactilely-associated visual cues always appear on the target). When tactile information lacks predictive validity, participants do not actively use the cue, and the crossmodal facilitation disappears. Regardless of mechanism, these studies demonstrate that information in other sensory modalities can trigger attentional biases toward associated visual information—selective attention to certain stimuli (Weierich et al., 2008). We hypothesized that participants' established color–flavor associations might similarly cause flavor cues to trigger attentional biases toward associated colors. We tested this hypothesis in two visual search experiments.

The current research examines how flavor information influences visual search, focusing specifically on attentional biases triggered by flavor cues. This work provides experimental evidence for color–flavor interactions, reveals mechanisms underlying visual-gustatory integration, and offers insights for understanding other types of crossmodal influence. We conducted two experiments to investigate whether real flavors could influence subsequent visual search. Participants first tasted a beverage and then performed a visual search for a shape target, with the beverage flavor providing a cue about the target' s color.

In Experiment 1, we informed participants about the specific flavors they would taste and the association between each flavor and the target color in the subsequent visual search. In Experiment 2, we eliminated flavor labels, referring to beverages only as "A" and "B" to rule out semantic priming. Flavors were delivered via computer-controlled peristaltic pumps (Peng et al., 2022; Wilton et al., 2019). For the visual search task, we adapted Moriya' s (2018) paradigm, requiring participants to find a target defined by a specific shape feature among stimuli of different colors and respond to the shape feature. By manipulating the relationship between target/distractor colors and flavor associations, we examined how genuine flavor cues influence visual search. Although the task required searching for a shape target, prior knowledge of the target' s color can accelerate search through redundancy gain (Grubert et al., 2011). Given that flavor labels can generate color expectations that guide visual search (Huang et al., 2019, 2021), we hypothesized (H1) that predictive gustatory cues would enable participants to generate color expectations that facilitate shape-based visual search, resulting in faster search when flavor cues predict target color than when they do not.

Importantly, flavor cues might also trigger attentional biases toward specific colors, causing participants to prioritize flavor-associated colors after tasting. To dissociate this attentional bias from the facilitative effect of color expectation, we randomly assigned participants to two groups. One group was told that flavors predicted target colors that were associated with those flavors (flavor-associated colors). The other group was told that flavors predicted target colors that were not associated with those flavors (flavor-nonassociated colors). In the latter condition, if the flavor-associated color appeared in a distractor, the flavor cue would trigger an attentional bias toward the distractor color, slowing shape target search (Munneke et al., 2020). In other words, the attentional bias triggered by flavor cues would counteract the facilitative effect of knowing the target color. Therefore, we hypothesized (H2) that when the flavor-associated color appears in a distractor, the flavor cue would trigger an attentional bias toward that distractor color, thereby weakening the facilitative effect of target color expectation on visual search.

2. Experiment 1

2.1. Methods

2.1.1. Participants We used G*Power software (Faul et al., 2007, 2009) to estimate the required sample size. For our experimental design, with a medium effect size (0.25), alpha level of 0.05, and power of 0.80, the minimum required sample size was 34 participants. Accounting for potential issues such as attrition, invalid data, or equipment failure, we recruited 46 participants. Two participants were excluded because their visual search accuracy fell more than three standard deviations below their group' s mean, leaving 44 participants (mean age = 21.05 ± 1.89 years; 22 females) for analysis. Post-hoc power analysis using G*Power indicated that this sample size could detect effects with effect sizes $\geq$ 0.22 at alpha = 0.05 with 80% power.

All participants were recruited from Tsinghua University' s psychology participant pool, with each participating in only one experiment. The study was approved by the Ethics Committee of Tsinghua University Medical Imaging Center and preregistered on the Open Science Framework (https://osf.io). Participants provided informed consent and received compensation at a rate of 1 yuan per minute. All participants were right-handed, had normal or corrected-to-normal vision, no color blindness or weakness, and normal taste function.

