The Interplay of Color and Context: Understanding Multisensory Influences on Flavor Perception and Hedonic Responses

Bilge Berfin Imren
University of Twente

Supervisors:
Dr. Funda Yildirim
Dr. ir. Juliet Haarman

Abstract

This study explored the influence of color modality representations on taste perception and hedonic responses. Using theories of multimodal perception, priming, and memory color effects, the study looks at how much visual context affects flavor intensity and liking impressions. Sixty participants were randomly assigned to four separate color modality presentations, which are Ambient Lighting, Sensory Interactive Table (SIT), Tableware, and Food Color conditions. During the experiment, the participants filled out ratings of perceived intensity and liking. While the color modality presentations did not significantly affect the perceived intensity, they significantly influenced the liking scores, with Food Color having a lower satisfaction than the other three color presentations. Yellow was linked to a lower perceived intensity compared to other colors, while it was linked to higher liking scores across the conditions together with the Red color. There was a significant interaction between the color modality presentations and colors in intensity ratings. We considered the baseline comparisons before investigating these results. this means that even before flavor manipulation, these modalities were affecting the taste of the food. The study contributes to multisensory research and might have practical implications for dining environments and consumer behavior strategies aimed at enhancing sustainable and appealing eating experiences.

Introduction

Eating habits are acquired early in life and has a lasting effect into adulthood. According to a study conducted on 132,489 children by the World Health Organisation (WHO) showed that 78.8% eat breakfast, meaning over one in five skip the most important meal of the day. Even more concerning, only 42.5% consume fresh fruit and just 22.6% eat vegetables daily—highlighting a significant gap in healthy eating habits among children. However, these eating habits are changeable, cognitive and unconscious processes. They play a significant role in shaping food consumption patterns. Cohen and Farley (2008) referred to these changeable and unconscious processes as "Automatic Behavior," suggesting that the environment often strongly influences eating habits more than individual choices. Our eating behaviours can heavily depend on the environmental context surrounding food—such as portion size, visibility, salience, and ease of access to the food—without us realizing it.

People's responses to their environment are frequently automatic, driven by contextual cues rather than active decision-making. These are subconscious reactions in many cases, as individuals respond to the environment around them without awareness. According to Cohen and Farley (2008), this situation aligns with priming, which refers to how the exposure to certain stimuli can shape our judgments and behaviors without us noticing. For example, Baskin et al. (2016) conducted a field study in a workplace setting and found that employees consumed more snacks when the snacks were placed near beverages, demonstrating how the placement can increase food intake. Thus, the placement of food, visual cues like the prominence of specific snacks, and even the influence of social settings can unconsciously prime individuals to consume more or less food than they intended.

Similar to the priming concept, color-based cues may elicit responses based on memory. Research shows that people often associate certain colors with specific objects or experiences due to prior exposure—this phenomenon is known as the memory color effect (Witzel & Gegenfurtner, 2013; Olkkonen et al., 2008). These associations shape our expectations and can influence perception even without conscious awareness. Similarly, these learned associations can influence eating behavior, with color-linked expectations playing a role in perceived taste and food appeal (Spence, 2015; Zellner & Durlach, 2003).

This memory-based priming may operate alongside contextual priming to shape eating responses. For instance, Kuhbandner et al. (2015), found out that colors like red or yellow are more strongly bound to objects in memory, increasing their perceptual salience. This finding suggests that environmental visual cues do not merely attract attention—they interact with memory systems to drive behavior, often without the individual’s conscious awareness.

As mentioned above, eating behaviors are often automatic and carried out without conscious thought. These automatic behaviours help explain why people might eat more in specific contexts, such as when presented with more significant portions or in social gatherings, without fully recognizing the external influences (Cohen and Farley, 2008). Ultimately, these findings highlight the decisive role of environmental factors in influencing our eating habits. Understanding these dynamics is essential for handling problems related to overeating, eating behaviors and also developing strategies to foster healthier and environment friendly eating behavior.

Literature review

Given the automatic nature of eating behaviors and the powerful role of environmental cues, it becomes essential to understand how specific sensory and contextual factors shape our food-related decisions. Environmental factors like portion size, food placement, and social context are some of the factors influencing eating patterns. The sensory cues add another layer to our understanding of eating behavior. Subtle elements such as lighting, color, smell, and texture can impact how we perceive and choose food. For example, the color of food often sets our expectations about its taste, which can influence how much we eat (Spence, 2015). Similarly, food texture affects our eating pace, with softer foods often leading to quicker consumption and potentially more significant intake (Forde and Bolhuis, 2022). Even the lighting in our eating environment can alter how we perceive taste and enjoyment, as studies have shown varying responses to taste and preference under different lighting conditions (Oberfeld et al., 2009). These sensory cues interact with our senses in ways that we may not consciously notice, yet they frequently drive automatic responses. We can better understand how these environmental elements guide our eating habits by exploring these subtle influences.

The approach by Spence (2015), which is about the multisensory perception of flavor, focuses mainly on five sensory perceptions and how they affect eating behavior. However, this thesis specifically focuses on visual cues, particularly the influence of color. Delwiche et al. (2004) highlighted the complex interplay between these sensory cues, and researchers found that all sensory experiences significantly affect the acceptance and liking of the food. Spence (2015), described this complex interplay as the cross-modal effect, which refers to one sense influencing or modifying the perception of another.

The Effects of Visual Cues on Taste

“We may say that, by and large, the evidence would certainly seem to support the suggestion that we do indeed eat with our eyes” (Spence, 2016, p.611). This quote underscores the idea that visual cues may have a significant impact on flavor and taste perception. According to the multisensory approach, some examples of visual cues are food color, tableware color, shape and size, cutlery color, etc. We will focus on the effect of color during this study and how taste perception changes with different color placements. Previous studies have established that the visual impact of color can alter how we experience the identity of the food and its flavors. According to Spence (2016), this impact is also a parameter to identify food quality, and it functions as an indicator to predict when a food is rotten or bad. Furthermore, the color creates a psychological anticipation for a particular flavor, which often remains fixed and difficult to alter (Harris, 2011; in Spence and Piqueras-Fiszman, 2016). For instance, the color impact on the perception of wine aroma was studied by Morrot et al. (2001). The participants were given white, red, and white wine colored in red and asked to describe the aroma. The results showed that what we see tends to overpower what we smell, as the participants described the colored white wine using typical red wine aroma descriptors. This indicates that the visual appearance (red color) influenced their perception, making them believe it smelled like red wine, even though it was white wine. This also aligns with the concept of color memory described by Witzel & Gegenfurtner (2013) and Olkkonen et al. (2008), which suggests that people create an association between colors and experiences or objects. Another study by Calvo et al. (2001) was conducted with yogurts to explore the influence of color intensity level on the perceived fruit flavor of the yogurt. The results showed that the color intensity also impacts the perceived flavor of the yogurt. “The greater the concentration of colorant, the greater the intensity of fruit flavor perceived” (Calvo et al., 2001, p.103).

While the influence of food color on taste and aroma has been discussed, it should also be noted that other visual cues can similarly affect flavor perception. For instance, the influence of the tableware extends beyond the food’s appearance, demonstrating that the entire visual context of the eating experience shapes our taste perception. The study of Piqueras-Fiszman et al. (2012) showed that a frozen strawberry mousse dessert tasted sweeter when eaten from a white plate rather than a black one. Also, participants liked the dessert on the white plate better. Other studies by Piqueraz-Fiszman et al. (2013) and Annette and Stafford (2023) highlighted that the plate's color again strongly affected how people perceive the effect of the color with different environmental sources on the taste of the food. These findings align with previous findings of Harrar et al. (2011, 2013), as mentioned in Annette and Stafford (2023). Likewise, studies proposed that his may be due to the association of the color with the food. Instead, this was because of people’s flavor associations with specific colors. For example, black color is linked to the intense flavor of chocolate (Piqueraz-Fiszman et al, 2013).

