Manipulating Predictive Focus Improves the Taste Appreciation of Coffee

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Abstract

Predictive processing plays a fundamental role in perception and decision-making. However, prediction can sometimes undermine our accurate evaluation of perceptual information. This study aimed to demonstrate this undermining effect in taste appreciation for everyday scenarios and to improve appreciation through targeted manipulations of predictive focus. We conducted cognitive experiments in which participants evaluated high-quality coffee with unusual flavors. We hypothesized that the initial appreciation would be low because of the coffee's unusual flavors, resulting in negative prediction errors. However, by directing the predictive focus toward specific taste features through instructions, we expected to observe an improvement in their appreciation. Our results support this hypothesis, suggesting that manipulating predictive focus can improve taste appreciation.

Keywords: prediction; taste appreciation; coffee

Introduction

Prediction is the process by which the brain generates expectations about incoming sensory inputs based on prior knowledge and contextual information. This predictive mechanism is thought to play an important role in various cognitive processes (Clark, 2015; Friston, 2010; Hohwy, 2013). Although it enhances perceptual robustness, prediction can also negatively impact perception and decision-making in certain cases (Spaak et al., 2022; Van Marcke et al., 2024; Zivony & Eimer, 2022). For example, predictions about the categories of visual objects lead to unexpected failures in object detection (Zivony & Eimer, 2022). These negative effects of prediction can prevent us from recognizing the true qualities of perceptual information, even in everyday situations.

Previous studies have shown that manipulating predictive processes—by deliberately altering prior knowledge, contextual cues, or expectations—can modulate perceptual experiences in various contexts (de Lange et al., 2018; Kersten et al., 2004; Summerfield & de Lange, 2014). These studies suggest that such predictive manipulation facilitates the perception of information related to prediction (Michael et al., 2014; Moldakarimov et al., 2010; Yan et al., 2023). In addition, predictive manipulation may help mitigate the negative effects of prediction by shifting predictive focus from the less preferred to the more preferred aspects of perceptual information. This shift may enhance awareness of the genuine qualities of the information. However, clear evidence supporting these possibilities, particularly in daily life situations, remains limited.

To examine these possibilities, we focused on taste experience, which is highly susceptible to prediction (Nitschke et al., 2006; Samuelsen et al., 2012; Small et al., 2008). The taste of food and beverages can be easily altered by factors other than the taste itself, such as prior knowledge (Honoré-Chedozeau et al., 2019; Palassmann et al., 2008; Yeomans et al., 2008) and appearances (Motoki et al., 2023). For example, product labels and prior knowledge can shape both the perception and preference of taste (Schifferstein et al., 2001). Visual manipulation using projective augmented reality, which alters the perceived appearance of food, can greatly change taste experiences (Nishizawa et al., 2016). Therefore, taste provides an ideal modality for studying the negative effects of prediction and their mitigation by manipulating predictive focus.

In this study, we aimed to demonstrate the negative effects of prediction on taste appreciation in everyday situations and to improve the undermined appreciation through the manipulation of predictive focus. While previous studies have mostly focused on how prediction influences perception, they have rarely addressed how its negative impact can be mitigated. In contrast, our study directly investigates whether and how such negative effects on appreciation can be reduced by deliberately shifting predictive focus. To this end, we used high-quality coffee with unusual flavors to design cognitive experiments. The participants evaluated the taste of unusual high-quality and standard coffee before and after receiving instructions to shift their predictive focus.

We hypothesized that the unusual flavors of high-quality coffee would initially receive a low evaluation because of a negative prediction error—a gap between expectation and actual perception. In other words, this prediction error may obscure the participants' awareness of the coffee's other high-quality features. This hypothesis aligns with the assimilation/contrast model (Piqueras-Fiszman & Spence, 2015), which posits that when perceived taste moderately deviates from expectations, the taste evaluation tends to assimilate toward the expectation, whereas a large deviation leads to a negative evaluation. However, we anticipated that after directing participants to shift their predictive focus

