PERSPECTIVES ON MULTISENSORY HUMAN-FOOD INTERACTION

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frontiers Research Topics

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PERSPECTIVES ON MULTISENSORY HUMAN-FOOD INTERACTION

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Editorial: Perspectives on Multisensory Human-Food Interaction

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Editorial on the Research Topic

Perspectives on Multisensory Human-Food Interaction

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INTRODUCTION

Eating and drinking are undoubtedly amongst life's most multisensory experiences. Take, for instance, the enjoyment of flavor, which is one of the most important elements of such experiences, resulting from the integration of gustatory, (retronasal) olfactory, and possibly also trigeminal/oral-somatosensory cues (Prescott, 2015). Nevertheless, researchers have suggested that all our senses can influence the way in which we perceive flavor, not to mention our eating and drinking experiences. For instance, the color and shape of the food, the background sonic/noise cues in our eating environments, and/or the sounds associated with mastication can all influence our perception and enjoyment of our eating and drinking experiences (Spence, 2020).

Human-Food Interaction (HFI) research has been growing steadily in recent years (e.g., Deng et al., 2021). Research into multisensory interactions designed to create, modify, and/or enhance our food-related experiences is one of the core areas of HFI (Multisensory HFI or MHFI, Altarriba Bertran et al., 2019; Velasco and Obrist, 2020). The aim being to further our understanding of the principles that govern the systematic connections between the senses in the context of HFI.

In this Research Topic, we called for investigations and applications of systems that create new, or enhance already existing, multisensory eating and drinking experiences (what can be considered the "hacking" of food experiences) in the context of HFI. Moreover, we were also interested in those works that focus on or are based on the principles governing the systematic connections that exist between the senses. HFI also involves the experiencing of food interactions digitally in remote locations. Therefore, we were also interested in sensing and actuation interfaces, new communication mediums, and persisting and retrieving technologies for human food interactions. Enhancing social interactions to augment the eating experience is another issue we wanted to see addressed here, what has been referred to as "digital commensality" (Spence et al., 2019).

CONTRIBUTIONS

In total, 12 papers were eventually accepted in this Research Topic. They consist of a mixture of basic research papers, perspective pieces, and review articles. Below are short summaries of these papers, following the contribution of Velasco et al. who present a reflection on the state of MHFI research. They identify different themes in which studies in this area can be classified and which may be considered to connect basic research on food and the senses, through the development of technology, to consumer-related applications. These themes are approached from a multidisciplinary perspective and involved: 1) psychological mechanisms; 2) data collection and analyses, 3) design studies and frameworks, 4) interfaces and augmentation, 5) applications. The papers included in the present Research Topic can be classified in all but category 2).

Psychological Mechanisms

In one review paper, Spence argues that the coffee-drinking experience should be conceptualized as engaging all of the senses rather than focusing solely on the chemical senses of smell and taste. The research now shows that everything from the sound of coffee preparation to the multisensory properties of the cup in which that coffee is served, and the multisensory attributes of the environment are among the product-extrinsic influences that affect the tasting experience. The paper reviews the crossmodal influences of sonic seasoning on the coffee-drinking experience. In a second review paper, Spence explores the convoluted history of blue coloring as it relates to food and drink. With a focus on the possibly apocryphal story of the blue steak meal that made people ill, the broader research on the changing meanings of color in relation to the consumer's experience of food and drink are discussed. The role of digital technology in the rise of blue foods and drinks on sites such as Instagram's The Art of Plating is also highlighted.

Motoki et al. investigate the topic of crossmodal correspondences between taste and temperature with a focus on food-extrinsic warmth. Experiments included the investigation of the association of temperature words with taste attributes such as sweet, sour, salty, bitter. They also address the question of how physical warmth influences sensory/hedonic ratings. The authors' research demonstrates the existence of taste-temperature correspondences.

Kokaji and Nakatani summarize the results of an exploratory study on the role of the peripheral visual presentation of different kinds of garnish for a main dish. It was shown that the garnish placed on the plates strongly contributes to the arousal of appetite. Suggested uses of their results include images of dishes on menus, food model displays, and the use of augmented reality to place specific garnishes on, or near, real foods in order to influence the multisensory dining experience.

Design Studies and Frameworks

In order to provide a general framework and first point of contact for researchers on multisensory experiences, Velasco and Obrist present a primer on the topic, as well as its relationship with MHFI. The authors conceptualize multisensory experiences as impressions shaped by specific events, such as stages of interaction, whose sensory elements have been constructed by someone, following different principles of multisensory perception. In the context of HFI, multisensory experiences refer to impressions shaped by specific food-related events, whose sensory elements (e.g., intrinsic, and extrinsic to the food, have been constructed by someone.

Velasco et al. introduce their reality-impossibility model to guide the design of experiences in extended reality. The model encompasses two continua, that is, the reality-fantasy nature of objects and environments (described in the form of nouns), and the degree to which they follow the laws of physics or other laws (described in the form of verbs). The authors suggest that by considering these dimensions, it allows one to approach impossible experiences, that is, experiences that would not be possible without extended reality technologies.

Interfaces and Augmentation

Wang et al. discuss how research into food color perception can benefit from Virtual Reality (VR) technology, by allowing for the easy alteration of the visual appearance of stimuli. They demonstrate how VR can be used to alter the appearance of cold brew coffee. Intriguingly, they show that coffee that was made to look milkier in VR (i.e., a lighter brown color) was rated as tasting creamier than coffee having a darker appearance, even though the coffee itself did not contain milk. That said, no effects on perceived sweetness or liking of the beverages were observed. The authors highlight how their use of VR can enable ways of changing the visual appearance of stimuli that would otherwise not be possible (e.g., changing visual appearance without the need for additives).