2.1.2. Apparatus and Materials We used strawberry- and pineapple-flavored beverages as gustatory stimuli, with flavorless purified water as a control. The fruit-flavored beverages were prepared by mixing Dunhuang brand concentrated juice (Shanghai Dunhuang Food Co., Ltd., Shanghai, China; http://www.doking365.com) with purified water at a 1:6 ratio. In a pilot test, 12 participants who tasted the beverages blindfolded could correctly identify both flavors and reported familiarity with them.

Gustatory stimuli were delivered using a Kamoer FX-STP peristaltic pump controlled by computer program, which allowed precise volume delivery. We set the pump to deliver beverages at 90 ml/min. As shown in Figure 1, three pumps were connected to strawberry beverage, pineapple beverage, and purified water, respectively, and placed in a room adjacent to the testing room. Tubing delivered the beverages to participants' mouths. To prevent participants from seeing the liquid color, we wrapped the tubing connected to the pumps with opaque tape and attached each tube near the participant' s mouth to an opaque plastic straw. Participants only contacted these straws, which were replaced before each experiment.

The visual search task was administered on a computer using Matlab 2014b with the PTB3 toolbox (Kleiner et al., 2007). Stimuli were presented on a 17-inch monitor with 1024$×$768 resolution and 85 Hz refresh rate. The visual search task was adapted from Moriya (2018, Experiment 4). As shown in Figure 2, a fixation cross (1.3° × 1.3°) appeared at the center of the search display, with two square outlines (1.1° × 1.1°) presented 5.5° to the left and right of fixation. Each square had a gap on one side: the gap could be on the top or bottom (0.28° horizontal × 0.12° vertical) or on the left or right side (0.12° horizontal × 0.28° vertical). Each display contained one target and one distractor. The target was defined as the square with a gap on the top or bottom, while the distractor had a gap on the left or right. The target and distractor were always different colors. Target colors were red (RGB: 255, 0, 0) or yellow (RGB: 255, 255, 0). Based on Wan et al. (2014), strawberry flavor was associated with red and pineapple flavor with yellow. Distractor colors could be red, yellow, green (RGB: 0, 255, 0), or orange (RGB: 255, 165, 0)—common beverage colors.

2.1.3. Experimental Design and Procedure We employed a 2 (taste stimulus predictiveness: predictive vs. non-predictive of target color) × 2 (target color–flavor association: associated vs. non-associated) mixed design, with taste stimulus predictiveness as a within-subjects factor and target color–flavor association as a between-subjects factor. The dependent variables were response time and accuracy in the shape search task.

All participants were informed that they would taste fruit-flavored beverages (strawberry and pineapple) or flavorless purified water. For all participants, fruit-flavored taste stimuli were predictive of the target color in the subsequent visual search, whereas "flavorless" taste stimuli were non-predictive. Participants were randomly assigned to two groups. One group was told that strawberry flavor meant the upcoming target would be red and pineapple flavor meant the target would be yellow (flavor-associated colors). The other group was told that strawberry flavor meant the target would be yellow and pineapple flavor meant the target would be red (flavor-nonassociated colors). In 50% of trials, the taste stimulus (flavored beverage) predicted the target color; in the remaining 50%, the taste stimulus (flavorless water) was non-predictive. Thus, strawberry, pineapple, and flavorless trials each comprised 25%, 25%, and 50% of trials, respectively. Each participant completed 96 trials, with 2 ml of beverage delivered per trial, totaling 192 ml of liquid consumed during the experiment.

The experiment used a block design with 16 mini-blocks, with optional breaks after every 4 blocks. Each block contained 6 trials with identical taste stimuli. Each fruit-flavored beverage block was followed by a purified water block to cleanse the palate before switching to the other fruit flavor. For half the participants, the experiment began with strawberry flavor; for the other half, it began with pineapple flavor. Across the 96 trials, red and yellow targets each appeared with 50% probability. Distractor colors appeared with probabilities of 1/6 for red, 1/6 for yellow, 1/3 for green, and 1/3 for orange. Target and distractor colors were always different, and target location (left/right) was counterbalanced.