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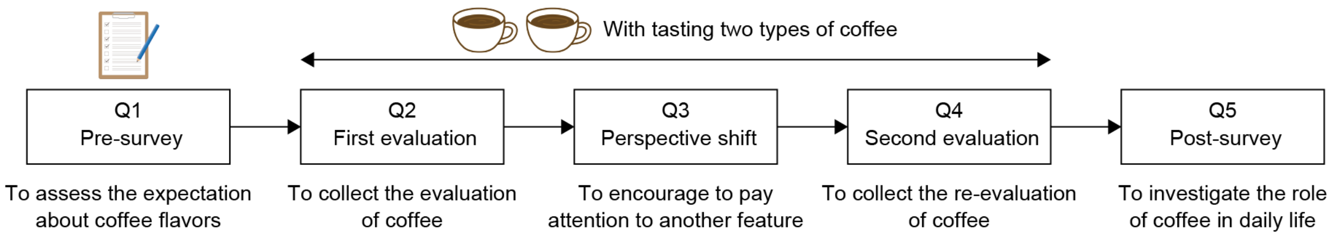

Figure 1: Experimental procedure. The participants sequentially completed five different questionnaires. They answered the three questionnaires in the middle while tasting high-quality and standard coffee.

toward these high-quality features, their awareness would increase, resulting in improved evaluations. We tested this hypothesis by analyzing the experimental data.

Methods

Participants

One hundred and eight healthy Japanese participants (27 females; mean age ± SD = 23.5 ± 5.4 years) were recruited for the experiments. The protocol was approved by the ethics committee of the National Institute of Information and Communications Technology. Written informed consent was obtained from all participants.

Coffee

The high-quality coffee used in the experiments was specialty coffee, which is known for its meticulously sourced, graded, and prepared beans that offer unique and distinctive flavors (Raveendran & Murthy, 2022). We selected two types of single-origin coffee beans: medium roasted beans from Yirgacheffe and Idido, both in Ethiopia. Either type of coffee was used in each experiment, with their use counterbalanced across the participants.

As a reference for the taste evaluation, we used the House Blend from Starbucks, which contains dark-roasted coffee beans, as standard coffee. This coffee was approximately half the price of the high-quality coffee. To maintain consistency in our reference standard, only this coffee was used as the standard coffee.

Although specialty coffee gained popularity in the second half of the 1980s worldwide, its prevalence occurred later in Japan (Grinshpun, 2014). Therefore, the recognizability of specialty coffee among Japanese consumers remains low. Indeed, in our questionnaire survey, only four out of the 108 participants had heard of the term "specialty coffee."

Specialty coffee is recognized for its unique flavors, which include fruitiness that may also be perceived as acidity (Raveendran & Murthy, 2022). These flavors differ markedly from those of standard coffee. This difference is likely to lead to a negative prediction error—a gap between the expectation and the actual perception of flavors. Thus, specialty coffee serves as an ideal stimulus for examining the effect of prediction errors on taste evaluations. In contrast, standard coffee is likely to induce small prediction errors.

The coffee beans were ground using a dedicated grinder (Next G2, Kalita, Japan) and brewed using a high-performance coffee machine (The Brew, BALMUDA, Japan), which simulates a hand-drip method. For brewing, the ratio of ground beans to water was approximately 28 g and 500 g for both types of coffee. To maintain consistency in coffee taste across different experimental sessions, we measured the concentration ratio (total dissolved solids) of each brew as follows: mean ± SD = 1.33 ± 0.08 % for high-quality coffee and 1.28 ± 0.20 % for standard coffee. The brewed coffee was then stored in thermal pots.

Experimental Procedure

Our experiments consisted of five different questionnaires: pre-survey (Q1), first-evaluation (Q2), perspective-shift (Q3), second-evaluation (Q4), and post-survey (Q5) questionnaires. Participants answered Q2 to Q4 while tasting the coffee (Figure 1). These experiments were conducted in an experimental room.

Initially, the participants completed Q1, which gauged their expectations about the coffee flavors. Subsequently, they were served a combination of one of the high-quality coffees with the standard coffee. The specific types of coffees were not disclosed and they were labeled as "A" and "B." The pairing of coffees and labels was counterbalanced across the participants. While tasting these two coffees freely, the participants sequentially completed Q2 through Q4. In Q2, they evaluated each coffee, whereas in Q3, they were encouraged to pay attention to different aspects of flavors. In Q4, they evaluated the coffees again. Finally, Q5 was completed to gather their opinions on the role of coffee in their lives.

To ensure that the coffee temperature remained consistent during the tastings, small amounts (25–30 g) were served and replenished as needed. To prevent flavor mixing between the two coffee types, participants were instructed to drink water between each tasting.