Stäger et al. not only consider how the visual appearance of a beverage can influence flavor perception, but also how flavor might influence color perception. Using a mixed-reality (MR) setup, they had their participants taste beverages having different colors and flavors. The participants rated the flavor and color of several beverages associated with different pairings of color and flavor. Color was found to crossmodally influence flavor perception, but no effects were observed in the other direction.

While the participants in the experiments reported in the last two papers had to wear head-mounted devices in order to see the manipulated colors of beverages, in the research reported by Suzuki et al. show how a boiling motion texture was actually projected directly onto the food itself. The experiment investigated whether this projection would enhance perception (e.g., of sweetness, sourness, saltiness, spiciness, or temperature) and/or value judgments (relating to the price of the food, or appetite). The study revealed the potential of the technology to increase the expectations of the consumers and promote their purchasing intentions.

Applications

Andersen et al. present a holistic overview on how the 1) viewing, 2) creating, and 3) online sharing of digital food photography can influence consumer eating behaviour. The authors highlight multiple gaps and insufficiencies in current state-of-the-art research. Through identifying those gaps, the authors provide valuable guidance on future research opportunities, such as if and how digital food photography can support an obesity-preventative lifestyle, and how we could shape the future human-food relationships in digital, analogue, and mixed reality worlds.

Barbosa Escobar et al. present a study designed to assess how utilizing different media associated with the origin of specialty coffee would influence consumers' expectations and experiences of premium coffee. Their results suggested that online images broadly associated with the origin of coffee (i.e., a farm) could influence premiumness expectations of coffee and that using a VR environment that depicted this general origin (vs. a control but not a city atmosphere) could enhance the perception of coffee premiumness for non-expert consumers and the enjoyment of the experience for coffee professionals.

CONCLUSION

Taken together, the articles brought together here therefore help to highlight the dynamic state of MHFI research currently as a growing number of opportunities are emerging for the merging of digital technologies to enhance and modify multisensory eating and drinking experiences.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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ORIGINAL RESEARCH
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Cross-Modal Correspondences Between Temperature and Taste Attributes

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Temperature is an important characteristic of food and drink. In addition to food-intrinsic temperature (i.e., serving temperature), consumers often experience food-extrinsic temperature (e.g., physical warmth). Emerging research on cross-modal correspondence has revealed that people reliably associate temperature with other sensory features. Building on the literature on cross-modal correspondence and sensation transference theory, the present study aimed to reveal mental representations of temperature–taste correspondence and cross-modal mental representations influencing corresponding sensory/hedonic perceptions of beverages, with a focus on manipulating food-extrinsic warmth. To reveal mental representations of temperature–taste correspondence, Experiment 1 investigated whether temperature words (*warm, cool*) are associated with sensory/hedonic attributes (e.g., sweet, sour, salty, bitter). The results of Experiment 1 demonstrated that *warm* (vs. *cool*) was matched more with saltiness, tastiness, healthfulness, and preference (intention to buy), whereas *cool* (vs. *warm*) was matched more with sourness and freshness. Experiment 2 assessed whether cross-modal mental representations influence corresponding sensory/hedonic perceptions of beverages. The participants wore hot and cold pads and rated sensory/hedonic attributes of Japanese tea (Experiment 2a) or black coffee (Experiment 2b) before and after tasting it. The results of Experiment 2a demonstrated that physical warmth (vs. coldness) increased healthfulness and the intention to buy Japanese tea. The results of Experiment 2b did not reveal any effects of physical warmth on sensory/hedonic ratings. These findings provide evidence of taste–temperature correspondence and provide preliminary support for the influence of food-extrinsic warmth on taste attributes related to positivity.

Keywords: temperature, physical warmth, cross-modal correspondence, multisensory experiences, beverages

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INTRODUCTION

Temperature and Food

Temperature is an important characteristic of food and drink. Food-intrinsic temperatures (i.e., serving temperature) as well as food-extrinsic temperatures (e.g., physical or ambient room temperatures) influence judgment and behaviors (McBurney et al., 1973; Moskowitz, 1973; Bartoshuk et al., 1982; Green and Frankmann, 1987, 1988; Cruz and Green, 2000;

Schiffman et al., 2000; Engelen et al., 2003; Mony et al., 2013; Kim et al., 2015; Stokes et al., 2016; Pramudya and Seo, 2017, 2018). Food-intrinsic temperatures influence consumer acceptance (Cardello and Maller, 1982; Lee and O'Mahony, 2002; Brown and Diller, 2008). Food and drinks are more acceptable when served in the temperature range at which they are usually consumed (Cardello and Maller, 1982). In addition, food-extrinsic temperatures are commonly involved in dining settings. People sometimes warm themselves with a gas/electric heater and/or by wearing warm clothes as well as cool themselves with a ceiling fan and/or by wearing light clothes. Moreover, food-extrinsic temperatures influence consumer preferences (Zwebner et al., 2014; Motoki et al., 2018b). For example, physical warmth increases one's willingness to pay for food (Zwebner et al., 2014). Taken together, this evidence suggests that temperature, even in the food-extrinsic form, influences consumer preference.