As shown in Figure 2, each trial began with a 500 ms fixation point, followed by a 4000 ms instruction screen: "Please taste this beverage carefully." During this period, the peristaltic pump delivered 2 ml of beverage (over 1500 ms). Next, a fixation screen appeared for 3000 ms, followed by the visual search display, which remained until participants responded. Participants indicated whether the target' s gap was on the top or bottom by pressing the Z or M key with their left or right index finger, respectively. The mapping of gap position to response key was counterbalanced across participants. The experiment lasted approximately 30 minutes. Before the formal experiment, participants completed 6 practice trials to familiarize themselves with the task and flavors. No feedback on response accuracy was provided during the formal experiment.

2.2. Results

Overall accuracy was high at 97.4%. We excluded trials with response times more than three standard deviations from the individual mean or shorter than 150 ms, resulting in the removal of 0.4% of trials. Mean response times and accuracy rates are shown in Figure 3. We conducted a 2 (taste stimulus predictiveness: predictive vs. non-predictive) × 2 (target color–flavor association: associated vs. non-associated) mixed-design ANOVA on response times and accuracy, with taste stimulus predictiveness as a within-subjects factor and target color–flavor association as a between-subjects factor.

The main effect of taste stimulus predictiveness on response time was significant: visual search was faster when taste stimuli predicted target color than when they did not (993 ms vs. 1079 ms), $F(1, 42) = 30.56$, $p < 0.001$, $\text{p}^2 = 0.42$, 95% CI = [-117.62, -54.74]. The interaction between taste stimulus predictiveness and target color–flavor association was also significant, $F(1, 42) = 4.79$, $p = 0.034$, $\text{p}^2 = 0.11$. No other main effects or interactions were significant for response time or accuracy, Fs < 2.82, ps > 0.10.

To interpret the interaction, we conducted simple effects analyses. When target color was associated with flavor, the main effect of taste stimulus predictiveness was significant: search was faster when taste stimuli predicted target color than when they did not (939 ms vs. 1059 ms), $F(1, 21) = 30.71$, $p < 0.001$, $\text{p}^2 = 0.59$, 95% CI = [-165.39, -75.13]. When target color was non-associated with flavor, the main effect of taste stimulus predictiveness was also significant: search was faster when taste stimuli predicted target color than when they did not (1047 ms vs. 1100 ms), $F(1, 21) = 5.43$, $p = 0.03$, $\text{p}^2 = 0.21$, 95% CI = [-98.59, -5.60]. Thus, predictive taste stimuli facilitated shape target search regardless of whether the predicted target color was associated or non-associated with the flavor. We calculated the magnitude of this color-based facilitation effect by subtracting response times in predictive trials from non-predictive trials. The facilitation effect was significantly smaller when target color was non-associated versus associated with flavor (52 ms vs. 120 ms), $t(42) = 2.19$, $p = 0.034$, Cohen' s $d = 0.66$, 95% CI = [-131.04, -5.28].

When target color was non-associated with flavor, the flavor-associated color could appear either in the distractor or be absent from the display. We analyzed these trial types separately, as shown in Figure 4. A one-way repeated-measures ANOVA revealed a significant main effect of trial type on response time, $F(2, 42) = 10.84$, $p < 0.001$, $\text{p}^2 = 0.34$, but not on accuracy, $F(2, 42) = 0.04$, $p = 0.96$. Bonferroni-corrected pairwise comparisons showed that when taste stimuli predicted the target color (even though it was non-associated), search was significantly faster than in non-predictive trials as long as the flavor-associated color did not appear in the distractor (1008 ms vs. 1097 ms), $t(21) = 4.39$, $p < 0.001$, Cohen' s $d = 0.94$, 95% CI = [-131.75, -47.12]. However, when the flavor-associated color appeared in the distractor, search speed did not differ from non-predictive trials (1122 ms vs. 1097 ms), $t(21) = 0.79$, $p = 0.44$. Critically, even when taste stimuli predicted the target color, search was significantly slower when the flavor-associated color appeared in the distractor than when it was absent (1122 ms vs. 1008 ms), $t(21) = 4.69$, $p < 0.001$, Cohen' s $d = 1.37$, 95% CI = [63.61, 164.81].

