

Taste Through a Different Lens: The Role of Mixed Reality Color Saturation in Sensory and Hedonic Evaluations

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Abstract—Visual perception significantly shapes food experiences, influencing taste expectations and sensory evaluation. While the impact of color on taste is well established, so far few studies have examined how specific visual manipulations in physical dining environments affect perception. This pilot study explores the relationship between visual manipulations of food appearance (i.e., color saturation) in Mixed Reality (MR) environments and taste perceptions. Twelve participants engaged in a MR dining experience where they consumed real food while experiencing controlled variations in color saturation. The study compared responses to sweet and savory stimuli under high and low saturation conditions. Participants provided ratings for both sensory attributes (sweetness, saltiness, sourness, bitterness, umami, and intensity) and hedonic attributes (goodness, freshness, naturalness, healthiness, quality, and perceived cost) both prior to and following tasting. Preliminary results suggest that color saturation may influence pre-consumption expectations and possibly affect post-consumption sensory evaluations for both taste and hedonic dimensions. Descriptive trends suggest differential effects based on the food stimulus. Despite preliminary, this study offers methodological insights for future investigations into crossmodal sensory integration and highlights the potential of MR as a tool for examining the complex interplay between visual context and taste perception.

Index Terms—eXtended Reality, color intensity, taste expectation, taste perception, immersive food technology

I. INTRODUCTION

Food perception is multisensory, significantly shaped by visual input that influences consumer expectations about taste and flavor. Visual attributes, particularly color, have been

extensively studied for their role in influencing perceived sweetness, saltiness, and overall food quality. These visual cues powerfully guide expectations and sensory experiences, underpinning the crossmodal integration between visual and gustatory systems [1]–[4]. Understanding how visual stimuli affect taste expectations and perceptions is crucial, as they can substantially influence consumer acceptance and eating behaviors. The influence of color manifests across multiple aspects of the dining experience: environmental color schemes influence consumption behavior [5], while tableware color influences taste perception [6]. Regarding food itself, the effect is particularly pronounced: red-colored beverages are typically perceived as sweeter than their clearer counterparts regardless of the actual sugar content, while blue-tinted foods often elicit confusion due to their rarity in natural edibles [7], [8]. The use of eXtended Reality (XR), which includes Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), is increasingly prevalent in food perception research. XR provides innovative methods for dynamically manipulating the appearance of food without altering intrinsic chemical properties. These technologies offer significant methodological advancements by enabling precise and real-time modifications of visual characteristics such as luminance, color, and texture [9]–[11]. Thus, XR emerges as a powerful tool for exploring how visually induced expectations interact with actual gustatory experiences, establishing a framework in which visual inputs not only predict but actively modify subsequent taste perceptions [12]. Despite the growing interest in this field, significant research gaps remain. Although numerous studies have examined color hue and brightness effects on taste

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perception, relatively few have specifically investigated color saturation, particularly in complex, multi-component foods rather than simple stimuli like beverages or single-ingredient foods [9], [10], [13]. Furthermore, most existing research has employed traditional sensory methods, such as chemical color manipulation or full VR environments. Very few studies have leveraged MR to manipulate the appearance of real food during consumption [11], [14], even though MR offers a unique balance between ecological validity and experimental control that may better reflect real-world eating contexts [15]. In this frame, we contribute to the existing literature by (1) specifically isolating saturation effects while controlling for hue and brightness, (2) comparing effects across structurally similar but taste-distinct foods (sweet vs. salty), and (3) employing MR technology that preserves the physical eating experience while systematically manipulating visual attributes. Accordingly, this pilot study aims to examine how food saturation manipulations in an MR environment influence consumer visual expectations and subsequent taste perception.

II. RELATED WORK

A. The Role of Color in Food Perception

Visual attributes significantly influence consumer expectations and perceptions about food. Color creates specific sensory expectations that guide subsequent taste experiences. Previous studies show that participants are usually significantly less accurate in identifying flavor when beverages are colored inappropriately, compared to appropriately colored or colorless conditions, with accuracy dropping up to 40% under mismatched conditions [3], [16]. The relationship between color characteristics and taste perception underlines remarkable consistency between studies. Manipulation of visual attributes, such as color and luminance, can dynamically alter perceived taste properties. Modifying the luminance distribution of the ketchup in real time affected both the perceived watery taste (increased by 20% with a lower luminance contrast) and the perceived deliciousness (increased by 15% with higher luminance contrast), indicating that visual texture independently influences sensory perception [9]. Increased color saturation significantly increases the perceived sweetness of a cake up to 13%, emphasizing the robust crossmodal impact of color. Projective AR systems can modify food color in real-time, showing that visual manipulations effectively alter taste perception without changing the chemical composition of food [10]. The environmental colors also significantly influence food perception and consumption behaviors. Red environmental cues reduced food and beverage intake by approximately 20% compared to blue or white environments, possibly due to the association of red with danger or avoidance signals [5]. Similarly, the high contrast between the food and plate colors improved the awareness of portion size and reduced serving sizes by up to 22% [17]. These findings highlight how food-specific and contextual color cues integrate to shape the overall sensory experience and subsequent consumption decisions.