Questionnaire

A summary of all questions in Q1–Q5 and all responses to them is available online[1]. Q1 consisted of six questions that assessed the participants' expectations of the six different aspects of flavors. The items were phrased as "Ideal coffee should have X," where "X" represented F1–F6 in Table 1.

[1] https://doi.org/10.6084/m9.figshare.28333775

Participants provided their responses using a 7-point scale rating from −3 (“Strongly disagree”) to 3 (“Strongly agree”).

Table 1: Flavors used in the questionnaire.

Name	Flavor
F1	Roasting aroma
F2	Acidity
F3	Bitterness
F4	Sweetness
F5	Body
F6	Aftertaste
F7	Fruitiness
F8	Freshness
F9	Clearness

Q2 included 12 questions that assessed the participants’ evaluations of coffees A and B. Six questions were asked about each coffee:

1. Select all flavors perceived to be stronger than your ideal coffee.
2. Select all flavors perceived to be weaker than your ideal coffee.
3. Rate the quality of this coffee.
4. Choose the most important flavor in evaluating the quality.
5. Rate your preference for this coffee.
6. Choose the most important flavor in evaluating preference.

Response options for items (1) and (2) were F1–F6 and “None”. Based on these responses, the discrepancy from expectations for each flavor was evaluated. Specifically, the discrepancy for a flavor was scored as 1 (“Stronger”) if the flavor was selected in item (1), −1 (“Weaker”) if selected in item (2), and 0 (“Not different”) if it was not selected in either, or if “None” was chosen for both items (1) and (2). Response options for item (3) included a seven-point scale from −3 (“Very bad”) to 3 (“Very good”); for item (4), F1–F6; for item (5), a seven-point scale from −3 (“Very disliking”) to 3 (“Very liking”); and for item (6), F1–F6. Responses were given while tasting the respective coffee.

Q3 included 21 questions intended to induce a shift in perspective toward the unique flavors of the high-quality coffee (F7–9 in Table 1), which are considered key attributes of its high quality (Raveendran & Murthy, 2022). Each flavor was associated with a set of seven questions:

i. Were you aware of X in the initial tasting?
ii. Do you perceive X in coffee A?
iii. If not “Do not feel,” what is X in coffee A similar to?
iv. Did your perception of X change since the initial tasting of coffee A?
v. Do you perceive X in coffee B?
vi. If not “Do not feel,” what is X in coffee B similar to?
vii. Did your perception of X change since the initial tasting of coffee B?

where “X” corresponds to each flavor. The response options included a four-point scale from 0 (“Not aware”) to 3 (“Aware much”) for item (i), and a four-point scale from 0 (“Do not feel”) to 4 (“Feel much”) for items (ii) and (v). Items (iii) and (vi) had varying options depending on the flavor: “Orange,” “Lemon,” “Mango,” “Berry,” “Pineapple,” and “Apple” for F7; “Clean and crisp with no lingering aftertaste” and “Leaving a cool and refreshing aftertaste” for F8; “Clean and clear feeling,” “Not muddy and clean,” and “Silky and shiny” for F9. For items (iv) and (vii), the options were a three-point scale of −1 (“Decreased”), 0 (“Not changed”), and 1 (“Increased”). Responses to items (ii)–(vii) were given while the participants tasted the respective coffees. Note that the accuracy of the responses for items (iii) and (vi) was not critical because the primary purpose was to shift their focus on each flavor regardless of the response.

Q4 consisted of 10 questions on the changes in the participants’ evaluation of coffees A and B. Each coffee was associated with five questions:

a. How did your taste perception change from the initial tasting?
b. Reevaluate the quality of this coffee.
c. Choose the most important flavor in evaluating the quality.
d. Reevaluate your preference for this coffee.
e. Choose the most important flavor in evaluating preference.

Options included a three-point scale of −1 (“Got worse”), 0 (“Not changed”), and 1 (“Got better”) for item (a); a seven-point scale from −3 (“Very bad”) to 3 (“Very good”) for item (b); F1–9 for item (c), a seven-point scale from −3 (“Very disliking”) to 3 (“Very liking”) for item (d), and F1–9 for item (e). The responses were provided while tasting the respective coffee.