Contextual Elements and Visual Cues Interaction

Spence (2015) mentioned the environmental factors in the multisensory approach and named them contextual elements. Based on this approach, the environment in which food is consumed, including ambient lighting, background noise, and social setting, plays a significant role in flavor perception. This interaction of the environment and visual cues has been investigated in different research with various experimental setups. For instance, different ambient lighting can enhance or diminish certain flavors, as seen in the study of Oberfeld et al. (2009), who also demonstrated this effect with their research on the taste experience of vines with different ambient lights. They found out that the taste of the vine appeared spicier in green and blue room lights, although the blue and red ambient color diminished the fruitness of the vine (Oberfeld et al., 2009).

In another similar research by Knoferle et al. (2015), nearly 3000 people tasted red wine from a black-tasting glass with ambient lighting. The analysis revealed that the wine was more likable and tasted fruitier when the participants were exposed to red ambient light with sweet background music. However, when exposed to green light and sour background music that the researchers defined as the highest pitch, roughness, sharpness and fastest tempo, the liking and fruitiness decreased (Knoferle et al., 2015). The two studies mentioned above aimed to conserve the color change of the food/drink itself. Thus, they only investigate the effect of the contextual elements. However, other than the food color itself and the tableware color, we are also interested in the interaction of ambient lights and the visual perception of the food, so this means that the ambient lighting (both coming from the light bulb or from the table itself) may modify the color of the food. Limited research is available in the literature that investigated this modification. A recent one is the VR study of Cornelio et al. (2022), which suggests that the shape of food and the ambient lighting in the environment affect taste perception and overall eating experience. The participants tasted food samples in a virtual environment and were exposed to different ambient lighting conditions (neutral, red, and blue) and different shapes. The results indicated that the blue lighting increased the perceived sweetness whereas the red light did not. Additionally, no association was found between the ambient light and the pleasantness of the whole eating experience.

Research Gap

Numerous studies have explored how the food color influences taste perception (Spence, 2016, 2018; Morrot et al., 2001; Calvo et al., 2001). These studies primarily focus on the color of the food item itself, often lacking the influence of external visual cues such as the surrounding environment or contextual visual settings. However, a growing body of research suggests that ambient lighting and visual context can subtly shape the taste perception of food (e.g., Oberfeld et al., 2009; Knoferle et al., 2015; Cornelio et al., 2022). Although previous studies have investigated the effects of either food color or environmental lighting on taste perception, their comparative impact has received little attention, particularly within a single experimental design.

This thesis addresses that gap by introducing an experiment design with four modality of color presentation including a sensory-interactive table setting. Unlike previous studies that have only manipulated food color or ambient lighting, this research examines how the *location* and *source* of color (e.g., from the plate, table, lighting, or background) impact perceived taste. Understanding these interactions may uncover new ways to enhance eating experiences and inform design strategies in gastronomy, marketing, and cognitive psychology fields. By exploring how the modality of color presentation shapes sensory perception, this study contributes to a more nuanced understanding of the role of visual context in food evaluation.

Research Questions

Main research question: How do different modality of color presentations (food color, tableware color, ambient lighting, and sensory interactive table lighting) influence taste perception and hedonic responses during the eating experience? The independent variables are the visual cues (modality of color presentations and different colors) manipulated to assess their impact on taste perception and hedonic responses.
The dependent variables are the perceived intensity of the flavor, which is the strongness of the flavor perceived by the participants, and the liking of the food, which reflects the participant's hedonic responses (the level of enjoyment and preference of the food).
Sub-questions:

1. How does the color of the visual cue effect the intensity of the food flavor and hedonic responses?
2. Which visual cue is the most effective in enhancing the perception of flavor intensity and liking of the food?

Method

Participants

Although the primary analysis involved a Kruskal-Wallis test due to the non-parametric nature of the data, a priori power analysis was conducted based on the equivalent one-way ANOVA to determine an appropriate sample size. Using G*Power (Faul et al., 2007), with a medium effect size (f = 0.25), alpha set at 0.05, and power at 0.80, the required total sample size was calculated as 60 participants. This conservative estimate is commonly used to approximate power for the Kruskal-Wallis test. Accordingly, a total of sixty participants (n=60) were selected for the study, with fifteen participants assigned to each condition. Participants were either recruited through the SONA system or invited to take part via social networks and in-person outreach within the surrounding buildings on the University of Twente campus. The ethical permission number given by the University of Twente for this study is 240670.

Materials and Study Design

Materials

The yogurts provided to participants for tasting were Alpro for plain, strawberry and blueberry flavours and Olvarit for the banana flavour, to ensure consistency across all conditions and inclusive participant group, including those with dietary restrictions such as lactose intolerance or veganism. The food colorants from {brand} were used to dye the yogurts in the food color condition of the experiment. Additionally, an Apple iPad Pro (Third Generation) was used for participants to complete a 32-question survey created with Qualtrics software, which collected responses on liking and flavor intensity

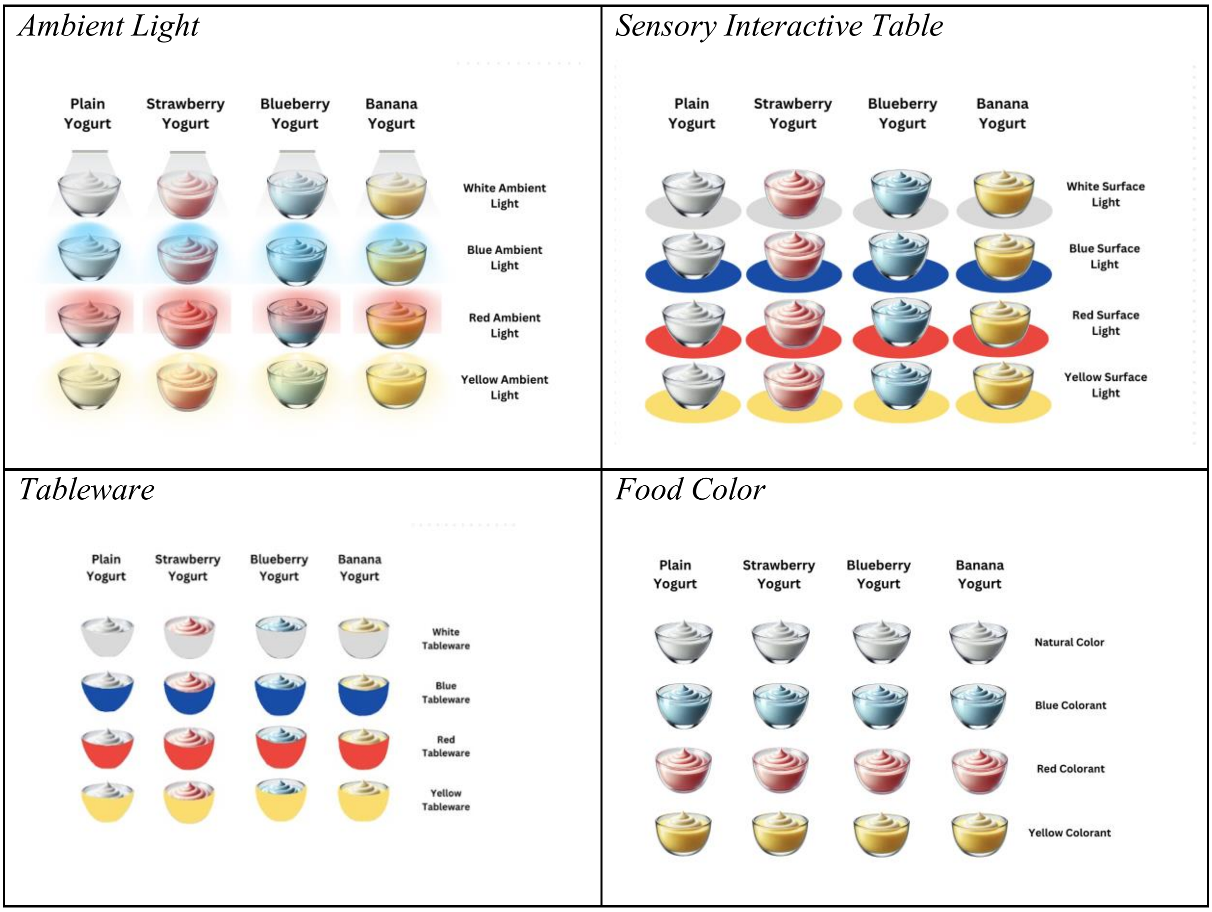
Transparent bowls were used in both the ambient light and Sensory Interactive Table (SIT) conditions, while white bowls were specifically utilized in the food colorant condition to clearly display the color of the yogurt. The flavours of strawberry, blueberry, banana and plain yogurt were used in all conditions. In the tableware condition, colored bowls, including white, red, blue, and yellow, were employed to assess the impact of bowl color on flavor perception. A Smart LED light was used to manipulate ambient lighting, alternating between white, red, blue, and yellow hues during the ambient light condition. The Sensory Interactive Table was used during the SIT condition, and it was coded with Unity Software. Standard cutlery, already present in the eHealth House, was used throughout the yogurt tasting sessions.