B. Extended Reality for Food Research and Application

XR technologies have revolutionized food perception studies by enabling researchers to manipulate visual food properties while preserving the physical eating experience [14]. The pioneering MetaCookie project demonstrated the potential of AR to influence flavor perception, with the majority of participants experiencing altered taste perceptions when visual and olfactory cues were modified without changing the actual cookie composition [11]. Recent applications have shown that manipulating visual properties through AR and MR produces significant effects on taste perception. Modifying the luminance distribution increased the perceived moistness in the cake up to 25% [9]. Similarly, VR-based visual manipulations have successfully altered taste perceptions, with environments incorporating sweet-congruent visual elements increasing perceived sweetness up to 15% compared to neutral environments [18]. Coffee color manipulations in VR increased perceived creaminess by 20%, though this effect was only observed with lower sugar content, suggesting an interaction between visual cues and actual taste intensity [19]. Despite growing interest in food perception research using extended reality, color saturation remains a notably underexplored aspect, especially in complex food contexts [3], [8], [20].

III. MATERIALS AND METHODS

A. Food Stimuli

For the experimental design, two food stimuli with distinct primary taste profiles were selected while maintaining structural similarities:

- **Salty stimulus (A):** nachos with guacamole, mainly salty.
- **Sweet stimulus (B):** mini tarts with apricot jam, mainly sweet.

Both food stimuli shared structural characteristics that facilitated comparison: a yellowish flour-based component (tart base and nacho chip) and a fruit-based topping (apricot jam and guacamole; Figure 1). Each portion of food presented during the trials was carefully controlled, weighing between 9 and 11 grams. All food items were freshly prepared immediately before the experimental session to maintain consistent organoleptic properties and eliminate potential confounders related to deterioration or food degradation. The preparation protocols were standardized across all sessions to ensure uniformity in appearance, temperature, and texture.

B. Experimental Design

The study adopted a 2×2 within-subjects factorial design with two independent variables: food stimulus type (sweet vs. salty) and color saturation level (low vs. high). This design resulted in four experimental conditions that each participant experienced, along with two additional dummy trials. The dummy trials were strategically placed between experimental conditions to serve as controls, minimizing carryover effects and reducing expectation biases that could occur when transitioning between stimuli with different saturation levels [9].

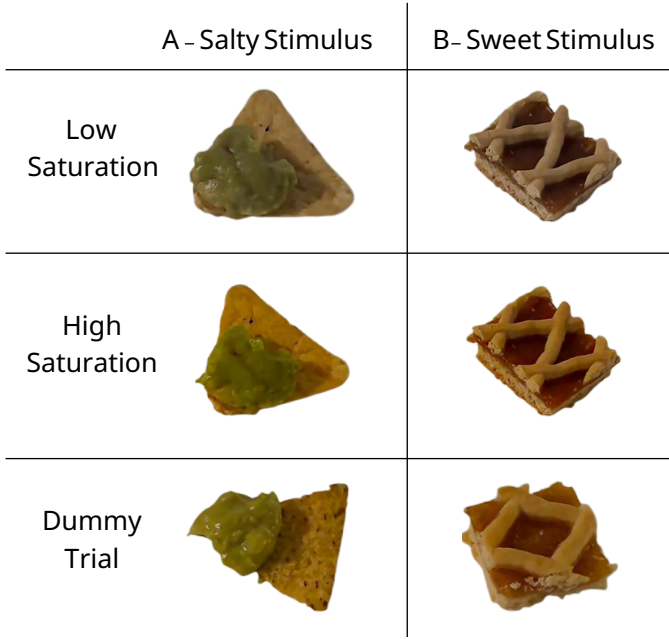


Fig. 1. Experimental food stimuli as viewed through Mixed Reality: (A) Salty Stimulus (nachos with guacamole) and (B) Sweet Stimulus (mini tarts with jam) under low saturation, high saturation, and dummy trial conditions

To control for order effects, the presentation sequence of experimental stimuli was systematically counterbalanced across participants. The table I shows the four possible stimulus presentation orders used to minimize order effects.

TABLE I
COUNTERBALANCING SCHEME FOR STIMULUS PRESENTATION ORDER.

Code	Stim 1	Stim 2	Stim 3	Stim 4	Stim 5	Stim 6
01	A low	B low	A dummy	B dummy	A high	B high
02	B low	A low	B dummy	A dummy	B high	A high
03	A high	B high	A dummy	B dummy	A low	B low
04	B high	A high	B dummy	A dummy	B low	A low

C. Set up and equipment

The experiment was carried out in a university living lab lit by artificial light to keep constant lighting conditions, which were calibrated to 4600K. The room temperature was maintained at a consistent level throughout the test. The participant was sitting at the table and during the tasting experience was left alone in the room. The experimenter followed the unfolding of the session from behind a curtain, in order to be able to promptly intervene in case of need, yet without affecting the tasting experience. Participants were seated at a table with appropriate dining utensils. A dedicated preparation area adjacent to the testing space allowed efficient food serving without interrupting the experimental flow. Participants experienced the MR environment through the Meta Quest 3 HMD.