Working hypothesis

We formulated the following working hypothesis: The high-quality coffee possesses unique features of flavors that the participants did not anticipate and the features in their ideal coffee differed from. This prediction error was expected to result in high or low scores for items (1) and (2) in Q2 for the high-quality coffee. We also anticipated lower scores of the high-quality coffee for items (3) and (5) compared with the standard coffee. Moreover, in items (4) and (6), the unexpected flavors were expected to be identified as important for the evaluations. The perspective shift induced in Q3 was hypothesized to redirect the participants’ predictive focus toward the coffee’s high-quality features, thereby enhancing their awareness of these features. This enhancement was expected to manifest in their responses to items (ii) and (iv) in Q3, and in turn, result in improved evaluations of the high-quality coffee in Q4. We anticipated increases in quality and preference scores of the high-quality coffee in the responses to items (b) and (d) in Q4 compared with the responses to items (3) and (5) in Q2. No similar improvement was expected for the standard coffee.

It is important to note that we did not explicitly instruct participants on the association of the additional features, F7–F9 in Table 1, with either quality or specific coffees.

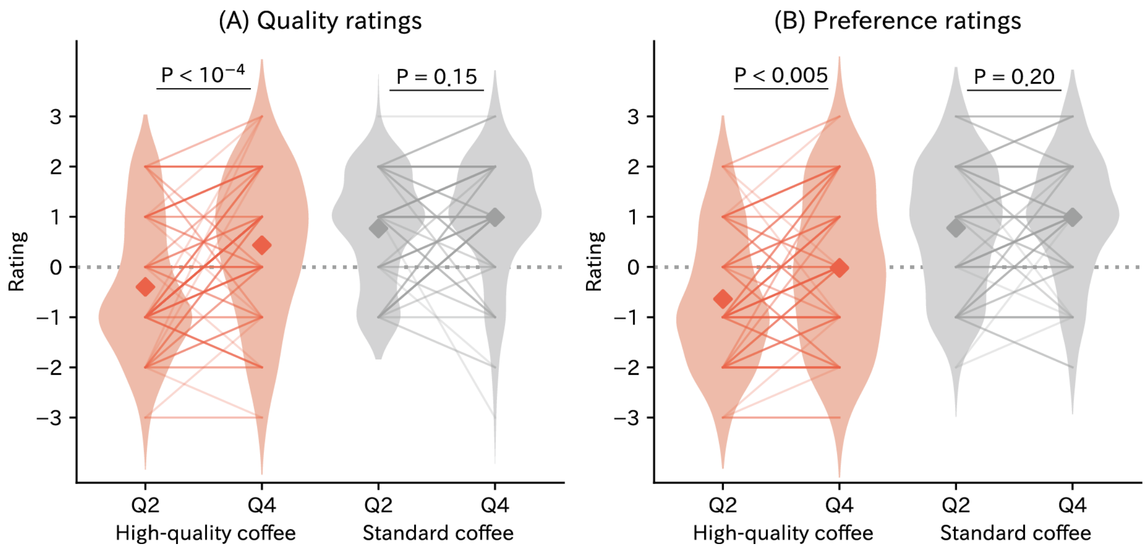

Figure 2: Coffee evaluation and its changes resulting from predictive manipulation. The distributions of participants' quality (A) and preference (B) ratings for high-quality (red) and standard (gray) coffee are plotted separately before (Q2) and after (Q4) predictive manipulation. Diamond marks indicate the mean values. The thickness of the lines between the plots represents the number of participants showing the same patterns of rating changes.

Participants were not informed whether each of these features was associated with high or low quality, nor which coffee was linked to these features. Thus, our testing approach was designed to be neutral.

Results

Flavor Expectations and Discrepancies

Participants initially rated whether their ideal coffee should exhibit each of the six distinct flavors (F1–F6 in Table 1) in Q1 using a 7-point scale from −3 to 3. These ratings likely reflected their expectations for each coffee flavor. We found that the ratings for roasting aroma (mean rating = 2.16), bitterness (1.29), body (1.95), and aftertaste (1.93) were significantly higher compared with the neutral point (i.e., 0; one-sample t-test, $t = 12.4$–30.4, $P < 10^{-21}$), indicating high expectations for these flavors. In contrast, the ratings for acidity (mean rating = −0.28) were significantly lower than the neutral point ($t = -2.1$, $P < 0.05$), indicating low expectations for this flavor. The ratings for sweetness (mean rating = −0.01) did not significantly differ from the neutral point ($t = -0.07$, $P = 0.95$).