Temperature-Cased Cross-Modal Correspondence

A recent study reviewed temperature-based cross-modal correspondence (Spence, 2020a). Cross-modal correspondence refers to sensory interactions among the senses (Spence, 2011). People map features in one sensory modality onto features in other modalities in a surprisingly consistent manner (e.g., sweet and round shape or high pitch) (e.g., Velasco et al., 2016; Motoki et al., 2019a,c). Previous research has documented correspondence between temperature and the other sensory modalities (Berry, 1961; Wright, 1962; Hardin, 2000; Michael and Rolhion, 2008; Velasco et al., 2013; Ho et al., 2014a,b; Lorentz et al., 2016; Wang and Spence, 2017; Wnuk et al., 2017; Roque et al., 2018; Motoki et al., 2019b). For example, warm (vs. cold) temperatures are perceived to be well matched with visual features, such as a red hue (Ho et al., 2014b) or light color (Motoki et al., 2019b), whereas visual features of coldness (e.g., ice cubes) facilitate categorizing a drink as fresh (Roque et al., 2018). In addition, temperatures are associated with different sound properties (Velasco et al., 2013; Wang and Spence, 2017). Warm (vs. cold) temperatures of beverages are likely to be associated with a lower pitch and a slower tempo (Wang and Spence, 2017). However, most previous research has investigated visual–temperature or sound–temperature correspondence (but see Wnuk et al., 2017). Although temperature is involved in various dining settings (Velasco et al., 2013; Zwebner et al., 2014; Kim et al., 2015; Motoki et al., 2018b), no study has investigated temperature–taste correspondence.

Some research on cross-modal correspondence is based on mental representations without actual experiences of sensory stimuli. Word matching has been used to investigate mental representations of temperature-based or taste-based correspondence (e.g., Velasco et al., 2015; Motoki et al., 2019b) because previous research suggests that cross-modal correspondence may result even when sensing words are used without sensory experiences (Spence et al., 2015; Velasco et al., 2015, 2018b; Saluja and Stevenson, 2018). For example, words related to sweetness/bitterness are well matched with roundness/angularity, and sweet/bitter tastants are similarly well matched with roundness/angularity (Velasco et al., 2015). Our first aim in this study was to reveal mental representations of temperature–taste correspondence and how people associate temperature words with taste attributes.

Sensation Transference Theory

Food-extrinsic temperatures (e.g., positive experiences of physical warmth) can transfer to corresponding sensory/hedonic ratings (e.g., positive evaluations of food products). Sensation transference theory suggests that food-extrinsic somesthetic sensory experiences can be transferred to expectations and experiences around food and drink (Cheskin, 1972). For example, food-extrinsic haptic sensations (e.g., the weight of cutlery) influence corresponding expectations and experiences of food and beverages (e.g., the perceived texture of foods) (Krishna and Morrin, 2008; Mobini et al., 2011; Piqueras-Fiszman and Spence, 2012; Tu et al., 2015; Biggs et al., 2016; Slocombe et al., 2016; Kampfer et al., 2017; Wang and Spence, 2018). In addition, cross-modal mental representations observed in word matching affect the corresponding taste experience. The words *sweetness/sourness* are well matched with round/angular typefaces, and foods (jelly beans) rated as sweeter and less sour are associated with round (vs. angular) typefaces (Velasco et al., 2018b). Thus, findings of cross-modal mental representations by means of word matching may be reflected in corresponding taste perceptions. The second aim of this study was to reveal whether cross-modal mental representations affect corresponding sensory/hedonic perceptions of beverages, with a focus on manipulating food-extrinsic warmth.

Hypotheses

We established our hypotheses based on the emotion mediation hypothesis of cross-modal correspondence. The emotion mediation hypothesis suggests that people associate sensory attributes with other attributes based on similarity in emotional meaning (Spence, 2020a). For example, roundness and sweet taste are well matched because both have a positive valence relative to angularity and other tastes (Velasco et al., 2015). Previous studies imply that warm temperatures have a positive valence (Stokes et al., 2016; Pramudya and Seo, 2017). For example, coffee and green tea served at higher temperatures are evaluated positively (e.g., happy and satisfied), whereas beverages served at lower temperatures are evaluated negatively (e.g., disgusting and bitter) (Pramudya and Seo, 2017). In addition, experiences of physical warmth induce positive emotions and lead to greater intentions to buy products (Zwebner et al., 2014). Thus, the word *warmth* (vs. *coolness*) would be more associated with positive taste terms (e.g., tastiness, healthfulness, buying intention, and sweetness), and experiences of physical warmth (vs. coldness) increase ratings of positive taste attributes (e.g., tastiness, healthfulness, buying intention, and sweetness). By contrast, the word *coolness* (vs. *warmth*) is more associated with negativity (e.g., bitterness), and experiences of physical warmth (vs. coldness) increase ratings of negative taste attributes (e.g., bitterness).

H1a: The word *warmth* (vs. *coolness*) is more associated with taste terms linked to positivity (e.g., tastiness, healthfulness, buying intention, and sweetness).

H1b: The word *coolness* (vs. *warmth*) is more associated with taste terms linked to negativity (e.g., bitterness).

H2a: Physical warmth (vs. coldness) increases ratings of positive taste attributes (e.g., tastiness, healthfulness, buying intention, and sweetness).

H2b: Physical coldness (vs. warmth) increases ratings of negative taste attributes (e.g., bitterness).

The Current Study

Building on the literature on cross-modal correspondence and sensation transference theory, the present study aimed to reveal temperature–taste correspondence. This study investigated mental representations of temperature–taste correspondence and whether cross-modal mental representations influence corresponding sensory/hedonic perceptions of beverages, with a focus on manipulating food-extrinsic warmth. In Experiment 1, participants were asked to determine how much temperature words (*warm, cool*) are associated with sensory/hedonic attributes (e.g., sweet, sour, salty, bitter). In Experiment 2, participants who physically experienced warm or cold temperatures were asked to rank sensory/hedonic attributes of Japanese tea (Experiment 2a) and black coffee (Experiment 2b) before and after tasting each beverage.

EXPERIMENT 1

Materials and Methods

Participants

A total of 103 participants (32 females and 69 males; two participants did not reveal their gender; age: 42.06 ± 9.45 years) gave their online informed consent to take part in the experiment. The sample size was based on recent online research on taste-based correspondence (Velasco et al., 2018a; Motoki et al., 2019d). The participants were recruited on Lancers[1] and completed the survey on Qualtrics[2]. The platforms allowed the participants to receive monetary compensation for completing the study (50 JPY). This research was conducted in September in Japan. All procedures were conducted according to the Declaration of Helsinki. The experimental protocol was approved by the Ethics Committee of Tohoku University School of Medicine.