Study Design

The study followed a between-subjects design, in which wach participant was randomly assigned to one of the four color modalities: ambient lighting, SIT color, tableware color or food colorant. Every participant tasted all four flavors of yogurt (plain, strawberry, blueberry and banana) in one condition and indicated their intensity and liking rate of the yogurt provided. Figure 1 visualizes the conditions: ambient light, sensory interactive table, tableware, and food colorant. The colors change for every bowl taste in different combinations. The white color was taken as a baseline to compare the red, blue, and yellow colors. The perception of the taste measured in two ways. First one is the intensity scores of the yogurt flavors evaluated by the participants. This measure is about how strong or pronounced the flavor is perceived. It is measured with a Likert scale of 1 to 9 where 9 represents a strong intensity and 1 represents a low intensity of flavor. The second measure is the hedonic responses of the participants. This is about the liking of the yogurt evaluated by the participants with a Likert scale of 1 to 9, where 1 represents the least liking and 9 represents the most liking (see Appendix A).

Figure 1

Overview of the four conditions



Control condition

In every experimental condition of this study, a control condition was implemented to establish a baseline for flavor perception and liking. One bowl of yogurt was served without any added flavor or any color imposed on them, providing a neutral reference point for comparing the effects which is the impact of the external stimuli in this case the modality of color (ambient lighting, sensory interactive table, tableware and food colorant conditions) on the perception of flavor.

Condition 1 Ambient Light

This condition will examine how the overall lighting in the environment affects the flavor perception of food. The standard ceiling lamp was replaced with a LSC Smart Connect Led light to control ambient lighting for each bowl in the yogurt set. This light was controlled by the researcher in every set of yogurts. The color was changed to white, red, blue, and yellow. The color of the lighting was altered between white, red, blue, and yellow to assess the effect of different light colors on flavor perception. The color of the ambient light was changed while the participant was rating the previous bowl of yogurt, ensuring the new light setting was in place before they tasted the next bowl.

Condition 2 Sensory Interactive Table

This condition investigated how the color emitted by the surface of the dining table influences the taste experience. The sensory interactive table (SIT) was used for this experiment condition. It was developed by the researchers Juliet Haarman, Roelof de Vries, Hermie Hermens, Emiel Harmsen, and Dirk Heylen at the University of Twente (Haarman et al., 2020) to understand and shape the eating experience by directly manipulating visual sensory cues. This interactive dining table has sensors that can detect the mass of the food and has cells with LED lighting that can be coded and controlled with Unity software. Thus, The SIT was programmed to display white, red, blue, and yellow lights on its surface to impose a different color on each bowl. SIT projected circles of white, red, blue and yellow colors on the table, aligning with the area beneath each bowl to influence the participants' visual environment during the yogurt tasting. The bowls were placed next to each other and the circles appeared next to each other. The table was programmed to change colors in 16 different combinations throughout the sets of yogurts to ensure that each color is paired once with each flavor.

Condition 3 Tableware

This condition was focused on how the color of the tableware impact the perception of the food's flavor. Yogurts were served in bowls of different colors (white, blue, red and yellow) to determine the influence of this color placement. Every flavor of yogurt was tasted by the participants in a different tableware color.

Condition 4 Food colorant

This explored how color of the food itself alters flavor perception of flavor and liking by using food colorant. For each color (red, blue and yellow), 3 tablespoons of yogurt were added into a transparent container. Then 1 drop of liquid foos colorant (from {brand}) were added and stirred with a spoon until the color was evenly distributed. For the control condition (natural color), 1 tablespoon of yogurt was left uncolored. All samples were served in white tableware to ensure the yogurt color remained visible and to avoid visual interference from the bowl or surface.

Procedure

The testing sessions took place in an experimental room within the e-Health House, TechMed Center at the University of Twente, free from distractions or external sensory input. Only the Sensory Interactive Table Condition took place in the T200 room of Citadel building because of logistical issues. To eliminate any potential confounding variables caused by the difference of the location, the same lighting and atmosphere of the e-Health House was replicated for the experiment in the T200 room. Participants were provided with a detailed information sheet explaining the study's aim and procedures. Testing commenced only after they confirmed their understanding of the research and voluntarily agreed to participate by signing a consent form. They were informed of their right to withdraw from the study at any point without providing an explanation and that the study focused on their individual sensory experiences rather than "correct" answers.

Participants were randomly assigned to one of the experimental conditions. Before starting the experiments, the researcher verbally explained the study's process and covered the important key points. The order of tasting is from left to right; participants should taste the yogurt first and then rate it. Only one spoonful should be taken before indicating the rating. Participants should leave the bowl on the table during the tasting and refrain from holding it in their hands. "Liking of the yogurt" refers to the participant's personal preference, indicating whether they liked it or not. Yogurts were prepared in advance and stored in the e- Health House kitchen. Additionally, a cup of water and a napkin were provided on the table for each participant for in between tasting flavors. The testing began with participants sampling the plain yogurt. After tasting each bowl of yogurt, participants rated both their liking of the yogurt and the intensity of the flavor. This process was carried out through a 32-question survey, created using Qualtrics.

Each participant first filled in their age, participant number, and selected their assigned condition to access the relevant survey questions. The same procedure was repeated for the second set (strawberry yogurt), the third set (blueberry yogurt), and the fourth set (banana yogurt). The order in which the colored yogurt samples were presented was pseudo-randomized to ensure that no two samples of the same color appeared consecutively and that each participant experienced a balanced presentation sequence. This approach minimized order effects while maintaining control over the sequence structure.

Statistical Analysis

The main independent variable in this study is the color modality presentation operationalised through four conditions: Ambient light, tableware, food color and sensory interactive table. Each condition is a manipulation of different visual context in with participant evaluated yogurt flavors. The effects of the different colors, conditions and their interactions are measured in the statistical analysis. The dependent variable is the perception of the taste measured in two ways. First one is the intensity scores of the yogurt flavors evaluated by the participants. Second dependent variable is the hedonic reponses of the participants.

First a Shapiro-Wilk normality test was conducted to see if the data is normally distributed in order to proceed with the statistical test. The outcome showed that the data is not normally distributed. Thus, a non-parametric test, Kruskal Wallis, was used for the statistical analysis. This test was used to see the effects of the different colors, conditions and their interactions. For the pairwise comparisons Mann Whitney test with a Bonferroni correction was applied in order to control Type I error, which increases when multiple groups are compared. By adjusting the significance threshold, the correction ensures that the family-wise error rate remains at 0.05, reducing the likelihood of falsely identifying significant differences. However, non-parametric tests like Kruskal-Wallis and Mann-Whitney U cannot test interaction effects between variables. Therefore, to examine the interaction between color and condition, the Aligned Rank Transform (ART) model was used. This model is specifically used for non-normally distributed data and enables the analysis of interactions in factorial designs, offering an alternative to traditional ANOVA when its assumptions are violated. Additionally, a Kruskal-Wallis test was conducted to assess whether baseline evaluations of plain yogurt differed across color conditions within each presentation condition. This step was performed to verify that baseline differences between participants did not confound the main experimental results. Results revealed a significant difference between conditions ($p = .006$), indicating that baseline evaluations of natural yogurt varied depending on the presentation condition. Although liking and intensity scores were later normalized based on each participant's natural yogurt evaluation under white lighting, the presence of initial baseline differences suggests that presentation factors, such as the lighting condition or environment, may have influenced participants' initial sensory perception independently of flavor. These baseline shifts should be considered when interpreting subsequent experimental results.