The participants tasted one high-quality and one standard coffee and evaluated the extent to which each coffee met or deviated from their expectations regarding flavors (F1–F6 in Table 1) in Q2 (Table 2). Their responses were scored as 1 ("Stronger"), 0 ("Not different"), and −1 ("Weaker") relative to their expectations. We performed statistical tests for each flavor based on these scores. For the high-quality coffee, participants perceived significantly stronger acidity (F2; one-sample t-test, $t = 10.9$, $P < 10^{-18}$) and significantly weaker roasting aroma (F1), bitterness (F3), body (F5), and aftertaste (F6) compared with the ideal coffee ($t = -5.7$–-2.8, $P < 0.01$). For the standard coffee, they perceived significantly stronger bitterness (F3) and body (F5; $t = 3.0$–4.3, $P < 0.01$) and significantly weaker sweetness (F4; $t = -4.2$, $P < 0.0001$). Although significant discrepancies were observed for both types of coffee, the most discrepant flavor was the acidity of the high-quality coffee.

Table 2: Expectation discrepancy

Flavor	% participants for the high-quality coffee		
	Stronger	Not different	Weaker
F1	17.6	37.0	**45.4**
F2	**72.2**	20.4	7.4
F3	12.0	38.0	**50.0**
F4	20.4	**61.1**	18.5
F5	16.7	39.8	**43.5**
F6	13.9	54.6	**31.5**
	% participants for the standard coffee		
	Stronger	Not different	Weaker
F1	29.6	**42.6**	27.8
F2	21.3	**52.8**	25.9
F3	**50.0**	31.5	18.5
F4	6.5	**64.8**	28.7
F5	34.3	**50.9**	14.8
F6	28.7	**47.2**	24.1

If these discrepancies are linked to prediction errors, we would expect a larger discrepancy for a given flavor as the gap between expected and perceived flavor strength increases. This relationship should manifest as differences in the expectation ratings in Q1, between those who perceived a discrepancy in Q2 and those who did not. We tested this possibility for the pair of coffees and flavors that significantly differed from the expectations (Table 2). Significant differences were observed only in the acidity for the high-quality coffee (two-sample t-test, $P < 0.0005$), suggesting the association of this flavor's discrepancy with prediction errors.

