Top-down processing in food perception: Beyond the multisensory processing

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Abstract: This article addresses the psycho-social attitude toward food perception using three prior studies to show that cognitive processes play an important role in food perception. Many existing studies about food perception are based on animal behavior experiments, leading to human cognitive processes in food perception being overlooked. The three studies in this article emphasize the importance of the human cognitive processes in human flavor perception.

Keywords: Gustation, Olfaction, Vision, Flavor, Brand

PACS number: 43.10.Mq [doi:10.1250/ast.41.182]

1. INTRODUCTION

1.1. Scope

There are many studies—including ours—which showed that the perception of food depends on multisensory processing, including gustation, olfaction, texture, vision, and audition. However, in our everyday lives, we perceive and evaluate foods based mainly on cognitive and top-down processing. For example, we evaluate foods as more palatable when we eat them at a social gathering than when we eat alone at home. We do not perceive the taste of the food only by gustatory sensory information, but by integrated sensory information such as olfactory and visual information, branding, memories, and the contextual information about the food. In other words, we do not perceive the foods according to a bottom-up system but by a top-down system.

This introduces the basic theory on psycho-social attitude concerning the perception of food. This theory is based on the Maslow’s hierarchy of needs theory. Next, three studies are introduced. The first study shows that there is a response bias in odor induced taste enhancement, meaning that cognitive bias plays an important role in taste-odor interaction. The second study shows that vision captures and controls individuals’ selective attention in olfaction and changes the perception of food. The third study shows that the brand of a beverage affects the perception of beverages.

1.2. Psycho-social Attitude for Food Perception

Figure 1 shows a schematic representation of the psycho-social attitude for food perception [1]. This schematic concept is based on the Maslow’s hierarchy of needs theory. The first or bottom stage is the physiological needs stage. In this stage, an individual’s need for food is generated by instinct based on the biological system, such as hunger, thirst, and the perception of mineral balance. In this stage, individuals are also motivated to avoid aversive foods, of which the acquired aversion is based on the association between the taste of the food and visceral intoxication. The inherent biological protective system controls the eating motivation in this stage using gustatory and olfactory cues.

The second stage is called the safety needs stage. In this stage, the need for food is also generated by instinct and the biological system, but is affected by learning acquired through daily eating experiences. In this stage, individuals are motivated to prefer familiar foods and to avoid harmful foods which have sour and/or bitter tastes. In this stage, individuals are also motivated to avoid aversive foods, of which the acquired aversion is based on the association between the taste of the food and visceral intoxication. The inherent biological protective system controls the eating motivation in this stage using gustatory and olfactory cues.

The third stage is called the love and belonging needs stage. In this stage, experience-based learning, memory,
and social motivations are key factors in the need for food. Individuals in this stage are motivated to approach foods which are familiar to themselves, family members, and friends, and which are eaten in comfortable and enjoyable situations. It also evokes nostalgia, especially childhood memories. In this stage, vision, audition, and verbal information also engage in food perception.

The fourth stage is called the esteem needs stage. In this stage, we eat foods not because they provide a biological benefit, but because they provide psychological and social benefits. For example, we drink bitter coffee and eat hot chili pepper—which are biologically aversive tastes—because we strive for the admiration other people. The admiration is a psychological and social motivation for us. A typical example of this stage is brand effects on the perception of foods. We do not aim to experience the taste of branded foods and beverages, because—as many studies have shown—taste palatability is not found when the stimuli are tasted in blind conditions. We ‘taste’ the representation that branded foods and beverages show. Therefore, tasting in this stage is not based on the bottom-up taste perception, but on the top-down cognitive processing of representations.

The same is true for the top stage, which is called the self-actualization needs stage. The difference between the fourth stage and fifth stage is the types of information. The former is based on socially motivated information, such as the admiration of others, whereas the latter is based on personal motivation.

People living in developed countries do not often feel true hunger nor safety threats in their daily lives. Therefore, most of our motivation for eating foods are based on the upper stages, rather than the physiological and safety needs. Next, we describe the three studies on the psychological biases and heuristics in psycho-social needs for food.

## Study 1

This study aimed to show the response bias in odor induced taste enhancement. Odor induced taste enhancement is well-known phenomenon. The most typical example of odor induced taste enhancement is based on the interaction of a sweet odor—for example vanilla—with a sweet taste, for example sugar. A previous study showed that the sweetness ratings for the gustatory stimulus, aspartame, was higher when the gustatory stimulus was presented along with an olfactory stimulus, vanilla odor, than without an olfactory stimulus [2]. The study also showed that this enhancement occurred in central information processing, not in the peripheral.