Procedure

The study used a within-participants design, with sensory/hedonic attribute (tastiness, healthfulness, sweetness, sourness, saltiness, bitterness, freshness, and buying intention) as the dependent variables and temperature (warm, cool) as the independent variable. Participants were informed that this study aimed to investigate how people associate warmth/coolness with taste attributes. Participants were asked to match temperature words (*warmth* and *coolness*) with each sensory/hedonic attribute (**Figure 1**). Buying intention was taken as an indicator of consumer preference. This measure was also used in Experiment 2. In total, there were 16 trials in which participants matched each word with a value on a visual analog scale (VAS) ranging from 0 (not at all) to 100 (very much). The order of the trials and rating attributes were randomized across participants.

Statistical Analyses

We calculated the degree to which the warm and cold words were matched with taste attributes using paired t tests. $p < 0.006$ (0.05/8) was considered significant with the Bonferroni correction. This procedure was similar to that used in a previous study on cross-modal correspondence (Motoki et al., 2019b).

We also conducted multivariate analysis of covariance (MANCOVA) to assess the effects of temperature (warm, cool) on taste ratings (tastiness, healthfulness, sweetness, sourness, saltiness, bitterness, warmth, freshness, and buying intention), with gender as a covariate. Gender was included because a previous study showed gender differences in perceptions of thermal sensation (Karjalainen, 2007). Two participants did not reveal their gender, so those two participants were excluded from analyses. The final sample included 101 participants. Each sensory/hedonic attribute was rated on a scale from 1 to 7. We focused on the interactive effects of temperature and gender.

FIGURE 1 | Temperature–taste matching task. Participants were asked to match a temperature word (warmth, coolness) with a sensory/hedonic attribute (tastiness, healthfulness, sweetness, sourness, saltiness, bitterness, freshness, buying intention) using a visual analog scale ranging from 0 (not at all) to 100 (very much).

[1] https://www.lancers.jp/

[2] https://www.qualtrics.com/jp/

Data were analyzed with SPSS software (version 25.0; SPSS Inc., Chicago, IL, United States).

Results

The word *warm* was matched more often with saltiness, tastiness, healthfulness, and buying intention than the word *cool*. By contrast, the word *cool* was matched more often with sourness and freshness than the word *warm* (**Figure 2**). The words *warm* and *cool* did not differ in terms of matching with sweetness and bitterness. A statistical summary is shown in **Table 1**.

The MANCOVA results revealed a significant main effect of temperature [$F_{(8,92)} = 28.967$, Wilks' lambda = 0.284, $p < 0.001$, $\eta_p{}^2 = 0.716$] and an interaction effect of temperature and gender [$F_{(8,92)} = 2.395$, Wilks' lambda = 0.828, $p = 0.022$, $\eta_p{}^2 = 0.172$]. No main effect of gender was observed [$F_{(8,92)} = 1.133$, Wilks' lambda = 0.910, $p = 0.349$, $\eta_p{}^2 = 0.090$]. Univariate ANCOVA showed that the word *cool* matched more frequently with saltiness and freshness than *warm*. A further univariate ANCOVA revealed significant interactive effects of temperature and gender on sour, healthfulness and buying intention. The matching scores for warmth–healthfulness [$F_{(1,99)} = 6.333$, $p = 0.014$, $\eta^2{}_p = 0.060$] and warmth–buying intention [$F_{(1,99)} = 5.973$, $p = 0.016$, $\eta^2{}_p = 0.057$] were higher in females than in males. In contrast, no differences were observed between males and females in coolness–healthfulness [$F_{(1,99)} = 1.503$, $p = 0.223$, $\eta^2{}_p = 0.015$] or coolness–buying intention [$F_{(1,99)} = 0.670$, $p = 0.415$, $\eta^2{}_p = 0.007$]. The matching score of coolness–sourness [$F_{(1,99)} = 8.969$, $p = 0.004$, $\eta^2{}_p = 0.083$] was higher in males than in females. By contrast, no differences were observed between males and females in warmth–sourness [$F_{(1,99)} = 0.561$, $p = 0.456$, $\eta^2{}_p = 0.006$]. A statistical summary is shown in **Table 2**.

The results of Experiment 1 revealed that people have specific associations between temperatures and sensory/hedonic attributes. Experiment 2 investigated whether these associations have consequences for taste expectations and experiences.

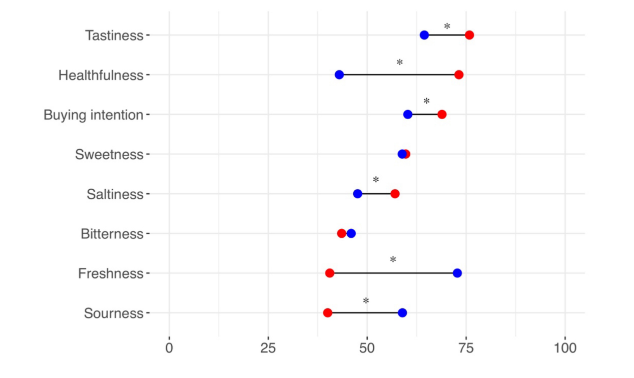

FIGURE 2 | An illustration of temperature–taste attribute matching. The match between temperature words (warmth, coolness) and sensory/hedonic attributes was rated using a scale ranging from 0 (not at all) to 100 (very much). Red circles represent the mean data for warmth. Blue circles represent the mean data for coolness. An asterisk indicates a significant difference at $p < 0.006$ (0.05/8).