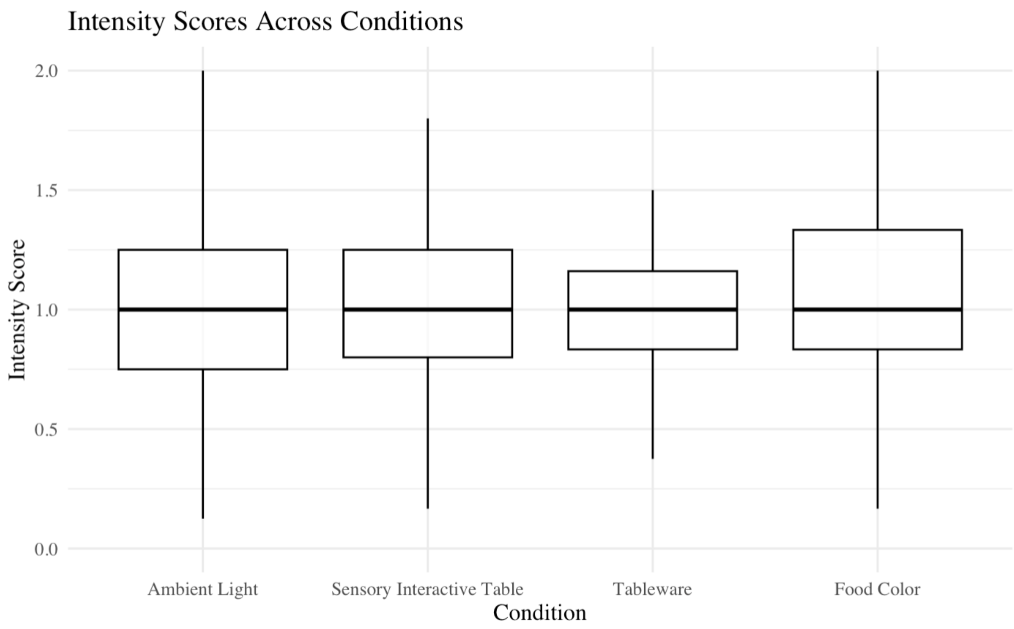
Results

A Kruskal-Wallis test was conducted to determine whether the intensity and liking scores of four conditions differ from each other. According to our findings, the difference between the color placements did not significantly affect the intensity of the food, $\chi^2(3) = 5.79$, $p = .122$. However, the liking scores of the food differed significantly between the four conditions, $\chi^2(3) = 20.58$, $p < .001$. Post hoc pairwise comparisons using Mann-Whitney tests with Bonferroni correction indicated that the Food Color condition differed significantly from all other conditions: Ambient Light ($p = .045$), Sensory Interactive Table ($p < .001$), and Tableware ($p = .001$). No significant differences were observed between Ambient Light, Sensory Interactive Table, and Tableware conditions (all $p = 1.00$). The Food Color condition resulted in significantly lower liking scores compared to all other conditions. As seen in the figure 2 the Food Color condition resulted in significantly lower liking scores compared to all other conditions.

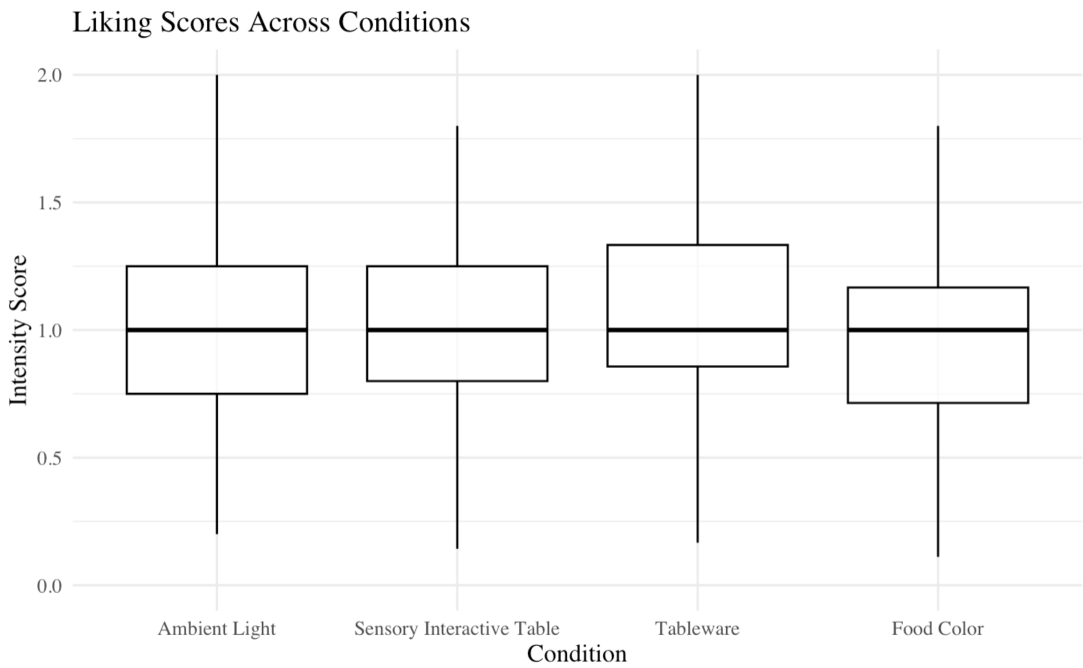
Figure 2

Boxplot of Intensity and Liking Scores Across Conditions

a) Intensity scores across four experimental conditions: Ambient Light, Sensory Interactive Table, Tableware and Food Color



b) Liking scores across four experimental conditions: Ambient Light, Sensory Interactive Table, Tableware and Food Color

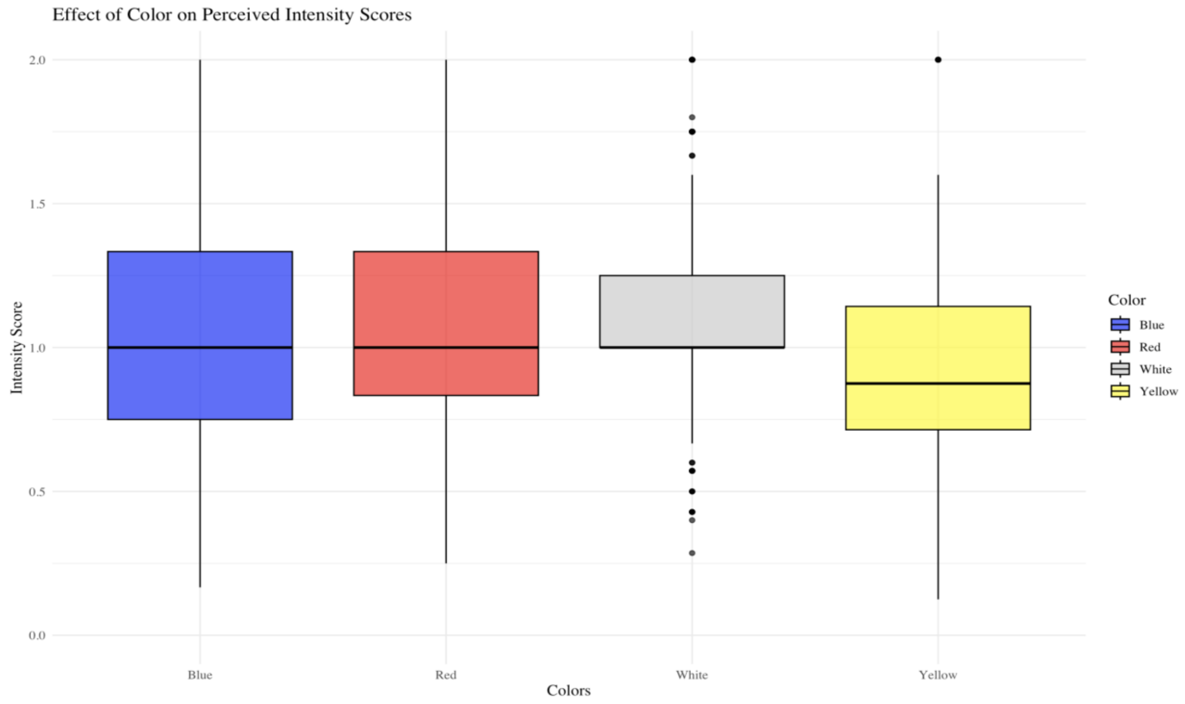


Note. This figure demonstrates the distribution of normalised intensity and liking scores for each experimental condition. The central line in each box represents the median, and the boxes represent the interquartile range. The Food Color condition in liking scores shows slightly lower score compared to the other conditions.