D. The Mixed Reality System

The MR dining application was developed to create a hybrid environment in which virtual and physical elements coexist

seamlessly, enabling augmented food presentations without disrupting natural eating behavior (Figure 2). Based on a prototype previously tested and validated [21], the current implementation was refined to preserve the ecological validity of typical dining scenarios while allowing controlled manipulation of a specific visual feature. Preliminary evaluations confirmed that the system did not interfere with the ability of participants to eat comfortably and naturally, ensuring an authentic and unobtrusive experience. [9], [15].

a) Technical Architecture and Implementation: The MR system was implemented using the Unity engine (version 6000.1.0a2) and deployed on the Meta Quest 3, a standalone headset equipped with passthrough capabilities and advanced spatial tracking. Development relied on the Meta XR All-in-One SDK (v69.0.1), which allowed the integration of both spatial anchors and interaction zones to register virtual content with real-world geometry. Passthrough texture rendering allowed users to maintain continuous visual contact with their hands, food, tableware, and the surrounding environment. This functionality was essential to support intuitive interaction, prevent collisions, and reduce disorientation. Visual transparency was limited to the immediate peripersonal space, ensuring clarity in task-relevant areas while maintaining immersion in the restaurant scenario. The interaction zones were carefully restricted to allow hand tracking and allow natural behaviors such as reaching, grasping, and utensil manipulation [21]. A key feature of the system was its markerless calibration. Participants were seated at a real table, and the virtual scene was anchored to this surface through spatial mapping and anchor placement, ensuring alignment between the physical and virtual environments. The table, plate, and utensils were physically present, but visually enhanced through the headset with digital overlays corresponding to the experimental conditions (Figure 2).

b) Stimulus Presentation Control: The food stimulus presentation system was designed to selectively manipulate color saturation while preserving all other visual attributes of the real food items. Our approach utilized the following features:

- **Selective Color Manipulation:** Using Unity scripting and the headset's passthrough capabilities, we manipulated the level of saturation of the main camera passthrough. Specifically, we applied saturation modulation with values of -0.3 (low saturation) and +0.3 (high saturation) on Unity's saturation parameter range (from -1 to 1).
- **Controlled Visual Environment:** The system featured a white background and white overlays applied to participants' hands through hand tracking, creating a visually neutral environment where only the food stimuli were subjected to saturation manipulation.

c) Virtual Environment Design: The virtual setting replicated a restaurant with panoramic views of an urban landscape. The environment spanned approximately $10 \times 7.5 \times 3.5$ meters and featured high-resolution textures and a coherent spatial layout. Pre-built assets from the ArchvizPRO Interior Vol.8



Fig. 2. (A) Participant's point of view (POV), displaying the MR environment. (B) Participant dining at a physical table while wearing the HMD.

package were combined with custom 3D models developed in Blender 4.2.

To ensure visual realism and reduce computational load, the environment used baked global illumination instead of real-time lighting. This allowed for stable rendering across different lighting conditions and ensured consistent visual quality among participants.

E. Measures

a) *Background Data*: Prior to the main experiment, potential participants completed a screening questionnaire to assess eligibility based on exclusion criteria and to collect demographic information. Exclusion criteria included food allergies or intolerances, absence of normal or corrected-to-normal vision, and history of neurological or eating disorders. Only individuals who rated all target foods at least "3" (that is, "moderately") on a liking scale were invited to participate in the laboratory session. To minimize possible confounders, participants were instructed not to smoke, eat, or drink coffee within two hours before the experimental session.

b) *Food Attributes Assessment*: Participants evaluated the taste and hedonic attributes of the food stimuli presented using a structured questionnaire. The scales were adapted from previous studies [22]–[24] and included:

- **Taste attributes**: *Sweet, Salty, Sour, Bitter, Umami, Intense, Bland* (with *Bland* reverse-coded to compute global intensity).
- **Hedonic attributes**: *Good, Fresh, Natural, Healthy, Expensive, Quality*.

Each attribute was rated on a 10-point scale ranging from 0 (Not at all) to 9 (Very much). Participants were instructed to base their answers on either visual impressions (pre-tasting) or gustatory experience (post-tasting), depending on the phase.

c) *Emotional and Physical Impact of the MR Dining Experience*: Before and after the experimental session, participants completed a series of measures to evaluate emotional responses and physical comfort during the MR dining experience.

- **Emotional Response**: The *Self-Assessment Manikin (SAM)* [25] was administered to measure valence, arousal, and dominance, providing a comparative assessment of participants' affective states before and after MR food exposure.

- **Cybersickness**: The *Virtual Reality Sickness Questionnaire (VRSQ)* [26] was used to assess levels of discomfort. The VRSQ evaluates two primary dimensions: Oculomotor disturbances (5 items) and Disorientation (4 items). Given the focus on food perception of this study, we expanded the VRSQ with the "Nausea" item from the original SSQ [27], as this symptom is particularly relevant in food contexts and might be influenced by potential dissonance between manipulated visual information and actual gustatory experience. Participants rated each symptom on a 4-point scale (0 = none, 1 = slight, 2 = moderate, 3 = severe).

F. Procedure

The experiment consisted of four sequential phases: screening, pre-experimental session, experimental session, and post-experimental session. The entire experiment lasted between 45–60 minutes. The study was approved by the local Ethics Committee.

a) *Screening Phase*: Potential participants were invited to complete a screening questionnaire. Those who met the eligibility criteria were then invited by the researchers to a university laboratory to read and sign the informed consent form.

b) *Pre-Experimental Session*: Upon arrival at the laboratory, participants read and signed the informed consent form. Baseline measurements were collected using the SAM and the VRSQ with the supplementary Nausea item.

c) *Experimental Session*: Participants were seated at a table in a dedicated area where they were fitted with the Meta Quest 3 headset and immersed in the virtual restaurant environment. Before starting, a short habituation period (approximately 1 minute) was given to familiarize themselves with the headset and surroundings.