TABLE 1 | Temperature–taste attribute matching.

	Warmth	Coolness	*p*-value	Cohen *d*
Buying intention	68.89 (15.72)	60.26 (19.43)	<0.001	0.364
Tastiness	75.83 (14.01)	64.43 (17.72)	<0.001	0.554
Healthfulness	73.17 (14.67)	42.94 (18.30)	<0.001	1.160
Sweetness	59.72 (19.76)	58.85 (22.58)	0.769	0.029
Sourness	40.02 (21.99)	58.90 (23.17)	<0.001	−0.581
Saltiness	57.03 (20.93)	47.58 (20.66)	<0.001	0.375
Bitterness	43.54 (19.35)	45.95 (23.10)	0.400	−0.083
Freshness	40.54 (21.26)	72.77 (18.58)	<0.001	−0.989

Mean (± SD) data for the match between temperature words (warmth, coldness) and sensory/hedonic attributes, rated using a scale ranging from 0 (not at all) to 100 (very much); df = 102.

EXPERIMENT 2

The aim of Experiment 2 was to reveal whether cross-modal mental representations (the findings of Experiment 1) affect corresponding sensory/hedonic perceptions of beverages, with a focus on manipulating food-extrinsic warmth. We investigated how physical warmth influences corresponding sensory/hedonic ratings of Japanese tea (Experiment 2a) and black coffee (Experiment 2b). These two beverages were chosen because both are popular beverages in Japan (Pitelka, 2013; Whitelaw, 2014) and therefore might be consumed in situations involving food-extrinsic temperatures.

Materials and Methods

Design and Participants

The experimental design was a 2 (physical warmth: warm, cold) × 2 (time: pretasting, posttasting) design in which all factors were within-participants variables. A total of 69 participants gave

TABLE 2 | Results of univariate analysis of covariance investigating the effects of temperature and gender on taste ratings.

Effect	Rating type	*F*	*p*-value	$\eta_p{}^2$
Temperature	Buying intention	0.856	0.357	0.009
	Tastiness	0.672	0.414	0.007
	Healthfulness	3.461	0.066	0.034
	Sweetness	2.85	0.095	0.028
	Sourness	0.127	0.723	0.001
	Saltiness	7.072	0.009	0.067
	Bitterness	1.083	0.301	0.011
	Freshness	8.008	0.006	0.075
Temperature × gender	Buying intention	5.306	0.023	0.051
	Tastiness	1.335	0.251	0.013
	Healthfulness	5.136	0.026	0.049
	Sweetness	3.468	0.066	0.034
	Sourness	6.664	0.011	0.063
	Saltiness	2.184	0.143	0.022
	Bitterness	2.037	0.157	0.020
	Freshness	0.322	0.572	0.003

The model included temperature (warm and cool) as a within-participants factor and gender as a between-participants factor; df = 99.

their informed consent to take part in one of the two experiments. Data from 35 participants were included in the final analyses for Experiment 2a (seven females; age: 20.77 ± 1.48 years), and data from 34 participants were included in the final analyses for Experiment 2b (15 females; age: 21.41 ± 3.21 years). The relatively small sample sizes were due to time constraints in data collection. The participants were recruited through notices on a university campus and provided written informed consent after receiving an explanation of the experiment. All procedures were conducted according to the Declaration of Helsinki. The experimental protocol was approved by the Ethics Committee of Tohoku University School of Medicine.

Stimuli

We used different beverages in Experiments 2a and 2b to test for the generalizability of the temperature effects on sensory/hedonic perceptions of beverages. In Experiment 2a, Japanese tea (Oi Ocha Roasted rice tea with matcha; Itoen, Tokyo, Japan) was used[3]. The ingredients of the Japanese tea included roasted rice, tea leaves, matcha, and vitamin C. In Experiment 2b, black coffee (Nescafé Gold blend full-boiled; Nestle, Tokyo, Japan) was used[4]. The black coffee was decaffeinated and served without sugar. The bottled Japanese tea (Experiment 2a) or black coffee (Experiment 2b) was poured into a white paper cup (about 10 mL per cup) and served to the participants. Both the Japanese tea and black coffee were stored at room temperature, and the serving temperature was not assessed in either experiment. Previous studies used about 10 mL of each solution and confirmed that this was sufficient for participants to perceive different taste qualities (Crisinel and Spence, 2011; Wang et al., 2016). Both Japanese tea and black coffee were stored at room temperature. As in previous studies (Crisinel and Spence, 2011; Wang et al., 2016), the serving temperature was not recorded because both beverages were stored in the same room in the second and third week of March. Thus, it is unlikely that the temperatures of the beverages varied across participants.

Manipulation of Physical Warmth

Participants wore a hot (warm condition) or a cold (cold condition) pad (**Figure 3**) around their neck. The warm and cold pads were of the same design. The procedure followed that of a previous study featuring the manipulation of physical warmth (Motoki et al., 2019b). It has been shown that this manipulation significantly affects subjective thermal sensations (Motoki et al., 2019b). The hot and cold pads were used following the manufacturer's instruction and were about 50°C and −5°C, respectively (Motoki et al., 2019b).

Procedure

Participants (one at a time) were led to a table and sat in a chair. At the start of the experiments, participants were told that they would drink tea (Experiment 2a) or coffee (Experiment 2b) while wearing a hot/cold pad. The timeline of the experimental procedure is shown in **Figure 4**.

[3]http://www.itoen.co.jp/products/detail.php?id=51

[4]https://shop.nestle.jp/front/contents/machine/ics/bottle/

FIGURE 3 | Hot/cold pad.