This study aimed to reconfirm the validity of odor induced taste enhancement using another gustatory stimulus and another olfactory stimulus; NaCl and soy-sauce odor. It also had two additional aims: to compare the degree of the effect of the odor induced taste enhancement with that of the taste induced taste enhancement (NaCl-monosodium glutamate: MSG), and to compare the degree of the effect of the enhancement gained by single item evaluation using a Time Intensity method (TI) with those by multiple items evaluation using a Visual Analogue Scale method (VAS). If there are no differences in the former comparison, this suggests that the odor induced taste enhancement is based on cognitive processing, such as the neural system involved in oral referral [3]. This can be said because soy-sauce does not contain any tastants and it therefore cannot stimulate the taste buds in oral cavity. However, the taste enhancement is perceived to occur in the mouth. This is a typical example of oral referral.

If there are no differences in the evaluation with TI and with multiple VAS, the enhancement is not based on cognitive processing, but based on perceptual processing. This is because TI mainly depends on peripheral sensation and multiple VAS depends either on peripheral sensation or cognitive perception. This study has been partly published as a part of a full paper [4].

### Materials and Methods

Forty university students participated in this study, with twenty participating in VAS study and the other twenty participating in the TI study.

In the VAS study, six items for each stimulus were evaluated by the participants using a 100 mm VAS presented to them on paper. The participants were asked to memorize the perception of the stimulus for 60 seconds and then evaluate the stimulus for each item. Five items concerned the stimulus intensities, such as saltiness, umami, sweetness, odor, and irritation. The other item concerned liking ratings for the stimulus.
In the TI study, participants were asked to evaluate only saltiness continuously from the beginning of stimulation. The evaluations were recorded after a maximum of 80 seconds. All the evaluations were done with a touch panel monitor connected to personal computer running FIZZ software (Biosystems) (Fig. 2). The averaged evaluation data with TI is shown in Fig. 3.

The gustatory stimuli were 0.18%, 0.58% and 0.80% NaCl solutions (described below as L, M, and H respectively). These solutions were used as control stimuli. The additional tastant was 0.10% of monosodium glutamate (MSG) solution. The additional odor was soy-sauce odor, presented by a special apparatus (see [4] for detail) that can deliver only odor to the participants’ nose ortho- and retro-nasally without any taste.

### 2.2. Results

The left column of Fig. 4 describes the results of the VAS study. There was a significant main effect of concentration of the NaCl solution \(F(2,36) = 3.75, p < 0.001\), and the post-hoc analysis revealed that there were significant differences among all three concentrations (L < M < H, Tukey’s HSD, \(p < 0.05\)). However, there were no significant main effect with the addition of MSG or the soy-sauce odor and no significant interaction between concentration and addition.

On the other hand, the results of TI study—described in the right-hand column of Fig. 4—showed significant main effects for the addition and concentration \(F(2,18) = 6.73, p < 0.01\), \(F(2,18) = 198.66, p < 0.001\) respectively. A post-hoc analysis revealed that there were significant differences among three concentrations (L < M < H) and significant differences between control (no MSG and no odor) and +MSG or +odor (Tukey’s HSD, \(p < 0.05\)). There was no significant difference between the enhancement effect of MSG and soy-sauce odor. There was also no significant interaction between concentration and addition.

### 2.3. Discussion

This study showed the possible odor induced taste enhancement using another gustatory stimulus and another olfactory stimulus; NaCl and soy-sauce odor. Because the participants in this study are all Japanese, they have experienced salty foods with a soy-sauce odor such as sushi with soy-sauce and Japanese stew. The participants have therefore acquired an association between a salty taste and soy-sauce odor and have developed learned synesthesia [5] based on their daily-life experience-based memory.

The study also showed that there were no differences between the effect size of odor induced taste enhancement and that of taste induced taste enhancement. Therefore, the study suggests that both enhancements are based on cognitive processing (activity around the inferior prefrontal cortex). These findings could help individuals with hypertension, for example, to select low-sodium but palatable foods with salty taste enhancement techniques.

Another finding of this study is that selective attention can explain the taste enhancement phenomena. A taste enhancement was found when the participants were asked to evaluate saltiness with TI method, but not with VAS method. In the TI study, the participants set their attention only to the saltiness. On the other hand, when the participants were asked to memorize the taste characteristics during a waiting period (60 seconds) as well as several other taste characters such as sweetness, umami, odor, and irritation. In the latter case, the participants had
to separate attentional resources into several sensory characteristics [6]. The shared attentional resources for the processing chemosensory stimuli affected the cognitive process of taste enhancement. However, this taste enhancement can be interpreted as sensory-based phenomenon and does not require any cognitive processes. It should be directly challenged to examine whether cognitive processes, such as attention, are involved in the odor induced taste enhancement or not.