The experimental session was composed of six sequential trials, each involving consumption and evaluation (pre - post) of one food stimulus: two food stimuli (A and B), each presented under two color saturation conditions (low and high), plus two dummy trials. Each trial followed this structure:

- 1) **Visual Exposure**: The food was presented on the plate. Participants were asked to observe the item for 30 seconds without touching it.
- 2) **Expectation Rating**: The Food Attributes Assessment Questionnaire was completed to evaluate pre-tasting expectations based on visual appearance.
- 3) **Tasting Phase**: Participants consumed the food freely.
- 4) **Perception Rating**: Immediately after tasting, they rated their actual experience using the Food Attributes Assessment Questionnaire.
- 5) **Inter-trial Reset**: Participants removed the headset, drank water to cleanse the palate, and rested for a brief interval while the next stimulus was prepared.

d) *Post-Experimental Session*: After completing all trials, participants filled out the post-experience SAM and VRSQ to assess the changes relative to the baseline.

G. Participants

Twelve participants (6 female; $M = 24.3$ years, $SD = 2.0$; range = 21-29) participated in the study. This sample size follows established recommendations for pilot studies [28] and allowed for complete counterbalancing across four presentation orders in the within-subjects design. Recruitment was based on convenience sampling among university students and staff. Only individuals who met the eligibility criteria and indicated at least moderate liking (3 on a 5-point scale) for all target foods were invited to the laboratory session.

IV. RESULTS

Due to the small sample size, only descriptive analyses were performed to explore the two main effects of color saturation (low vs. high) and taste experience (pre vs. post) on participants' sensory and evaluative ratings for two food items (Table II). Specifically, the analyses focused on (1) the impact of color saturation on both expected and perceived attributes, and (2) differences between expectations and actual taste experience (post-pre) at each saturation level. The two dummy trials were excluded from analysis as they involved no saturation manipulation and served only to prevent carry-over effects between experimental conditions. For this study, only the main results are reported.

A. Impact of Saturation (High vs. Low)

a) *Pre-tasting Expectations*: Figure 3 shows the mean deltas (Δ = high-low saturation) for each attribute before tasting. Descriptive consistent trends across both food stimuli are reported below:

- Quality: Both food stimuli showed positive deltas (mini tarts: $\Delta +0.58$, nachos: $\Delta +0.42$).
- Flavour Intensity: Both food stimuli displayed positive deltas (mini tarts: $\Delta +0.67$, nachos: $\Delta +0.12$).
- Bitter: Neither food stimulus showed a saturation effect on expected bitterness (both $\Delta 0.00$).

Descriptive different trends between food stimuli are reported below:

- Fresh: Mini tarts $\Delta +0.50$, while nachos $\Delta -0.75$.
- Natural: Mini tarts $\Delta 0.00$, while nachos $\Delta -0.50$.
- Healthy: Mini tarts $\Delta 0.00$, while nachos $\Delta -0.50$.
- Umami: Mini tarts $\Delta -0.50$, while nachos $\Delta +0.33$.
- Salty: Mini tarts $\Delta -0.25$, while nachos $\Delta +0.42$.

b) *Post-tasting Perceptions*: The effect of saturation on attribute ratings after tasting is shown in Figure 4. Descriptive consistent trends across both food stimuli are reported below:

- Flavour Intensity: Both food stimuli showed negative deltas (mini tarts: $\Delta -0.17$, nachos: $\Delta -0.50$).
- Sour: Both food stimuli showed negative deltas (mini tarts: $\Delta -0.42$, nachos: $\Delta -1.00$).

Descriptive different trends between food stimuli are reported below:

- Fresh: Mini tarts $\Delta +0.17$, while nachos $\Delta -0.75$.
- Quality: Mini tarts $\Delta +0.50$, while nachos $\Delta -0.17$.
- Umami: Mini tarts $\Delta +0.25$, while nachos $\Delta -0.42$.
- Bitter: Mini tarts $\Delta -0.17$, while nachos $\Delta +0.58$.

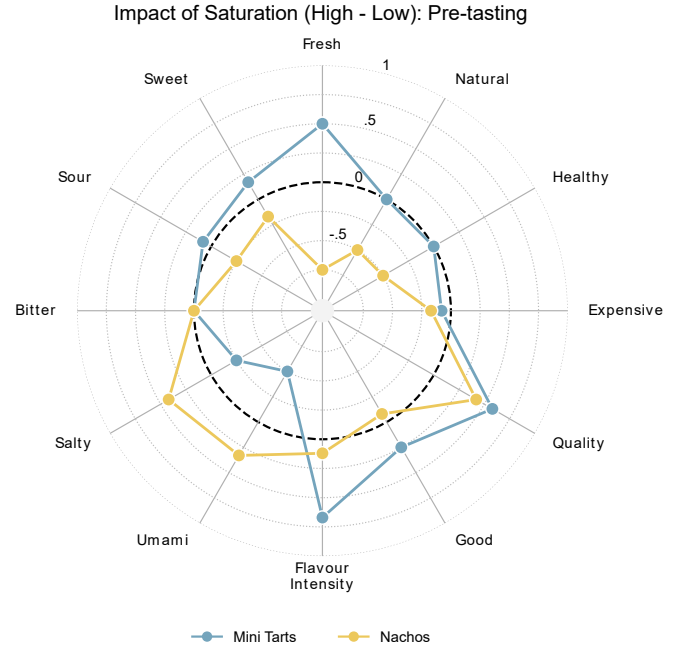


Fig. 3. Radar chart showing the impact of color saturation (Δ high-low) on pre-tasting expectations for mini tarts and nachos.