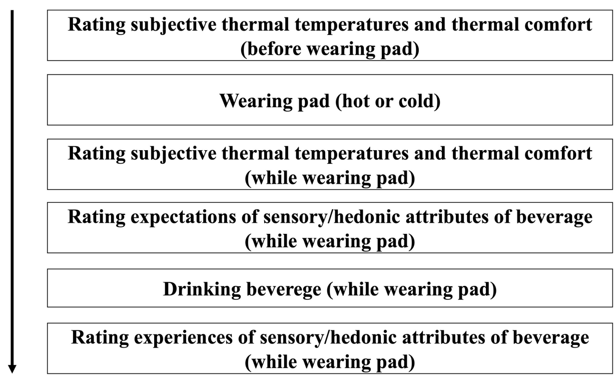

FIGURE 4 | Timeline for the experimental procedure. The procedure was repeated in the other condition (hot or cold), and the order of the conditions was randomly allocated.

The two drinks were served at the same temperature, although we told the participants that both drinks were different. Before they put on the pad (hot or cold), they answered baseline questions on thermal temperature (1: very cold to 7: very hot) and thermal comfort (1: very negative to 7: very positive) using a 7-point Likert scale. After putting on the pad (hot or cold), participants answered the temperature and comfort questions again.

While wearing the pad, participants saw the served drinks (Japanese tea for Experiment 2a and black coffee for Experiment 2b) and gave their expected sensory/hedonic ratings (tastiness, healthfulness, sweetness, sourness, saltiness, bitterness, drink warmth, freshness, buying intention). The rating procedure used a 7-point Likert scale ranging from 1 (not at all) to 7 (very much) for each question. After participants provided their expected ratings, they drank the beverage and provided their experience ratings (tastiness, healthfulness, sweetness, sourness, saltiness, bitterness, drink warmth, freshness, and buying intention). The procedure was repeated in the other condition (hot or cold), and the order of the conditions was randomly allocated. The participants rested for about 1 min between conditions. None of the participants in either of the two experiments were informed about the brand name, origin, taste, temperature, or flavor profile of the drinks that they were served; they only knew that they would drink Japanese tea (Experiment 2a) and coffee (Experiment 2b). To reduce discomfort during wearing the pads, it took a short amount of time (about 30–60 s) to complete the thermal and beverage ratings. The time required to complete the entire procedure was about 5 min.

Statistical Analyses

To verify the influence of physical warmth on thermal sensation and comfort, we conducted paired *t*-tests on the change in scores (while wearing the hot/cold pad minus before wearing the pad).

For both Experiments 2a and 2b, repeated-measures (RM) ANCOVAs were conducted to assess the effects of physical warmth (warm, cold) and time (pretasting, posttasting) on the taste ratings (tastiness, healthfulness, sweetness, sourness, saltiness, bitterness, warmth, freshness, and buying intention) with gender and thermal comfort as covariates. Gender was included as a covariate because a previous study reported gender differences in perceptions of thermal sensation (Karjalainen, 2007), and the results of Experiment 1 showed gender differences. Each sensory/hedonic attribute rated on a scale from 1 to 7 was a dependent variable in the RM-ANCOVAs. The analyses were conducted with SPSS version 25 (IBM, Chicago, IL, United States).

Results of Manipulating Physical Warmth

The means and SDs of thermal sensation were wearing the hot pad (Experiment 2a: $M = 5.600 \pm 0.695$; Experiment 2b: $M = 5.382 \pm 0.922$), before wearing the hot pad (Experiment 2a: $M = 2.914 \pm 0.818$; Experiment 2b = 3.029 ± 0.797), wearing the cold pad (Experiment 2a: $M = 1.714 \pm 0.667$; Experiment 2b: $M = 1.971 \pm 0.717$), and before wearing the cold pad (Experiment 2a: $M = 3.171 \pm 0.857$; Experiment 2b = 3.353 ± 0.883). The means and SDs of thermal comfort were wearing the hot pad (Experiment 2a: $M = 5.551 \pm 1.222$; Experiment 2b: $M = 5.529 \pm 1.134$), before wearing the hot pad (Experiment 2a: $M = 3.543 \pm 1.197$; Experiment 2b = 4.147 ± 1.282), wearing the cold pad (Experiment 2a: $M = 2.686 \pm 1.255$; Experiment 2b: $M = 3.235 \pm 1.281$), and before wearing the cold pad (Experiment 2a: $M = 4.086 \pm 1.337$; Experiment 2b = 4.588 ± 1.373).

Thermal sensation in the warm condition was rated as warmer than that in the cold condition (Experiment 2a: $M_{hotpad-beforehotpad} = 2.686 \pm 0.832$ vs. $M_{coldpad-beforecoldpad} = -1.457 \pm 0.950$, $t_{34} = 21.977$, $p < 0.001$; Experiment 2b: $M_{hotpad-beforehotpad} = 2.353 \pm 1.252$ vs. $M_{coldpad-beforecoldpad} = -1.382 \pm 0.817$, $t_{33} = 16.930$, $p < 0.001$). Thermal comfort in the warm condition was rated more favorably than that in the cold condition (Experiment 2a: $M_{hotpad-beforehotpad} = 1.971 \pm 1.689$ vs. $M_{coldpad-beforecoldpad} = -1.400 \pm 0.976$, $t_{34} = 10.699$, $p < 0.001$; Experiment 2b: $M_{hotpad-beforehotpad} = 1.382 \pm 1.701$ vs. $M_{coldpad-beforecoldpad} = -1.353 \pm 1.276$, $t_{33} = 8.958$, $p < 0.001$). Although the thermal sensation manipulations were successful, a difference in thermal comfort was observed between the warm and cold conditions. Thus, we included a thermal comfort score (changed comfort in the warm condition – changed comfort in the cold condition) as a covariate in further analyses.