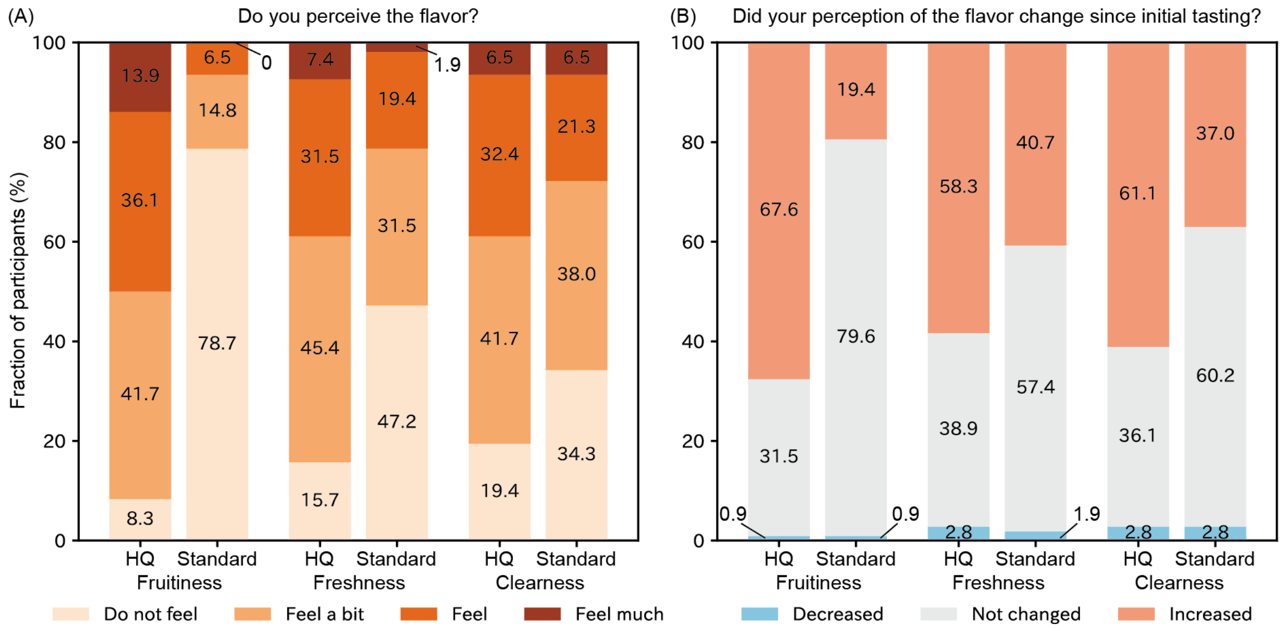

Figure 3: Effects of the perspective shift. Each bar represents the percentage of participants who assigned each rating to additional flavors (fruitiness, freshness, and clearness) based on whether the flavor was perceived (A) and how the perception of the flavor changed since initial tasting (B). The ratings are shown separately for each coffee: HQ, high-quality coffee; standard, standard coffee.

First Coffee Evaluation

Before the predictive manipulation, the participants assessed the quality and preference of coffee in Q2 using a 7-point scale ranging from −3 to 3 (Figure 2). Both the quality and preference ratings for the high-quality coffee were significantly lower than not only the neutral point (i.e., 0; one-sample t-test, $t = -3.1$, $P < 0.005$) but also those of the standard coffee (paired t-test, $t = 7.4$, $P < 10^{-10}$), which was consistent with our hypothesis.

Table 3: Percentage (%) of identifications of flavors as the most important in positive and negative ratings of the high-quality coffee during the first evaluation.

	Quality		Preference	
Flavor	Positive	Negative	Positive	Negative
F1	6.5	**17.6**	6.5	11.1
F2	**10.2**	11.1	**8.3**	**25.0**
F3	3.7	4.6	1.9	9.3
F4	0.9	0.9	1.9	0.9
F5	3.7	**17.6**	1.9	11.1
F6	1.9	5.6	1.9	2.8

The participants identified the flavors that were most important for their evaluations in Q2. Table 3 shows the percentage of participants who identified a specific flavor as the most important for high-quality coffee. In both quality and preference evaluations, negative ratings, with scores below 0, were associated with roasting aroma (F1), acidity (F2), and body (F5), which were also the flavors identified as unexpected in Q2 (Table 2). Note that the participants who rated the coffee neutrally were excluded from this analysis. This result suggests that negative prediction errors related to these flavors negatively affected the evaluations of both quality and preference for high-quality coffee.

Perspective Shift

We hypothesized that Q3 would cause a shift in the predictive focus toward previously unnoticed high-quality flavors (F7–F9 in Table 1) of the high-quality coffee. The responses in Q3 first confirmed that most of the participants were unaware or little aware of these flavors, with 87.0% for fruitiness, 87.0% for freshness, and 85.2% for clearness. We then tested this hypothesis by analyzing the participants' ratings of these features in Q3 (Figure 3). The ratings for which participants perceived each flavor in the initial evaluation for fruitiness and freshness in the high-quality coffee were significantly higher compared with those in the regular coffee (chi-square test, $\chi^2 = 26.4$–112.5, $P < 10^{-5}$); however, the ratings for clearness did not show a significant difference ($\chi^2 = 7.1$, $P = 0.069$). For all flavors, the ratings for the intensity of each flavor perceived in the high-quality coffee were significantly higher than not only the neutral point (i.e., 0; one-sample t-test; $t = 10.4$–14.1, $P < 10^{-17}$), but also compared with those in the standard coffee (chi-square test, $\chi^2 = 12.9$–51.3, $P < 0.05$). These results indicate that Q3 effectively enhanced the participants' awareness of these high-quality flavors.

Second Coffee Evaluation

After predictive manipulation, the participants reassessed the quality and preference of each type of coffee in Q4 (Figure 2). Consistent with our hypothesis, both quality and preference ratings significantly increased for the high-quality coffee (paired t-test, $t = 3.2–4.3$, $P < 0.005$) but not for the standard coffee ($t = −0.19–1.3$, $P = 0.20$). In addition, the participants revealed that fruitiness was the most important factor in their positive evaluations of the high-quality coffee in Q4 (Table 4). Given that fruitiness (F7) was the flavor we aimed to emphasize by shifting the predictive focus, these results suggest that our predictive manipulation effectively increased the awareness of this flavor and enhanced the appreciation of high-quality coffee.