A Kruskal-Wallis test was conducted to determine if there were significant differences between the four colors for both intensity and liking scores. For the intensity scores, the test revealed a statistically significant difference between the four colors, $\chi^2(3) = 35.85$, $p < .001$. Follow-up Mann-Whitney test with a Bonferrori correction was applied for the pairwise comparisons. The Yellow color condition significantly differed from all other colors. Specifically, scores in the Yellow condition were significantly different from Blue ($p < .001$), Red ($p < .001$), and White ($p < .001$). No significant differences were Blue and White ($p = 1.00$), or Red and White ($p = 1.00$).

Figure 3

Effect of Color in Percieved Intensity Scores

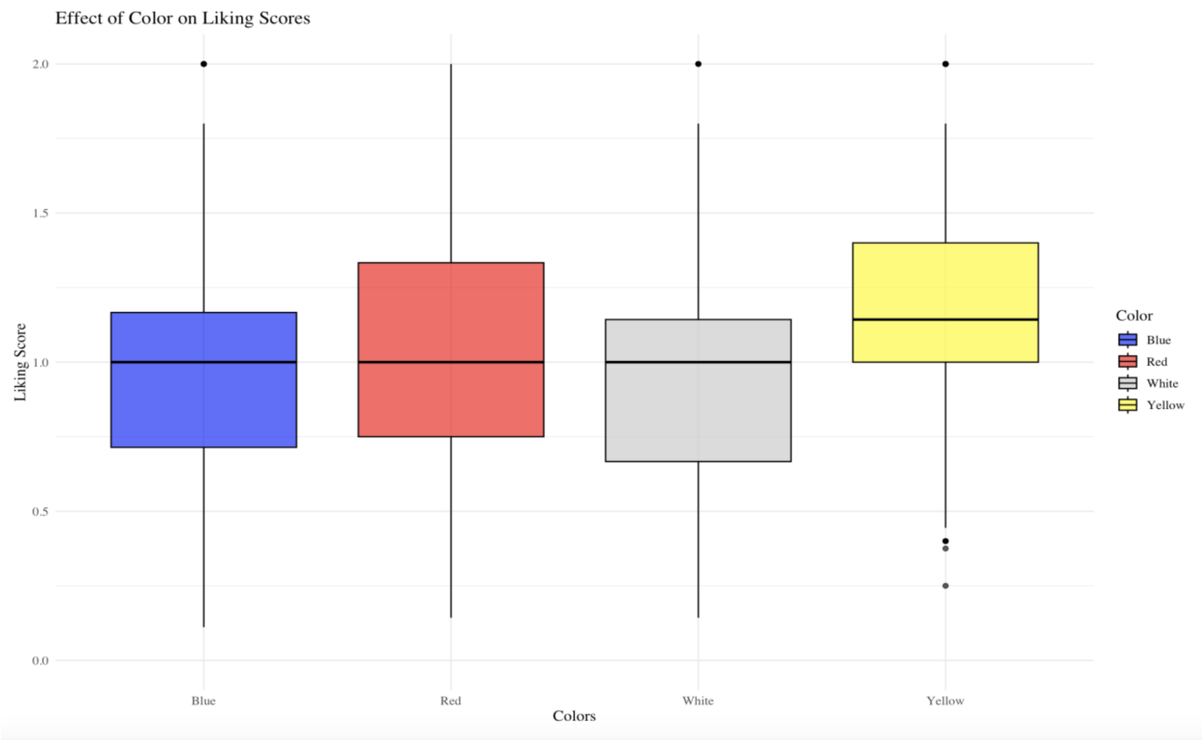


Note. Boxplot illustrating the distribution of perceived intensity scores across four colors: Blue, Red, White, and Yellow. The Yellow condition has a noticeably lower median and a narrower spread compared to the other colors.

For the liking scores, the test revealed significant differences between four colors, $\chi^2(3) = 32.06$, $p < .001$. To see the pairwise comparisons, Mann-Whitney test with a Bonferrori correction was applied. White color significantly differed from Red ($p < .001$) and Yellow ($p < .001$), but not from Blue ($p = 1.00$). Additionally, Yellow significantly differed from both Blue ($p < .001$) and Red ($p = .003$), and Blue significantly differed from Red ($p = .005$).

Figure 4

Effect of Color in Liking Scores

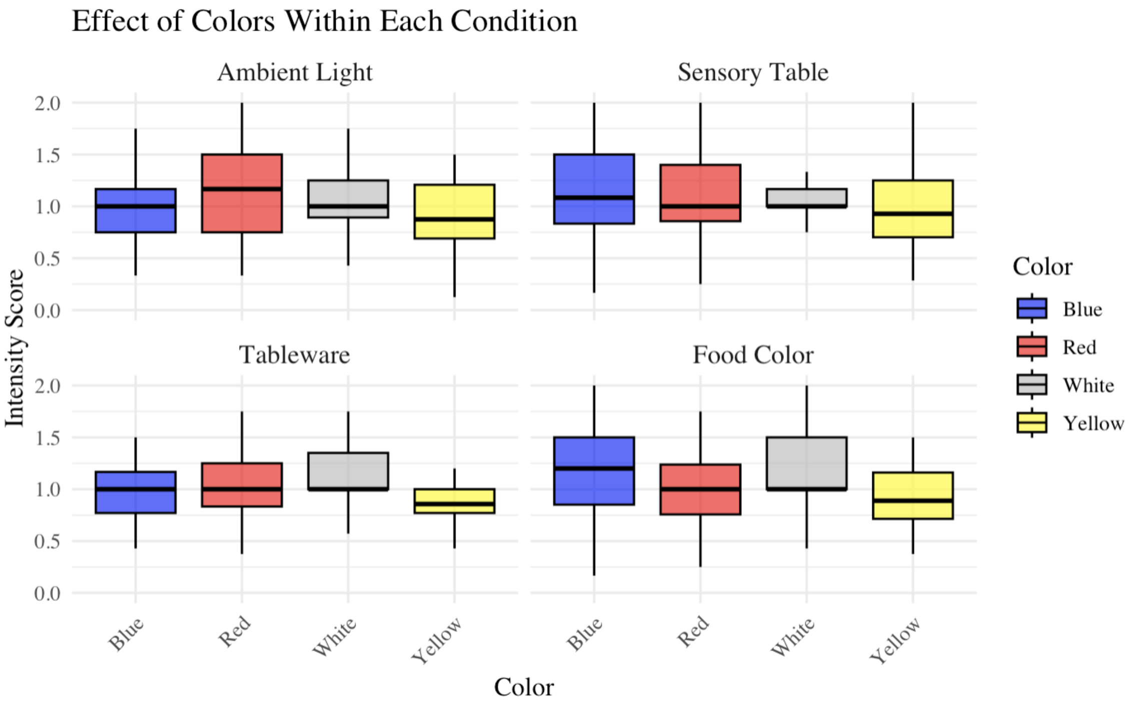


Note. Boxplot displaying the distribution of liking scores across four color conditions: Blue, Red, White, and Yellow. The Yellow color has a higher median and tighter spread, following by Red color indicating more consistent and generally more favorable ratings compared to the other colors.

Aligned Rank Transform (ART) model was conducted to examine the effects of Color and Conditions on normalized taste scores. The analysis revealed a significant main effect of Color, $F(3, 924) = 12.69$, $p < .001$, indicating that taste ratings differed across conditions.