Results for Japanese Tea (Experiment 2a)

The analyses revealed significant main effects of physical warmth and time. However, no main effects of gender or thermal comfort or any interactive effects were observed ($p > 0.05$; **Table 3**). Univariate ANCOVAs showed that the participants in the warm (vs. cold) temperature increased their buying intention and healthfulness ratings (**Table 4**). Further univariate ANCOVAs showed that posttasting (vs. pretasting) increased the buying intention, tastiness, and healthfulness ratings but decreased ratings of sourness, saltiness, and bitterness (Appendix Table A). The statistics are shown in **Table 5**. The results are illustrated graphically in **Figure 5**. Note that the main results were unchanged when we ran ANOVAs without the covariates (gender and thermal comfort).

Results for Black Coffee (Experiment 2b)

The analyses revealed significant main effects of time. However, no main effects of temperature, gender, or thermal comfort or any interactive effects were observed (**Table 6**). Follow-up univariate ANCOVAs revealed that pretasting (vs. posttasting) increased the buying intention, tastiness, healthfulness, sweetness, drink warmth, and freshness ratings (Appendix Table B). The basic statistics are shown in **Table 7**. The data are illustrated graphically in **Figure 6**. Note that the main results were unchanged when we ran the ANOVAs without the covariates (gender and thermal comfort).

Discussion

This study aimed to determine temperature–taste correspondence. We investigated mental representations of temperature–taste correspondence and cross-modal mental representations that influence corresponding sensory/hedonic perceptions of beverages, with a focus on manipulating the extrinsic warmth of food. The results of Experiment 1 showed that the word *warmth* (vs. *coldness*) was matched more with saltiness, tastiness, healthfulness, and buying intention. By

TABLE 3 | Results of repeated-measures analyses of covariance investigating the effects of temperature (warm and cold) and time (pretasting and posttasting) on taste ratings with gender and thermal comfort as covariates.

Effect	*F*	Wilks' lambda	*p*-value	η_p^2
Temperature	2.672	0.500	0.026	0.500
Time	11.106	0.194	<0.001	0.806
Temperature × time	1.202	0.689	0.339	0.331
Temperature × thermal comfort	1.525	0.636	0.196	0.364
Temperature × gender	0.910	0.746	0.532	0.254
Time × thermal comfort	1.901	0.584	0.101	0.416
Time × gender	1.202	0.689	0.338	0.311
Temperature × time × thermal comfort	0.813	0.766	0.610	0.234
Temperature × time × gender	0.869	0.754	0.565	0.246

TABLE 4 | Results of univariate analyses of covariance investigating the effects of temperature on taste ratings.

Rating type	*F*	*p*-value	η_p^2
Buying intention	18.48	< 0.001	0.37
Tastiness	2.00	0.167	0.06
Healthfulness	5.66	0.002	0.27
Sweetness	0.41	0.529	0.01
Sourness	0.50	0.483	0.02
Saltiness	0.26	0.612	0.01
Bitterness	1.45	0.237	0.04
Temperature	0.27	0.605	0.01
Freshness	0.98	0.330	0.03

The design included temperature (warm and cold) and time (pretasting and posttasting) as within-participants factors and gender and thermal comfort as covariates.

TABLE 5 | Basic statistical summary of Experiment 2a.

Rating type	Expectation		Experience	
	Warm	Cold	Warm	Cold
Buying intention	3.60 (1.29)	2.80 (1.41)	4.23 (1.22)	3.83 (1.40)
Tastiness	4.20 (1.23)	3.86 (1.17)	5.03 (1.12)	4.77 (1.42)
Healthfulness	4.89 (1.02)	4.40 (1.31)	5.46 (1.12)	5.11 (1.13)
Sweetness	2.97 (1.71)	2.91 (1.72)	2.49 (1.42)	2.54 (1.63)
Sourness	2.17 (1.34)	2.14 (1.48)	1.29 (0.62)	1.40 (0.98)
Saltiness	2.26 (1.36)	2.09 (1.31)	1.40 (0.85)	1.51 (1.01)
Bitterness	3.09 (1.48)	3.49 (1.81)	2.29 (1.23)	2.46 (1.34)
Temperature	3.60 (1.19)	3.06 (0.87)	3.31 (0.90)	3.54 (0.78)
Freshness	3.97 (1.12)	3.91 (1.42)	4.23 (1.46)	4.03 (1.38)

The influence of physical warmth on expectations and experiences of Japanese tea on a 7-point Likert scale ranging from 1 (not at all) to 7 (very much) for each rating. Standard deviations are in parentheses.

contrast, the word *coldness* (vs. *warmth*) was matched more with sourness and freshness. The results of Experiment 2a revealed that the experience of physical warmth (vs. coldness) increased healthfulness and buying intention for Japanese green tea. The results of Experiment 2b did not reveal any changes in sensory/hedonic attributes of black coffee following warm versus cold temperatures. These findings provide the evidence of taste–temperature correspondence and provide preliminary support for the association between food-extrinsic temperature and corresponding hedonic attributes.

Temperature–Taste Correspondence

The results of Experiment 1 revealed that people have specific associations between temperature and sensory/hedonic attributes. Although the emerging literature on cross-modal correspondence has shown that temperature has a specific association with other sensory modalities (Velasco et al., 2013; Ho et al., 2014b; Wang and Spence, 2017; Roque et al., 2018; Motoki et al., 2019b), temperature-based cross-modal correspondence has only been reported for visual and auditory features (e.g., warmth and red color). Although a close relationship has been shown between temperature and taste attributes (McBurney et al., 1973; Moskowitz, 1973; Bartoshuk et al., 1982; Green and Frankmann, 1987, 1988; Cruz and Green, 2000; Schiffman et al., 2000; Engelen et al., 2003; Mony et al., 2013; Kim et al., 2015; Stokes et al., 2016; Pramudya and Seo, 2017, 2018), it has not been shown how temperature is specifically associated with taste attributes in the subjective matching task. Our findings show that the word *warmth* (vs. *coldness*) was matched more with saltiness, tastiness, healthfulness, and buying intention. By contrast, the word *coldness* (vs. *warmth*) was matched more with sourness and freshness. Taken together, these findings provide evidence of temperature–taste correspondence and show how people map the concept of temperature onto sensory/hedonic attributes.