3. STUDY 2

There are existing studies that have explored the role of vision in the sense of taste: These studies found that the color of wine distorted the perception of wine [7], the color of the packages of chocolate distorted the perception of its taste [8], and the color of syrup affected the participants’ ability to identify the flavor. These results show the vision is an important component of the sense of taste.

The visual effects on taste are supposedly mediated by olfaction [9]. There are many existing studies showing that vision affects olfaction [10] but very few—and often inconsistent—studies that shows how vision affects gustation.

This study aimed to discover the effect of color on the evaluation of tuna sushi. Vision does not have a direct connection with gustation in peripheral processing and in central processing before and within the primary taste cortex. Additionally, there are no reports showing learned synesthesia concerning gustation and vision. Therefore, if there is an interaction between vision and gustation, it would be based on highly cognitive processing, not on simple sensory or simple perceptual processing such as flavor. A part of this study was presented at IMRF 2011 and published in an abstract form [11].

3.1. Materials and Methods

A total of 23 university students participated in this study. Twelve students liked tuna sushi and reported eating it regularly at that time. Another eleven students did not like tuna sushi and eat it by themselves. Before starting the experiment, it was confirmed that no participants have allergies or a learned aversion to tuna sushi. All participants ate tuna sushi four times, each time with a different visual stimulus. Visual stimuli were the same picture in different colors of tuna sushi. The colors were blue, red, yellow, and white. All the pictures were presented with face-mount monitors. Participants were asked to mount the monitor, eat sushi handed to them by an experimenter, and evaluate the palatability and intensity of fishy smells of the sushi with a software programed with visual basic for excel. The order of presentations were counter-balanced. The procedure of the experiment is shown in Fig. 5.

3.2. Results

The top line of Fig. 6 describes the results of palatability ratings. The white bars describe the results of tuna sushi likers, and the filled bars describes tuna sushi “dislikers.” The results showed that there were significant main effects of tuna liking and of colors ($F[1,90] = 6.79$, $p < 0.05$, $F[3,88] = 4.93$, $p < 0.01$ respectively) in the palatability ratings. The former means that tuna sushi likers
reported higher palatability ratings for the sushi than tuna sushi dislikers. For the latter, the post-hoc analysis (Tukey’s HSD) revealed that sushi presented with the yellow colored picture or white colored picture were rated more palatable than those with red or blue ($p < 0.05$). There were no significant interactions in the tuna liking group with particular colors.

Additionally, in fishy smell ratings, there was significant main effect of colors ($F[3,38] = 3.69, p < 0.05$). The post-hoc analysis revealed that the fishy smell of tuna sushi presented with red colored pictures was rated more intense than with yellow or white colored pictures ($p < 0.05$).

More interestingly, the results concerning the tuna dislikers group showed there are significant effects of colors both in the palatability ratings and fishy smell ratings ($F[3,40] = 4.06, p < 0.05, F[3,40] = 3.05, p < 0.05$). The post-hoc analysis revealed that the tuna dislikers reported a more palatable and less fishy smell when the sushi was presented with yellow colored pictures than red colored pictures (Tukey’s HSD, $p < 0.05$). On the other hand, there were no significant effects according to the colors in the results of tuna likers.

### 3.3. Discussion

This study showed that the color observed while eating sushi changes participants’ perception of the flavor and palatability of the sushi. Tuna dislikers did not evaluate tuna sushi as palatable when the sushi was presented with the red color, the original color of tuna sushi. They evaluated the same tuna sushi as palatable when the sushi was presented with yellow color, partly because they did not the fishy smell so strong. This result suggests that individuals anticipate the taste of food when we see the color of the food and that the anticipation affects the attentional system and taste perception of the food. This supports the results of preceding studies [6–11].

### 4. STUDY 3

This study aimed to reveal the effect of brands on evaluation of coffee flavored milk beverages. The brand of foods and beverages play an important role in the selection of products. For example, the Coca-Cola—or Coke—brand is evaluated higher than the Pepsi brand in the cola market. The reason of this brand value is based on individuals' higher brain functions [12]. The Coke brand activated participants’ hippocampus and lateral prefrontal cortex—which are both areas are involved in memory processing,—but the Pepsi brand could not activate these areas. Therefore, the authors suggested that the brand effect is based on memory systems.