Figure 5

Effect of Colors in Percieved Intensity Scores Within Each Condition



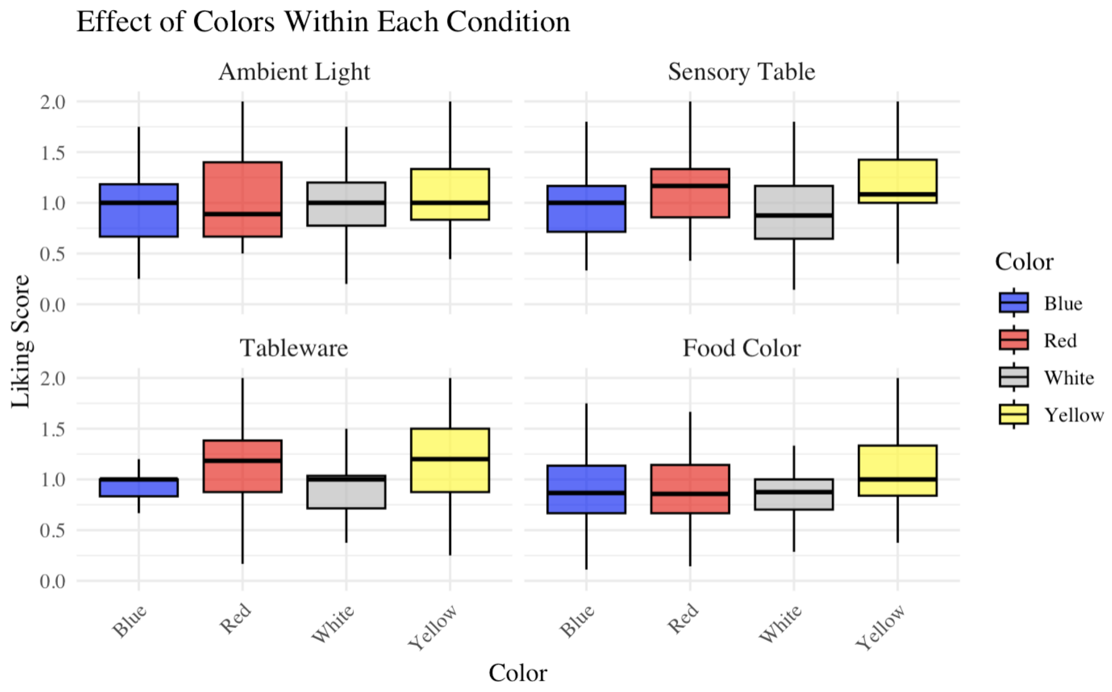
Note. This figure illustrates the effect of different colors (blue, red, white, yellow) on perceived intensity scores within each experimental condition: Ambient Light, Sensory Table, Tableware, and Food Color. Each boxplot represents the distribution of normalized intensity ratings across participants for each color.

Regarding medians, blue consistently showed high-intensity scores in the Sensory Table and Food Color conditions. Red also showed high median scores in the Ambient Light condition, around 1.4–1.5, but was slightly lower in other contexts. White tended to have moderate intensity scores, especially under the Tableware condition. In contrast, yellow generally received lower intensity ratings, particularly in the Tableware condition, where the median was below 1.0. Overall, the effects of color on perceived intensity varied by condition, with blue and red often associated with more vigorous perceived flavor intensity.

However, the interaction between Color and Condition was not significant for the liking scores $F(9, 924) = 1.45$, $p = .163$. This indicates that the effect of color on liking ratings did not significantly vary across different conditions.

Figure 6

Effect of Colors in Liking Scores Within Each Condition



Note. This figure displays the effect of different colors (blue, red, white, yellow) on liking scores across four experimental conditions: Ambient Light, Sensory Table, Tableware, and Food Color. Each boxplot represents the distribution of normalized liking ratings per color within each condition.

Across all conditions, yellow tended to receive slightly higher median liking scores, especially under the Sensory Table and Food Color conditions. In contrast, blue generally showed the lowest median liking scores, particularly in the Tableware and Food Color conditions. Red had relatively high liking scores under Ambient Light and Sensory Table conditions, while white was more variable but consistently moderate across most conditions. These patterns suggest some color preferences, although they did not significantly interact with the experimental conditions.

Discussion

It It is essential to state that visual cues affect taste and satisfaction after tasting the food (Linné et al., 2002). This study investigated the influence of different color modality presentations—food color, tableware color, ambient lighting, and sensory interactive table lighting—on taste perception and hedonic responses during the eating experience. We expected that different color modality presentations would enhance both the perceived flavor intensity and the liking of the food, and that their effects would vary depending on the specific presentation.

These expectations come from how people use their senses and the connections they've learned over time. For instance, yellow yogurt for bananas can increase the intensity of the flavor and could make the food more enjoyable since the color would look exactly as people expect it to. This effect happens because of several reasons according to the research. Firstly one is that the color makes the food seem like it has real ingredients. Secondly, people are mostly used to seeing specific colors with certain flavors, like in packaging or in ads during everyday life (Spence, 2015; Zellner & Durlach, 2003).

This information is further supported by the Color Memory Theory, which highlights that people keep stable mental representations of the typical colors of familier foods. The mismatch of these expected and the actual color of the food can influence the identification and evaluation of it (Schlintl and Schienle, 2020). When the appearance of food matches this internal color memory, the perceptual coherence becomes more easy and this may enhance the intensity and liking of the food. Understanding the mechanisms behind these effects deepens our insights of multisensory food perception. This might give us the chance to enhance the satisfaction, with practial applications, throught different design elemtents in immersive dining experiences. Furthermore, the marketing strategies could be shaped by these multisensory experiences and their practical applications.

Effect of Condition on Intensity and Liking Scores

Differences between four color placement modalities were expected. The results demonstrated that the presentation of the color significantly influenced participants' liking scores. This suggests that visual presentation plays an crucial role in determinigng food satisfaction. In contrast, no significant differences were found in the perceived intensity of the yogurts across the four conditions. Regardless of the color presentation the actual intensity of the flavor remained the same across four conditions. Thus, while visual cues can shape the hedonic responses, they may not necessarily change the evaluation of flavor intensity. A possible explanation for this might be due to the subjective and sensitive nature of the hedonic responses in general. However, perceived intensity is more strongly tied to the actual chemical properties of the food, such as sweetness, sourness, spiciness, or aroma. These results contrast with the findings of Knoferle et al. (2015), who showed that environmental changes, such as ambient lighting or background music, could influence wine perception and evaluation. One reason for this difference could be the type of food or drink tested: flavor perception in wine may be more easily influenced by environmental factors than the flavor perception of yogurt.

The liking scores showing significant differences between the conditions, the post hoc analyses revealed that the scores were significantly lower in the Food Color condition compared to the other three. While the ambient and contextual color manipulations enhanced the hedonic evaluation of the yogurts, direct color manipulation of the food had a lower impact on its appeal. Similarly, Oberfeld et al. (2009) found that colored lighting affected the taste ratings. Furthermore, Spence (2015) showed that people often react with disgust or rejection when encountering food that appears incongruent or unexpectedly colored, due to violations of expectations shaped by prior knowledge. This could support why the direct coloring of the yogurt led to lower liking scores compared to the more subtle environmental manipulations.

Effect of Color on Perceived Intensity Scores

Our findings indicate that color plays a role in modifying the perceived intensity of taste. We expected the Blue, Red, and Yellow colors to differ from White, which served as the control condition. The results revealed a significant difference between Yellow and White for intensity scores. The Yellow color showed the lowest intensity ratings. Although, Red-White and Blue-White differences were not statistically significant, the median scores for these colors were higher than the Yellow color, indicating that these colors may contribute to a more vigorous perceived flavor intensity.

Prior research on cross-modal effects, specifically the influence of visual color cues on taste perception align with our results. Spence (2015) found that color significanlty influences taste experiences and acts as a sensory cue that shapes the flavor expectations. The lower scores for the Yellow color in our study underlines the idea that certain colors are associated with a richer taste experiences than others.

Similarly, Morrot et al. (2001) demonstrated that the color change of wine could significantly alter the parception of its aroma, even when the tasted wine remained the same across the different colors. Their findings highlight the importance of the visual cues and how powerful they can be in shaping the sensory experiences of individuals, often overriding the actual sensory input from taste. These findings support the idea that color manipulations in our study influenced the perception of intensity, even though the actual yogurt flavors were identical across conditions. Overall, these findings emphasize that visual context plays a crucial role in the multisensory eating experience and can meaningfully shape both perceptual and emotional responses to food.