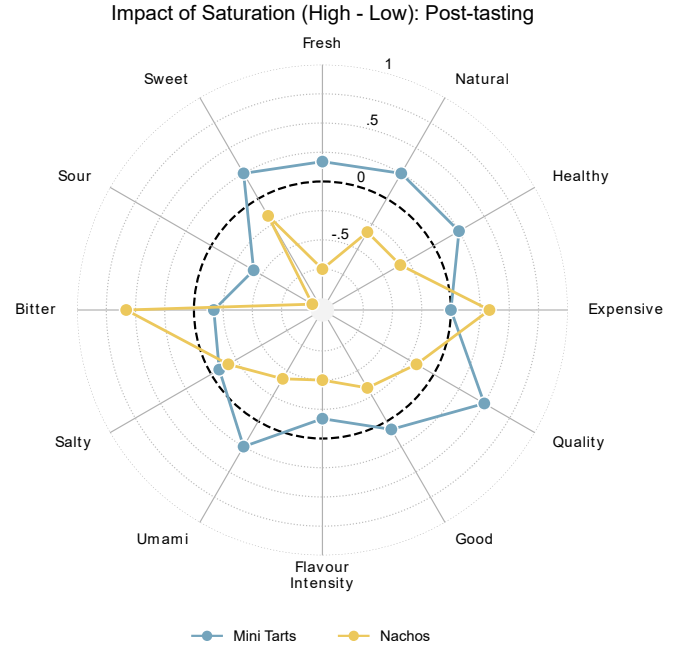


Fig. 4. Radar chart showing the impact of color saturation (Δ high-low) on post-tasting attribute ratings for mini tarts and nachos.

B. Taste Perception vs Expectation (Post-Pre)

a) *High Saturation Condition*: Figure 5 shows the mean deltas between post-tasting and pre-tasting ratings for high-saturation stimuli. Descriptive consistent trends across both food stimuli are reported below:

- Umami: Both food stimuli showed positive deltas (mini

TABLE II
DESCRIPTIVE STATISTICS FOR SENSORY AND EVALUATIVE ATTRIBUTES BY FOOD STIMULUS, SATURATION LEVEL, AND PHASE

Attribute		Mini tarts with apricot jam (Sweet Stimulus)						Nachos with guacamole (Savory Stimulus)					
		Pre-Tasting			Post-Tasting			Pre-Tasting			Post-Tasting		
		Low	High	Δ (H-L)	Low	High	Δ (H-L)	Low	High	Δ (H-L)	Low	High	Δ (H-L)
<i>Taste Attributes</i>													
Sweet	Mean	6.92	7.08	+0.17	6.17	6.42	+0.25	4.58	4.42	-0.17	5.08	4.92	-0.17
	Median	7.00	7.50		6.00	7.00		4.50	4.00		5.00	5.00	
	SD	1.16	1.44		1.64	1.73		1.78	1.98		1.38	1.56	
Salty	Mean	1.67	1.42	-0.25	1.83	1.83	0.00	5.42	5.83	+0.42	5.00	4.58	-0.42
	Median	1.50	1.00		2.00	2.00		5.50	6.00		5.00	5.00	
	SD	1.23	1.38		1.27	1.34		1.51	1.75		1.71	1.62	
Sour	Mean	3.33	3.42	+0.08	2.75	2.33	-0.42	3.58	3.33	-0.25	4.08	3.08	-1.00
	Median	3.00	3.00		2.50	2.00		4.00	3.00		4.00	3.00	
	SD	1.30	1.56		1.29	1.30		1.83	1.97		1.51	1.38	
Bitter	Mean	1.92	1.92	0.00	1.58	1.42	-0.17	2.83	2.83	0.00	3.00	3.58	+0.58
	Median	2.00	2.00		1.50	1.00		3.00	3.00		3.00	4.00	
	SD	1.08	1.31		1.00	0.90		1.85	1.80		1.41	1.68	
Umami	Mean	2.75	2.25	-0.50	2.67	2.92	+0.25	4.58	4.92	+0.33	5.67	5.25	-0.42
	Median	3.00	2.00		3.00	3.00		5.00	5.00		6.00	5.50	
	SD	1.60	1.76		1.56	1.68		2.07	1.93		1.15	1.29	
Flavour Intensity	Mean	5.83	6.50	+0.67	5.42	5.25	-0.17	5.67	5.78	+0.12	6.33	5.83	-0.50
	Median	6.00	7.00		5.00	5.00		6.00	6.00		6.50	6.00	
	SD	1.27	1.38		1.73	1.48		1.23	1.64		1.23	1.40	
<i>Hedonic Attributes</i>													
Good	Mean	6.83	6.83	0.00	5.83	5.92	+0.08	5.75	5.75	0.00	6.17	5.83	-0.33
	Median	7.00	7.00		6.00	6.00		6.00	6.00		6.00	6.00	
	SD	1.11	1.11		1.95	1.78		1.71	1.91		1.53	1.34	
Quality	Mean	6.08	6.67	+0.58	5.58	6.08	+0.50	5.25	5.67	+0.42	6.17	6.00	-0.17
	Median	6.00	7.00		6.00	6.00		5.50	6.00		6.00	6.00	
	SD	1.38	1.15		1.62	1.44		1.71	1.56		1.34	1.35	
Fresh	Mean	5.92	6.42	+0.50	5.17	5.33	+0.17	6.33	5.58	-0.75	6.75	6.00	-0.75
	Median	6.00	6.50		5.00	5.50		6.50	6.00		7.00	6.00	
	SD	1.51	1.51		1.53	1.67		1.61	1.51		1.29	1.35	
Natural	Mean	5.67	5.67	0.00	5.17	5.42	+0.25	6.00	5.50	-0.50	6.00	5.67	-0.33
	Median	6.00	6.00		5.00	5.50		6.00	5.50		6.00	6.00	
	SD	1.50	1.67		1.47	1.68		1.35	1.38		1.35	1.23	
Healthy	Mean	5.50	5.50	0.00	5.33	5.58	+0.25	6.25	5.75	-0.50	6.17	5.83	-0.33
	Median	6.00	6.00		5.50	6.00		6.50	6.00		6.00	6.00	
	SD	1.51	1.51		1.23	1.68		1.29	1.36		1.27	1.27	
Expensive	Mean	4.75	4.75	0.00	4.17	4.08	-0.08	4.67	4.67	0.00	5.00	4.83	-0.17
	Median	5.00	5.00		4.00	4.00		5.00	5.00		5.00	5.00	
	SD	1.36	1.36		1.59	1.56		1.37	1.23		1.35	1.11	