Table 4: Percentage (%) of identifications of flavors as the most important in positive and negative ratings of the high-quality coffee during the second evaluation.

Flavor	Quality Positive	Negative	Preference Positive	Negative
F1	3.7	3.7	2.8	4.6
F2	6.5	**12.0**	0.9	**24.1**
F3	0.9	0	2.8	2.8
F4	0.9	0	2.8	0
F5	3.7	5.6	0	4.6
F6	0.9	0.9	0	0
F7	**28.7**	1.9	**20.4**	1.9
F8	2.8	0.0	2.8	0
F9	4.6	0.9	4.6	1.9

Our additional analysis supported this notion. Our hypothesis predicts that a stronger awareness of high-quality flavors could lead to larger improvements in the evaluation of high-quality coffee. To test this, we examined whether the improvement in ratings between Q2 and Q4 was greater for the participants who identified fruitiness (F7) as the most important flavor in their positive evaluation of high-quality coffee. As expected, this tendency was observed in the data, with mean rating differences between Q2 and Q4 of 1.71 vs 0.48 for quality ratings and 1.63 vs 0.36 for preference ratings (two-sample t-test, $t = 4.2–4.3$, $P < 0.0001$), respectively.

Discussion

We examined the hypothetical effect of prediction and its manipulation on the appreciation of high-quality coffee with unusual flavors. Our results indicate that a gap between the expectation and perception of unusual flavors undermined the evaluation of the coffee by masking its high-quality features. However, a deliberate manipulation to redirect the predictive focus toward the high-quality features effectively enhanced the awareness of these features, resulting in an improved evaluation of the coffee. Importantly, this effect of predictive manipulation was observed only for high-quality coffee, not for standard coffee. This suggests that the observed improvement was not simply due to the repeated exposure of coffee or arbitrarily induced associations between coffee and high-quality features. These findings demonstrate that taste appreciation can be undermined by prediction and improved by manipulating the predictive focus even in everyday situations.

Previous studies have indicated that expectations can modify taste perception and its underlying neural processes (Khalid et al., 2019; Luo et al., 2024; Nitschke et al., 2006; Veldhuizen et al., 2011; Wilton et al., 2019). Some studies have shown that expectations alone can alter perceptual experiences during taste appreciation (Luo et al., 2024; Nitschke et al., 2006). However, while these studies have concentrated on the effects of expectation itself, our results indicate that prediction errors, which are caused by discrepancies between expected and perceived tastes, can negatively impact taste appreciation. Furthermore, our study also showed that manipulating the predictive focus can effectively mitigate this negative effect. To our knowledge, this is the first study to demonstrate such a mitigating effect of predictive manipulation in everyday scenarios, providing valuable insights for research on predictive processing in the brain.

Our results indicated that prediction errors in the perception of flavors, specifically acidity, adversely affect the initial evaluation of coffee, whereas a predictive shift toward fruitiness enhanced the evaluation in the subsequent assessment (Figure 2 and Tables 3–4). Because of the close association between acidity and fruitiness (Stampanoni, 1993), it is reasonable that they might similarly affect taste appreciation. However, acidity-induced prediction errors had a detrimental effect, whereas the potential positive impact of fruitiness was obscured. One possible explanation for the dominant effect of acidity is its biological significance, which may result in stronger prediction errors. Acidity, often linked with spoiled food and harmful substances, typically triggers an inherent human aversion response (Salles, 2021; Zhang et al., 2022). This may facilitate the processing of prediction errors, automatically drawing attention to acidity. Nevertheless, our findings also indicate that manipulating predictive focus toward fruitiness can alleviate such automatic responses to prediction errors, thereby enhancing coffee appreciation. Thus, our study demonstrates the dynamics of predictive processing that can underpin the cognitive mechanisms for altering taste appreciation.

We demonstrated that coffee evaluations can be improved through predictive manipulation (Figure 2). However, the final quality and preference ratings for the high-quality coffee were lower compared with those for the standard coffee, suggesting that the impact of our manipulation on taste appreciation may be limited. Nevertheless, our approach to predictive manipulation is easily implemented, making it potentially applicable to various social situations, in which enhancing taste appreciation is desirable, such as overcoming food aversions or promoting high-quality, lesser-known foods. To achieve this, further studies are needed to determine whether predictive manipulation can similarly benefit other types of drinks and foods.

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