In the Japanese coffee market, the Starbucks brand have the highest value. The preceding study revealed the brand value of Starbucks with a comparison of palatability evaluations in a brand-blinded condition and a brand-opened condition. Participants reported higher palatability ratings in the brand-opened condition than in the brand-blinded condition. Other coffee brands—such as Tully’s and Doutor—did not have the same brand effect. There were differences in brand images between Starbucks and the other brands which were revealed with SD methods, especially in the stylishness ratings. This study aimed to reconfirm that participants’ concept of stylishness affect their taste perception of coffee flavored milk beverages. A part of this study has been published in a Japanese article with an English abstract [13].

### 4.1. Materials and Methods

A total of 90 university students participated in this study. Participants were grouped into 3 groups and each group evaluated only one pair of stimuli.

Each stimulus consisted of a visual stimulus and taste stimulus. There were three kinds of stimulus consisting of three different visual stimuli paired with the same taste stimuli. A canned coffee with milk was used as a taste stimulus.

Three different pamphlets were used as visual stimuli. One visual stimulus was made by the experimenter (U). The fake pamphlet consisted of three photographs of a coffee shop, a fake logo, and fabricated descriptions of the coffee shop as follows: “This coffee company was established in Paris in 2002 and has 3 shops in Paris, a shop in London, and a shop in Hongkong. The company will open its 6th shop in Minami Aoyama, and wants to test their products to survey Japanese customers’ preferences.” These descriptions were evaluated as highly stylish in a preliminary study. The other two pamphlets were of the same format, one describing Starbucks (S) and the other Tuley’s (T).

The participants were presented with 15 ml of the coffee with milk with one of the visual stimuli. They were then asked to evaluate the taste stimulus according to their personal preference, the intensity of coffee flavor, the taste intensity, and its palatability on a 100 mm VAS scale. The procedure of the experiment 3 in shown in Fig. 7.

### 4.2. Results

The overall results of the evaluation were $S > U > T$. One-way ANOVAs revealed that there were significant main effects of visual stimuli in the preference ratings and palatability ratings ($F[2,89] = 9.25, p < 0.001$ for palatability, $F[2,89] = 10.73, p < 0.001$ for preference). These results are shown in Fig. 8.

### 4.3. Discussion

This study reconfirmed that brand representation and perceived stylishness affects preference and palatability
ratings. However, this study could not show the effects of brand representation on the intensity ratings. This result suggests that the brand representations affects the hedonic ratings but not the sensory ratings. Therefore, this study confirms the differences in brain processing between hedonic aspects of taste perception and sensory aspects.

5. GENERAL DISCUSSION

This manuscript consists three studies. The first study showed that soy-sauce odor and added MSG enhanced the salt taste perception. This result is however highly dependent on our cognitive function. The enhancement effect disappeared when the participants were required to divide their attention for several sensory experiences. Previous studies that revealed that brain function is involved in taste-odor association in rats showed that rats can display learned synesthesia of taste and odor, but that association mainly depends on the hedonic aspects of the taste-odor association, not on the sensory aspects [14]. The rats approached the water flavored with the odor paired with saccharin (sweet) and avoided the water flavored with the odor paired with quinine (bitter). The study also showed that the rats’ approach-avoid behaviors were not because they associated the odor with the quality of taste, but because they like the odor paired with saccharin and disliked the odor paired with quinine. However, humans showed quality based taste-odor association, for example the odor paired with saccharin is perceived as sweet. These results suggest that there are differences in the brain mechanisms involved in taste-odor association between humans and rats and that the former depends on higher cognitive functions than the latter.

The second study showed that the color of tuna sushi affects the fishy-smell and the palatability ratings of tuna sushi. The correlation between the color and the fishy-smell and the palatability ratings in the tuna-disliker group suggests that the vision influences flavor perception though our attentional system. When the color of sushi is yellow, our olfactory attentional system for fishy-smell is weakened. On the other hand, our olfactory attentional system sets our selective attention to the fishy-smell when the color red is displayed. These changes in our attentional system are not innate and sensory-based but a highly cognitive system developed by our eating experiences though our daily lives. The relationships among the visual attentional system, the olfactory attentional system, and the memory system should be examined further in future studies.

The third study showed that brand representation such as stylishness affects the hedonic ratings, for example the palatability and the preference ratings. It does not, however, affect the sensory ratings, for example the taste intensity and coffee flavor intensity. This result suggests that we do not evaluate the hedonics of the stimuli based on the sensory and perceptual characteristics of foods and the beverages.

This means that there are discrepancies between the bottom-up sensory system and the top-down hedonic system. This concept is similar to what was discussed in study 1. Humans are highly dependent on the cognitive system to evaluate food and the beverages. This cognitive dependence could lead to mistakes and misattributions in the perception of food and beverages. This study focused on the brain and the physiological mechanisms underlying these mistakes and misattributions to apply these phenomena to increase our quality of life.

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