Note: The table presents descriptive statistics (Mean, Median, Standard Deviation) for each attribute across food stimuli (mini tarts and nachos), experimental phases (Pre-Tasting and Post-Tasting), and saturation levels (Low and High). Delta values represent the mean difference between High and Low saturation conditions. Ratings were made on a 10-point scale (0-9).

tarts: Δ +0.67, nachos: Δ +0.33).

- Sour: Both food stimuli showed negative deltas (mini tarts: Δ -0.58, nachos: Δ -0.25).

Descriptive different trends between food stimuli are reported below:

- Fresh: mini tarts Δ -1.08, while nachos Δ +0.42.
- Expensive: mini tarts Δ -0.50, while nachos Δ +0.33.
- Quality: mini tarts Δ -0.58, while nachos Δ +0.33.
- Good: mini tarts Δ -1.00, while nachos Δ +0.42.
- Flavour Intensity: mini tarts Δ -0.62, while nachos Δ +0.04.
- Sweet: mini tarts Δ -0.67, while nachos Δ +0.50.

b) *Low Saturation Condition:* The mean deltas between post-tasting and pre-tasting ratings for low-saturation stimuli

are shown in Figure 6. Descriptive consistent trends across both food stimuli are reported below:

- Flavour Intensity: Both food stimuli showed positive deltas (mini tarts: Δ +0.21, nachos: Δ +0.67), indicating stronger intensity perception than expected.

Descriptive different trends between food stimuli are reported below:

- Fresh: mini tarts Δ -0.75, while nachos Δ +0.42.
- Quality: mini tarts Δ -0.50, while nachos Δ +0.92.
- Good: mini tarts Δ -0.83, while nachos Δ +0.67.
- Umami: mini tarts Δ -0.08, while nachos Δ +1.08.
- Sour: mini tarts Δ -0.08, while nachos Δ +0.50.
- Sweet: mini tarts Δ -0.75, while nachos Δ +0.50.

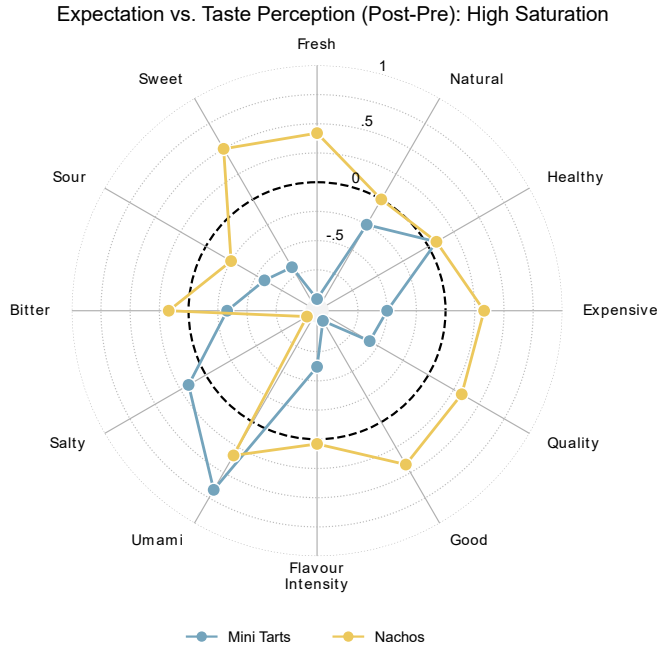


Fig. 5. Radar chart illustrating the differences between actual perception and visual expectations (Δ post-pre tasting ratings) in the high saturation condition for mini tarts and nachos.

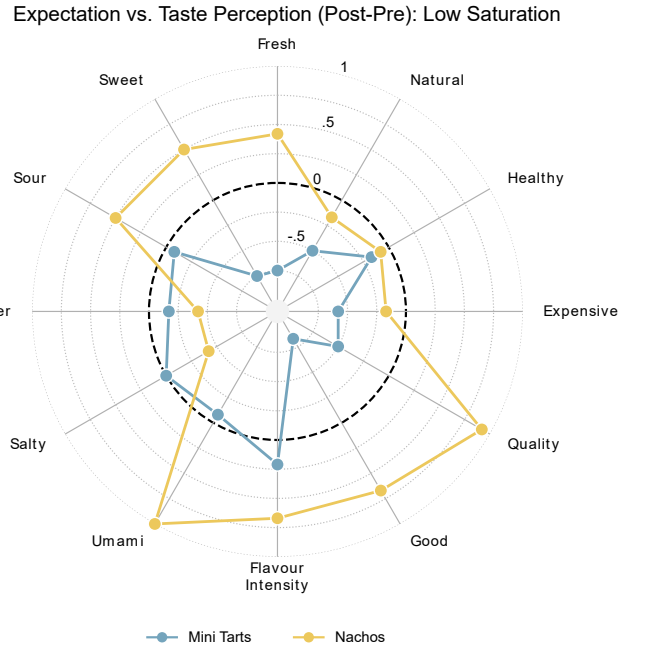


Fig. 6. Radar chart illustrating the differences between actual perception and visual expectations (Δ post-pre tasting ratings) in the low saturation condition for mini tarts and nachos.