2.3. Discussion

Experiment 1 yielded two main findings. First, shape-based visual search was faster when taste stimuli predicted target color than when they did not, and this facilitative effect was significant regardless of whether the predicted target color was associated or non-associated with the flavor. These results indicate that participants could generate color expectations based on predictive gustatory cues to guide visual search, consistent with our hypothesis (H1). This finding aligns with Huang et al. (2019), who demonstrated similar facilitation using flavor labels. Critically, because flavor information was delivered through gustatory stimuli in the present study, these results show that participants can generate color expectations from actual flavor experiences to accelerate shape-based visual search, likely through redundancy gain (Grubert et al., 2011).

Second, the color-based facilitation effect was smaller when target color was non-associated versus associated with flavor because, in the non-associated condition, the flavor-associated color sometimes appeared in distractors, counteracting the facilitative effect of target color expectation. This pattern supports our hypothesis (H2). We found that as long as the flavor-associated color did not appear in the distractor, participants could use the learned flavor-color mapping to accelerate search, even when this mapping conflicted with their inherent color-flavor associations. This demonstrates that flavor cues trigger attentional biases toward associated colors. In summary, Experiment 1 suggests that real flavors can trigger visual attentional biases toward associated colors. However, because participants were exposed to flavor labels in the instructions, we could not rule out potential semantic influences. Therefore, we conducted Experiment 2 without any flavor labels, requiring participants to identify flavors through taste alone.

3. Experiment 2

To eliminate the influence of flavor labels, we conducted Experiment 2 without informing participants of the specific flavors at any stage. Participants were only told that one flavor predicted a red target and another predicted a yellow target, requiring them to rely entirely on gustatory experience to form color expectations. As in Experiment 1, participants were randomly assigned to two groups: one where flavor cues predicted associated colors, and another where they predicted non-associated colors. We tested the same hypotheses under these conditions.

3.1. Methods

Given the similar design to Experiment 1, we recruited 37 new participants from the same participant pool (none had participated in Experiment 1). Three participants were excluded due to accuracy more than three standard deviations below their group' s mean, leaving 34 participants (mean age = 21.47 ± 1.75 years; 17 females) for analysis. Post-hoc power analysis indicated this sample could detect effects with effect sizes ≥ 0.25 at alpha = 0.05 with 80% power.

The design and procedure were identical to Experiment 1, with the crucial difference that flavor labels were eliminated. Participants were told they would taste two flavored beverages (Flavor A and Flavor B) and flavorless water, with one flavor predicting a red target and the other predicting a yellow target. Participants were randomly assigned to groups: for one group, strawberry flavor predicted red targets and pineapple flavor predicted yellow targets (associated condition); for the other group, strawberry predicted yellow and pineapple predicted red (non-associated condition). The assignment of which beverage (A or B) predicted red was counterbalanced across participants. During practice trials, participants were explicitly told whether they were tasting Beverage A or B to learn the flavors, but in formal trials, they received no information and had to identify the flavors through taste alone.

3.2. Results and Discussion

Overall accuracy was 96.3%. We excluded trials with response times more than three standard deviations from the individual mean or shorter than 150 ms, removing 0.8% of trials. Mean response times and accuracy are shown in Figure 5. A mixed-design ANOVA revealed a significant main effect of taste stimulus predictiveness on response time: search was faster when taste stimuli predicted target color than when they did not (914 ms vs. 988 ms), $F(1, 32) = 31.59$, $p < 0.001$, $\mathrm{p}^2 = 0.50$, 95% CI = [-103.4, -46.02]. The interaction between taste stimulus predictiveness and target color-flavor association was also significant, $F(1, 32) = 4.79$, $p = 0.03$, $\mathrm{p}^2 = 0.14$. No other effects were significant, Fs < 0.55, ps > 0.46.