Effect of Color on Liking Scores

All three colors were expected to affect participants' liking of the yogurt. Test results indicated significant differences in liking scores only for two colors, Red and Yellow, showing that participants satisfaction was higher when the food was presented woth these two colors. The Yellow color showed the highest liking scores, followed by Red color. While the Blue color had the lowest liking median and did not differ much from the baseline condition. Interestingly, despite being associated with lower perceived intensity, the Yellow color showed the highest liking ratings. One reason for this might be that the participants prefer yogurts that are perceived as less intense and they favor more subtle and mild flavors over stronger ones. A mild taste may match better with what people expect from yogurt, making it more enjoyable. In addition, we should also remember again that the hedonic responses tend to have a subjective nature. These findings are consistent with previous research by Yang et al. (2015), who found that food appeared more appealing and increased willingness to eat when shown in Yellow compared to Blue.

Another possible explanation is that color-flavor matching expectations may have influenced participants' liking. When the color of the yogurt matches a familiar flavor association, such as yellow with banana, red with strawberry, it may create a more coherent and pleasant eating experience (Spence et al., 2010; Shankar et al., 2010). In this case, yellow may have aligned with participants' learned expectations for sweet or mild flavors, contributing to higher liking scores. This also contributes to the color memory theory that introduced in the introduction part of this paper. Overall, 90% of individuals' first impressions are influenced by colors (Khandelwal et al., 2024). These results contribute to the growing research showing how visual elements, particularly color, shape consumers' food experiences and preferences.

Color and Condition Interaction

Contextual elements such as ambient lighting, background noise, and social settings interact with sensory cues to influence perception. Therefore, we expected not just overall differences, but an interaction between color and condition. Specifically, we expected that the way color was presented — either directly on the food (Food Color) or through the environment (Ambient Light, Sensory Interactive Table, or Tableware) — would change how strongly it influenced participants' taste perception and liking. For example, we anticipated that changing the food's color would have a stronger effect on flavor intensity and liking compared to changing the surrounding environment, because the food itself is the primary focus during tasting.

Our results showed that the perceived intensity scores of the yogurt flavors had a visible variability across conditions. For instance, Blue and Red tended to produce higher intensity scores: Blue was more effective in Sensory Table and Food Color conditions, and Red was more effective in Ambient Light condition. These findings are valuable especially when it comes to the eating experience. Tuncel (2009) indicated that proper lighting sets the atmosphere of the environment, affects appetite, and can even alter taste perception and that the recent research shows that the lighting used in places such as restaurants and cafes directly influences the customer experience.

However, Yellow was often rated the lowest in intensity, especially in the Tableware condition. This suggests that not all colors enhance perceived intensity equally across different contexts. In particular, Yellow may not create strong sensory expectations in a tableware setting, where the focus might be more on environmental cues than on direct flavor signaling from the color itself. While Blue and Red seem to strengthen the flavor experience depending on the context, Yellow's association with lighter, softer flavors could explain its lower intensity ratings, especially when the color is part of the serving environment rather than the food itself. That said, baseline comparisons showed that intensity ratings for Yellow were already lower in the Tableware condition, even before any flavor manipulation. This suggests that part of the observed effect may reflect initial perceptual biases related to baseline differences across color presentations, rather than an interaction effect alone. Similarly, the effect of the Red color in the Ambient Light condition may also be partly driven by baseline differences, as it seems to enhance intentisty ratings for the plain yogurt even before other flavors in the baseline comparisons. These baseline influences should be acknowledged when interpreting context-dependent effects.

The study of Piqueras-Fiszman et al. Flavour (2013) suggests that the color of the plate significantly influenced how appealing, appetizing and intense the color of the food appeared. As seen in Figure 5, the Tableware condition appeared to show the least variation and the smallest median in perceived intensity ratings across different colors. This may be due to the fact that the actual color of the food was not altered by the surrounding color. In other conditions, such as sensory interactive table and ambient lighting or when the food itself is colored, the effect tends to be more pronounced. For example, Calvo et al. (2001) found that higher color saturation enhances the perceived fruit flavor of yogurt. In the Tableware condition, however, the yogurt's visual properties remained relatively constant, potentially limiting the impact of color. Overall, evidence suggests that a clear variation in color effects across conditions is present in the across condition is present in perceived intensity of the yogurt flavors.

On the other hand, the liking scores did not show a significant difference for the interaction of color and condition. The effect of color on liking did not vary across conditions. However, visible patterns were found in the data. Red and Yellow generally had higher medians across conditions, specifically the Sensory Table, Food Color and Ambient Light conditions. Blue and White tended to have lower liking scores, particularly in Tableware and Food Color conditions. This may be because of the subjective and individually varying nature of hedonic responses. As Tourila (1996) indicated, liking of the food flavors is shaped not only by innate taste preferences but also by personal experiences, cultural exposure, and situational factors such as hunger, health motivations, or environmental cues. Our results might also be affected by these individual factors, so the response to the same sensory stimuli might differ across individuals. While the intensity of the flavor may follow more consistent pattern across individuals, the liking of the flavor may vary due to these learned preferences, which will make the individual less sensitive to contextual manipulations like lighting, tableware or food color change.

Conclusion

This research aimed to understand the influence of the different color modality presentations on the perception and enjoyment of the food. Contextual cues were specifically effective in increasing the satisfaction of the food, suggesting that the environmental elements play an important role in shaping food experience. These insights add to a growing body of research in multusensory perception and offer practical applications for prompting behaviour through environmal cues. Subtle changes in lighting or presentation can be used to increase the meal satifaction, potentially increasing acceptance of sustainable or alternative food options, and encouraging pro-environmental behaviors in consumption contexts. The findings also support psychological models of cue-based perception, where memory, expectation, and context jointly influence experience. Personally, this project has strengthened my interest in the applied side of psychology—especially how invisible cues in our surroundings can powerfully shape everyday behaviors, including eating. It has highlighted for me the importance of integrating sensory science, behavioral design, and sustainability efforts in future food-related interventions. On a more personal level, this project has been eye-opening for me. Investigating how color and context influence food choices gave me the chance to reflect on my own habits and experiences with eating. I found this research not only academically interesting but also personally relevant. It helped me understand how easily external factors can shape what and how we eat, often without us even noticing. This has made the whole process more meaningful, and it deepened my interest in how psychology and sensory perception intersect with everyday life.

Limitations

Further evidence that visual cues—particularly color—significantly influence taste perception and hedonic responses is provided in this study. These findings have practical implications for the food and beverage industry, including product design, marketing, and dining environments. For instance, restaurants and food manufacturers can strategically use specific color schemes to enhance the perceived appeal and intensity of their products.

In addition to the practical applications, also a cultural dimension of the color perception in food is important regarding the literature of research. Celik and Evren (2024) stated in their research that the perception of the taste was influenced by the place of the color in a certain culture. This leads us to the idea that not all colors are universally accepted—certain colors may be perceived as natural and appealing in some contexts, while being considered unusual.

A color that is acceptable in one type of food may not be perceived the same way in another. Supporting this view, Piqueras-Fiszman et al. Flavour (2013) also indicated in their research as cultural or learned associations about the colors and flavors that could influence the results of the study, and they highlighted that this was mostly regarding to intensity.

Future Research

For future research, exploring how colors influence emotions could provide valuable insights and further enhance this field. Incorporating emotions into a survey could be a meaningful addition to better understanding the psychological impact of color which will lead us the color psychology as Khandelwal et al. (2024) studied in their research about marketing. Incorporating an emotional level into future studies could provide a richer understanding of how color affects individuals' responses and could help researchers to see if certain colors create specific emotions that affect how individuals experience taste and preference. On the other hand, while color effects were robust, their interaction with broader contextual elements deserves further exploration. For instance, testing different food types could clarify whether these results are generalizable or specific to yogurt-based products.