C. Emotional Response

The Self-Assessment Manikin (SAM) was administered before and after the experimental session to measure participants' emotional states across three dimensions.

Valence (scale: 1 = happy, 9 = sad) showed pre-session values ($M = 3.73$, $Mdn = 3$, $SD = 1.10$) and post-session values ($M = 2.91$, $Mdn = 3$, $SD = 1.22$).

Arousal (scale: 1 = excited, 9 = calm) exhibited pre-session values ($M = 6.82$, $Mdn = 7$, $SD = 1.08$) and post-session values ($M = 7.55$, $Mdn = 8$, $SD = 1.44$).

Dominance (scale: 1 = no control, 9 = in control) demonstrated pre-session values ($M = 7.55$, $Mdn = 7$, $SD = 0.93$) and post-session values ($M = 7.27$, $Mdn = 7$, $SD = 1.35$).

D. Cybersickness

The VRSQ with the additional nausea item yielded the following pre-session scores: Oculomotor dimension ($M = 11.52$, $Mdn = 6.67$, $SD = 16.08$) and Disorientation dimension ($M = 5.30$, $Mdn = 0.00$, $SD = 8.56$).

Post-session measurements indicated Oculomotor values of $M = 47.88$ ($Mdn = 40.00$, $SD = 17.59$) and Disorientation values of $M = 41.67$ ($Mdn = 41.67$, $SD = 7.45$). The calculated pre-post differences were $M = 36.36$ ($Mdn = 33.33$, $SD = 10.48$) for the Oculomotor dimension and $M = 36.36$ ($Mdn = 33.33$, $SD = 10.05$) for the Disorientation dimension.

The Nausea item registered pre-session values of $M = 0.33$ ($Mdn = 0.00$, $SD = 0.50$) and post-session values of $M = 1.09$ ($Mdn = 1.00$, $SD = 0.30$), with a mean pre-post difference of $M = 0.78$ ($Mdn = 1.00$, $SD = 0.44$).

All twelve participants completed the full experimental protocol with no session terminations due to discomfort.

V. DISCUSSION

This pilot study investigated how manipulating the color saturation of food presentations in mixed reality (MR) might influence both pre-consumption expectations and post-consumption sensory evaluations. The findings suggest a complex interplay between visual cues and taste perception that varies by food stimulus and attribute dimension.

A. Impact of Saturation (High vs. Low)

1) *Pre-tasting Expectations:* Our results revealed that colour saturation manipulation influenced participants' pre-tasting expectations across multiple attributes differently depending on the food stimulus. However, for both mini tarts and nachos, higher saturation consistently led to increased expectations of quality and flavour intensity. This aligns with previous research suggesting that visual intensity can enhance anticipated sensory experiences [29]. The differences between food stimuli were more pronounced in other attributes, with mini tarts receiving higher ratings for freshness under high saturation ($\Delta +0.50$), while nachos showed the opposite trend ($\Delta -0.75$). Similarly, perceived healthiness and naturalness were unaffected by saturation for mini tarts but decreased for nachos ($\Delta \text{healthy} = -0.5$, $\Delta \text{natural} = -0.5$). These differences suggest that colour saturation may interact with learned associations specific to food categories, with heightened vibrancy potentially signaling positive qualities in sweet foods but artificiality in savory contexts [30]. The food-specific responses to

saturation manipulation support the importance of considering product category when designing visual enhancements in food presentation [16].

2) *Post-tasting Perceptions*: After tasting, the influence of colour saturation showed shifts from pre-tasting expectations. Both food stimuli demonstrated negative deltas for flavour intensity (mini tarts: $\Delta -0.17$, nachos: $\Delta -0.50$) and sourness (mini tarts: $\Delta -0.42$, nachos: $\Delta -1.00$) in the high saturation condition. This consistent decrease suggests that intense visual cues may create elevated expectations that actual taste experiences fail to meet, resulting in a relative disappointment effect [6]. The persistence of food-specific trends was evident in the post-tasting phase as well. Mini tarts maintained positive associations with high saturation for quality ($\Delta +0.50$), while nachos showed slight negative trends ($\Delta -0.17$) for the same attributes. The contrast between pre-tasting and post-tasting responses highlights the dynamic nature of multisensory integration, where initial visual-based expectations are recalibrated once actual taste information becomes available [31].