Simple effects analyses showed that when target color was associated with flavor, the main effect of taste stimulus predictiveness was significant (899 ms vs. 1004 ms), $F(1, 16) = 33.30$, $p < 0.001$, $\mathrm{p}^2 = 0.66$, 95% CI = [-143.37, -66.33]. When target color was non-associated, the main effect was also significant (928 ms vs. 973 ms), $F(1, 16) = 5.27$, $p = 0.035$, $\mathrm{p}^2 = 0.25$, 95% CI = [-85.72, -3.43]. Thus, predictive taste stimuli facilitated search regardless of association. The facilitation effect was smaller when target color was non-associated versus associated (45 ms vs. 105 ms), $t(32) = 2.27$, $p = 0.03$, Cohen' s $d = 0.75$, 95% CI = [-114.43, -6.13].

As in Experiment 1, we analyzed trials where target color was non-associated, separating those where the flavor-associated color appeared in the distractor from those where it was absent (Figure 6). A one-way repeated-measures ANOVA showed a significant main effect of trial type on response time, $F(2, 32) = 6.79$, $p = 0.003$, $\mathrm{p}^2 = 0.29$, but not on accuracy, $F(2, 32) = 0.16$, $p = 0.90$. Bonferroni-corrected comparisons revealed that when taste stimuli predicted the target color (even though non-associated), search was faster than in non-predictive trials as long as the flavor-associated color was absent from the distractor (905 ms vs. 991 ms), $t(16) = 4.05$, $p = 0.003$, Cohen' s $d = 0.57$, 95% CI = [-143.66, -29.45]. When the flavor-associated color appeared in the distractor, search speed did not differ from non-predictive trials (979 ms vs. 991 ms), $t(16) = 0.43$, $p > 0.99$. Critically, even when taste stimuli predicted the target color, search was significantly slower when the flavor-associated color appeared in the distractor than when it was absent (979 ms vs. 905 ms), $t(16) = 2.78$, $p = 0.041$, Cohen' s $d = 0.49$, 95% CI = [2.76, 146.37].

We also combined data from Experiments 1 and 2 in a 2 (taste stimulus predictiveness) × 2 (target color-flavor association) × 2 (flavor label mention: mentioned vs. not mentioned) mixed-design ANOVA. Taste stimulus predictiveness was a within-subjects factor; target color-flavor association and flavor label mention were between-subjects factors. The main effect of taste stimulus predictiveness was significant, $F(1, 72) = 57.33$, $p < 0.001$, $\mathrm{p}^2 = 0.44$, as was the interaction between taste stimulus predictiveness and target color-flavor association, $F(1, 72) = 9.14$, $p = 0.003$, $\mathrm{p}^2 = 0.11$. These results replicate the findings from the individual experiments. No other effects were significant, $Fs < 2.63$, $ps > 0.11$.

In summary, Experiment 2 replicated Experiment 1's pattern. Because no flavor labels were presented, flavor information was conveyed entirely through gustatory stimulation, confirming that participants can generate color expectations from genuine flavor experiences and that flavor information triggers attentional biases toward associated colors. The combined analysis showed no effect of flavor label mention, indicating robust findings across experiments.

4. General Discussion

The present research yielded two consistent findings. First, both experiments demonstrated that participants could use flavor cues to guide visual search. When predictive taste stimuli (flavored beverages) preceded the search for shape targets, search was faster than when non-predictive stimuli (flavorless water) preceded search. This facilitative effect was significant regardless of whether the predicted target color was associated or non-associated with the flavor. These results indicate that after receiving instructions about flavor–color relationships, participants could generate color expectations from actual flavor experiences to guide visual attention top-down, accelerating shape-based search through redundancy gain (Grubert et al., 2011).