References

Annette, M., & Stafford, L. D. (2023). Plate colour influences flavour perception and food intake: A replication and extension. *Appetite, 182*, 106401. https://doi.org/10.1016/j.appet.2022.106401

Aslam, M. M. (2014). The role of color in marketing: A review of the literature. *Frontiers in Psychology, 5*, 1278. https://doi.org/10.3389/fpsyg.2014.01278

Baskin, E., Gorlin, M., Chance, Z., Novemsky, N., Dhar, R., Huskey, K., & Hatzis, M. (2016). Proximity of snacks to beverages increases food consumption in the workplace: A field study. *Appetite, 103*, 244–248. https://doi.org/10.1016/j.appet.2016.04.025

Calvo, C., Salvador, A., & Fiszman, S. M. (2001). Influence of colour intensity on the perception of colour and sweetness in fruit-flavoured yoghurts and drinks. *Food Quality and Preference, 12(6)*, 409–415. https://doi.org/10.1016/S0950-3293(01)00053-7

Celik, H., & Evren, S. (2024). Cultural influences on color perception in food marketing. *Journal of Consumer Culture*.

Cohen, D. A., & Farley, T. A. (2008). Eating as an automatic behavior. *Preventing Chronic Disease*, *5*(1), A23. https://doi.org/10.5888/pcd5.1.07_0046

Cornelio, P., Dawes, C., Maggioni, E., Bernardo, F., Schwalk, M., Mai, M., Pawlizak, S., Zhang, J., Nelles, G., Krasteva, N., & Obrist, M. (2022). Virtually tasty: An investigation of the effect of ambient lighting and 3D-shaped taste stimuli on taste perception in virtual reality. *International Journal of Gastronomy and Food Science, 30*, 100626. https://doi.org/10.1016/j.ijgfs.2022.100626

Delwiche, J. (2004). The impact of perceptual interactions on perceived flavor. *Food Quality and Preference, 15*(2), 137–146. https://doi.org/10.1016/S0950-3293(03)00041-7

Dzhondzhorova, N. (2023). *[Thesis on the effectiveness of the Sensory Interactive Table]*. University of Twente.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. https://doi.org/10.3758/BF03193146

Forde, C. G., & Bolhuis, D. (2022). Interrelations between food form, texture, and matrix influence energy intake and metabolic responses. *Current Nutrition Reports, 11*(2), 124–132. https://doi.org/10.1007/s13668-022-00413-4

Harrar, V., & Spence, C. (2013). The taste of cutlery: The weight of the cutlery affects perceived density, creaminess, and price of food. *Flavour, 2*, 21. https://doi.org/10.1186/2044-7248-2-21

Harrar, V., Piqueras-Fiszman, B., & Spence, C. (2011). There's more to taste in a coloured bowl. *Perception, 40*(7), 880–882. Doi:10.1068/p7040

Khandelwal, R., Garg, P., & Singh, R. (2024). Color psychology in marketing: Exploring consumer perceptions and behavior. *International Journal of Marketing Studies, 16*(1), 45–59.

Kuhbandner, C., Spitzer, B., Lichtenfeld, S., & Pekrun, R. (2015). Differential binding of colors to objects in memory: Red and yellow stick better than blue and green. *Frontiers in Psychology, 6*, 231. https://doi.org/10.3389/fpsyg.2015.00231

Knoeferle, K., Woods, A., Käppler, F., & Spence, C. (2015). That sounds sweet: Using cross-modal correspondences to communicate gustatory attributes. *Psychology & Marketing, 32*(1), 107–120. https://doi.org/10.1002/mar.20766

Morrot, G., Brochet, F., & Dubourdieu, D. (2001). The color of odors. *Brain and Language, 79*(2), 309–320. https://doi.org/10.1006/brln.2001.2493

Olkkonen, M., Hansen, T., & Gegenfurtner, K. R. (2008). Color appearance of familiar objects: Effects of object shape, texture, and illumination changes. *Journal of Vision, 8*(5), 13. https://doi.org/10.1167/8.5.13

Oberfeld, D., Hecht, H., Allendorf, U., & Wickelmaier, F. (2009). Ambient lighting modifies the flavor of wine. *Journal of Sensory Studies, 24*(6), 797–832. https://doi.org/10.1111/j.1745-459X.2009.00239.x

Piqueras-Fiszman, B., Alcaide, J., Roura, E., & Spence, C. (2012). Is it the plate or is it the food? Assessing the influence of the color (contrast) of the plate on the perception of the food. *Food Quality and Preference, 24*(1), 205–208. https://doi.org/10.1016/j.foodqual.2011.08.011

Piqueras-Fiszman, B., & Spence, C. (2013). The taste of cutlery: how the taste of food is affected by the weight, size, shape, and colour of the cutlery used to eat it. *Flavour, 2*(1), 1–5. https://doi.org/10.1186/2044-7248-2-21

Schlintl, C., & Schienle, A. (2020). The impact of food colors on expected taste and flavor intensity in younger and older adults. *Food Quality and Preference, 79*, 103781. https://doi.org/10.3389/fpsyg.2020.589826

Shankar, M. U., Levitan, C. A., Prescott, J., & Spence, C. (2010). The influence of color and label information on flavor perception. *Chemosensory Perception, 3*(1), 19–29. https://doi.org/10.1007/s12078-009-9046-4

Spence, C. (2015). Multisensory flavor perception. *Cell, 161*(1), 24–35. https://doi.org/10.1016/j.cell.2015.03.007

Spence, C. (2015). Eating with our eyes: On the color of flavor. In A. J. Elliot, M. D. Fairchild, & A. Franklin (Eds.), *Handbook of color psychology* (pp. [page range if known]). Cambridge University Press. https://doi.org/10.1017/CBO9781107337930.030

Spence, C. (2016). Gastrophysics: The new science of eating. Penguin UK.

Spence, C. (2015). On the psychological impact of food colour. *Flavour, 4*, Article 21. https://doi.org/10.1186/s13411-015-031-3

Spence, C., Levitan, C. A., Shankar, M. U., & Zampini, M. (2010). Does food color influence taste and flavor perception in humans? *Chemosensory Perception, 3*(1), 68–84. https://doi.org/10.1007/s12078-010-9067-z

Spence, C., & Piqueras-Fiszman, B. (2016). *Multisensory flavor perception: From fundamental neuroscience through to the marketplace.* Elsevier. https://doi.org/10.1016/C2013-0-18196-7

Tourila, H. (1996). Hedonic responses to taste and odor and their relation to preferences. *Food Quality and Preference, 7*(5–6), 215–219. https://doi.org/10.1016/S0924-2244(96)10048-0

Tuncel, A. (2009). *Renklerin insanların psikolojisine etkisi ve pazarlamada renklerin önemi* [Yüksek lisans tezi, Selçuk Üniversitesi]. Yükseköğretim Kurulu Ulusal Tez Merkezi. https://tez.yok.gov.tr/UlusalTezMerkezi/

Wansink, B., Painter, J. E., & Lee, Y.-K. (2006). The office candy dish: Proximity's influence on estimated and actual consumption. *International Journal of Obesity*, *30*(5), 871–875. https://doi.org/10.1038/sj.ijo.0803217

Witzel, C., & Gegenfurtner, K. (2014). Memory color. In R. Luo (Ed.), *Encyclopedia of color science and technology*. Springer. https://doi.org/10.1007/978-3-642-27851-8_58-8

World Health Organization. (2021, March 3). *How healthy are children's eating habits? WHO Europe surveillance results.* World Health Organization Regional Office for Europe. https://www.who.int/europe/news/item/03-03-2021-how-healthy-are-children-s-eating-habits-who-europe-surveillance-results

Yang, F. L., Cho, S., & Seo, H.-S. (2016). Effects of light color on consumers' acceptability and willingness to eat apples and bell peppers. *Journal of Sensory Studies, 31*(1), 50–59. https://doi.org/10.1111/joss.12183

Zampini, M., & Spence, C. (2004). The role of auditory cues in modulating the perceived crispness and staleness of potato chips. *Journal of Sensory Studies, 19*(5), 347–363. https://doi.org/10.1111/j.1745-459X.2004.080403.x

Zellner, D. A., & Durlach, P. (2003). Effect of color on expected and experienced refreshment, intensity, and liking of beverages. *The American Journal of Psychology, 116*(4), 633–647. https://doi.org/10.2307/1423663

Appendices

Appendix A: Experiment Survey

https://utwentebs.eu.qualtrics.com/jfe/preview/previewId/9d4bbfd2-6b5e-457f-ae34-146293179455/SV_8c6pa8L9ZGBtP70?Q_CHL=preview&Q_SurveyVersionID=current