B. Taste Perception vs Expectation (Post-Pre)

1) *High Saturation Condition*: When comparing posttasting to pre-tasting evaluations in the high saturation condition, we observed an interesting pattern of expectation fulfillment or disconfirmation. Both food stimuli showed positive deltas for umami perception (mini tarts: $\Delta +0.67$, nachos: $\Delta +0.33$) and negative deltas for sourness (mini tarts: $\Delta -0.58$, nachos: $\Delta -0.25$), suggesting that high colour saturation may have created misleading expectations for these specific taste attributes. The most striking differences between food stimuli emerged in hedonic evaluations. Mini tarts consistently showed negative post-pre deltas for freshness ($\Delta -1.08$), expensiveness ($\Delta -0.50$), quality ($\Delta -0.58$), and goodness ($\Delta -1.00$), indicating that the actual tasting experience fell short of the expectations created by high saturation. In contrast, nachos displayed positive deltas for the same attributes, suggesting that the actual tasting experience exceeded the lower expectations created by high saturation for this savory food. These contrasting patterns align with expectation-disconfirmation theories [32], where the magnitude and direction of sensory disconfirmation influence overall evaluation.

2) *Low Saturation Condition*: In the low saturation condition, both food stimuli demonstrated positive deltas for flavour intensity (mini tarts: $\Delta +0.21$, nachos: $\Delta +0.67$), indicating that actual taste intensity exceeded the more modest expectations set by lower visual intensity. This finding supports the role of expectation moderation in enhancing post-consumption satisfaction [33]. Similar to the high saturation condition, substantial differences emerged between food stimuli. Nachos consistently showed more positive post-pre deltas across multiple attributes, including freshness ($\Delta +0.42$), quality ($\Delta +0.92$), goodness ($\Delta +0.67$), and umami ($\Delta +1.08$). These results suggest that low saturation visualization may have set more appropriate expectations for savory foods, leading to a more positive taste experience relative to expectations. The mini tarts, however, showed predominantly negative post-pre

deltas even in the low saturation condition, particularly for freshness ($\Delta -0.75$), quality ($\Delta -0.50$), and goodness ($\Delta -0.83$). This pattern suggests that for sweet foods, reduced colour vibrancy might still create certain expectations that are not fully met by the actual taste experience [3].

C. Emotional and Environmental Modulation of Eating Experiences

Beyond sensory expectations, the MR dining context itself appeared to influence the emotional states of the participants. In general, participants reported a more positive mood after eating in the MR environment setting, suggesting that the visually enriched experience was enjoyable. This positive affect may, in turn, have subtle contributions to taste perception, as a happier emotional state has been observed to improve taste perception and general food liking [29].

The participants tolerated the MR experience well, with no dropouts due to discomfort. We observed a slight increase in cybersickness indicators, particularly in the oculomotor dimension. These results suggest that prolonged exposure to augmented visuals can introduce some perceptual strain, consistent with previous reports that prolonged use of AR/VR during eating may cause mild to moderate discomfort [34]. Although the level of cybersickness in our study was low and did not interrupt the experiment, it indicates an important practical consideration to design extended MR dining experiences.

D. Practical and Methodological Implications for Research and Industry

This pilot study establishes mixed reality as a potentially valuable methodological approach to investigate crossmodal sensory interactions. Unlike traditional sensory tests or fully virtual simulations, our approach maintained high ecological validity without sacrificing experimental precision [35]. From a practical perspective, the strategic leveraging of visual enhancements opens up creative avenues for food product development. One promising application is in the reformulation of healthier foods: by adjusting a product's visual appeal, it seems possible to have an impact on reducing sugar or salt content. Previous studies have noted that increasing the vividness of the color of a food can increase perceptions of sweetness, freshness, or overall flavor intensity [36]. Our preliminary findings provide positive trend of higher saturation on sweetness perception in mini tarts ($\Delta +0.25$ after tasting) suggests that, for example, a low sugar dessert could potentially look more indulgent through color saturation enhancement.

E. Limitations and Future Directions

Despite its promising insights, this study has several limitations that warrant caution. First, our participant sample was small and relatively homogeneous, which limits the generalizability of the findings. Second, we manipulated only one visual parameter, color saturation, while keeping other sensory modalities untouched. Although our study intentionally isolated visual effects, it is important to acknowledge that taste perception can be significantly influenced by auditory,

olfactory, and tactile cues as well [37]. Our focus was solely on the visual-gustatory link, while food experiences are inherently multisensory – aroma, mouthfeel, and even sound contribute to flavor. Future experiments should consider integrating additional sensory stimuli into MR environments, based on recent virtual reality studies that demonstrate the benefit of multisensory integration in altering flavor perception [18]. Another avenue for future work is to examine the longevity of the observed trends. Our trial captured immediate reactions to a one-time visual manipulation; it remains unknown how repeated exposures would influence consumers. Longitudinal studies could inform whether the impact on perception is transient or leads to lasting perceptual changes. Additionally, future studies with larger samples should examine potential order effects to ensure the robustness of the observed saturation effects. A further promising direction is to investigate whether the saturation effects observed are influenced by the contrast between food stimuli and environmental background, which could be systematically manipulated within MR settings to determine the relative contribution of contextual factors to taste perception.

VI. CONCLUSION

This exploratory study suggests that altering food's visual presentation through MR techniques can influence both taste expectations and actual consumption perceptions. Color saturation emerged as a prominent visual factor, and increased saturation affected perceived qualities in both sweet and savory items. The effects varied between food stimuli, with sweetness perception showing opposite patterns between mini tarts and nachos, indicating that intrinsic flavor profiles interact with visual cues in shaping sensory outcomes. These findings contribute to the understanding of multisensory integration and illustrate the potential of MR technology to study. By manipulating visual properties without altering food composition, researchers can explore how visual modifications influence flavor perception and sensory expectations while practitioners develop applications to improve eating experiences, such as making healthier foods more visually appealing through strategic color enhancement.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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