Second, both experiments showed that the color-based facilitation effect was smaller when target color was non-associated versus associated with flavor. Even when flavor cues predicted a non-associated target color, facilitation occurred as long as the flavor-associated color was absent from the display. However, when the flavor-associated color appeared in a distractor, the predictive cue failed to facilitate search. This indicates that tasting a specific flavor triggers an attentional bias toward its associated color. This may occur because flavor experience activates the concept of the associated color, and prior research shows that such activated representations can produce attentional biases toward items possessing those features (Moriya, 2018). Alternatively, participants may think of the color of foods associated with that flavor, which is typically the color associated with that flavor. Regardless of the mechanism, flavor experience produced an attentional bias toward associated colors. Consequently, when target color was non-associated, the appearance of the flavor-associated color in distractors partially counteracted the facilitative effect of target color expectation.

This study is the first to examine how real flavor cues influence visual search, revealing attentional biases toward associated colors triggered by gustatory information. Our findings align with previous research using flavor labels (Huang et al., 2019, 2021) but extend this work by delivering flavor information through the gustatory modality, eliminating visual confounds and semantic associations from flavor labels. Although Experiment 1 mentioned specific flavors in the instructions, Experiment 2 eliminated all flavor labels, providing strong evidence that flavor information can modulate color processing. The combined analysis showed no effect of flavor label mention, demonstrating robust effects.

These results show that despite visual dominance, which makes it easier for color to influence flavor processing (Stäger et al., 2021), flavor information can modulate color processing under appropriate task conditions. Regarding multisensory perception, although visual stimuli more readily capture attention than stimuli from other modalities (Koppen & Spence, 2007) and the visual system may actively inhibit other senses (Spence et al., 2012), information from other modalities can influence visual processing. Recent research has identified "olfactory dominance" in visual categorization (Hörberg et al., 2020), and Huang et al. (2022) found that learned flavor–self associations influenced subsequent color–self learning more than the reverse. Our findings, together with this emerging research, demonstrate that other sensory modalities can influence visual information processing.

The mechanisms underlying crossmodal influences on visual search have been debated. Some argue for bottom-up guidance (Van der Burg et al., 2008), while others support top-down guidance (Orchard-Mills et al., 2013). Our results align with Orchard-Mills et al. (2013), showing that crossmodal influences depend on predictive relationships with target visual features, suggesting top-down attentional guidance. Auditory, tactile, and gustatory stimuli can all facilitate search for associated visual stimuli through crossmodal correspondences (Klapetek et al., 2012; Orchard-Mills et al., 2013). Our study' s unique contribution is that gustatory information preceded visual information rather than being synchronous, and visual color was task-irrelevant. Thus, flavor' s influence on visual search may operate more subtly than auditory or tactile effects.

This research has practical implications for marketing professionals seeking to understand consumer visual attention in eating and drinking contexts (Topolinski et al., 2014). For example, after tasting coffee, consumers may show attentional biases toward coffee colors, informing store design and marketing strategies around coffee shops. Methodologically, we developed a system for precisely controlling flavor delivery that eliminates visual interference, providing a viable paradigm for future color–flavor interaction research.

Several limitations warrant consideration. First, our "flavor" stimuli were fruit flavors that participants could associate with specific foods, potentially activating semantic representations even in Experiment 2. Future research could use novel flavors difficult to link to specific foods. Second, our paradigm cannot determine whether attentional biases require participants to think of specific foods and their colors. Future studies should address this question. Third, our block design, while necessary to avoid flavor interference, is less robust than random designs. Future research could improve gustatory delivery systems to enable randomization without repeated palate cleansing.

In conclusion, our two experiments consistently demonstrated that flavor cues facilitate visual search when they predict targets in associated colors, but this facilitation disappears when the associated color appears in distractors. These findings reveal that genuine flavor experience triggers attentional biases toward associated colors, demonstrating gustatory-to-visual crossmodal influence. This work provides new evidence for color-flavor interactions, reveals mechanisms of visual-gustatory integration, and offers insights for understanding other crossmodal influences. Our study also enables comparisons across sensory modalities and establishes a foundation for investigating the psychological and neural mechanisms of crossmodal influence.

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Note: Figure translations are in progress. See original paper for figures.