The results of Experiment 2 showed that the experience of physical warmth (vs. coldness) increased healthfulness and buying intention for Japanese green tea. This finding was partially consistent with the results of the word-matching task (Experiment 1), such that warmth (vs. coldness) was more associated with the concepts of healthfulness and buying intention. According to embodiment theory (Barsalou, 2010), abstract psychological concepts (e.g., emotional warmth and positive reactions) are metaphorically grounded in concrete physical experiences (e.g., physical warmth) (Barsalou, 2010). Previous research has demonstrated that physically warm temperatures lead to more positive evaluations of beverages (Zwebner et al., 2014). Although the results of Experiment 1 demonstrated that warmth and coolness are matched more with taste attributes (e.g., warmth with saltiness and coolness with sourness), we did not find any effects of physical warmth on basic taste ratings (sweet, sour, salty, bitter). Taken together, these results indicate that an experience of physical warmth increases the evaluation of abstract food concepts (i.e., healthfulness, buying intention) but does not influence basic taste evaluations.

Underlying Mechanisms for Taste–Temperature Correspondence

The explanation behind temperature–taste correspondence is linked to statistical regularity (Spence, 2011). People may be regularly exposed to a certain mapping of temperatures and taste-related information. For example, salty food (e.g., miso soup) is often served at a warm temperature. By contrast, sour and fresh food (e.g., gumi and carbonated drinks) is often served cold. Consumers might often see such associations between temperatures and tastes in daily dining settings. Repeated exposure to the statistical co-occurrence of temperature and taste attributes may influence internalization of the environmental statistics.

An alternative explanation has to do with valence matching (Velasco et al., 2015; Kantono et al., 2016, 2019; Motoki et al., 2019d; Xu et al., 2019). As we showed here, warm sensations elicit positive feelings, which transfer to a higher willingness to pay for products (Zwebner et al., 2014). People generally like warm foods (Pramudya and Seo, 2018). Both healthfulness and tastiness are positively correlated with food preferences (Motoki et al., 2018a). Given the similarity in valence, people tend to associate warmth with likable taste attributes (tastiness, healthfulness, and greater buying intention). Although valence matching often reveals changes in sweet and bitter perceptions (Velasco et al., 2015; Motoki et al., 2019d), we did not find any associations between temperature and sweetness or bitterness in

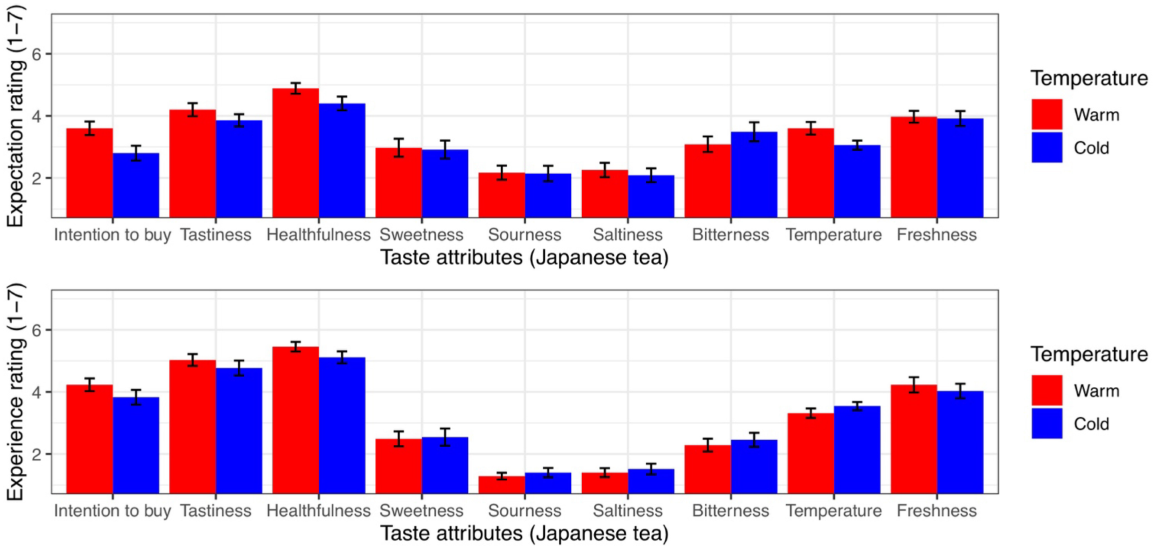

FIGURE 5 | The influence of physical temperature on the taste attributes of Japanese tea. The error bars represent standard error.

TABLE 6 | Results of repeated-measures analyses of covariance investigating the effects of temperature (warm and cold) and time (pretasting and posttasting) on taste ratings with gender and thermal comfort as covariates.

Effect	*F*	Wilks' lambda	*p*-value	η_p^2
Temperature	1.160	0.688	0.365	0.312
Time	7.277	0.260	< 0.001	0.740
Temperature × time	1.657	0.607	0.158	0.393
Temperature × thermal comfort	0.797	0.762	0.623	0.238
Temperature × gender	1.391	0.648	0.249	0.352
Time × thermal comfort	1.647	0.608	0.160	0.392
Time × gender	0.842	0.752	0.586	0.248
Temperature × time × thermal comfort	1.534	0.625	0.195	0.375
Temperature × time × gender	0.758	0.771	0.654	0.229

TABLE 7 | Basic statistical summary of Experiment 2b.

Rating type	Expectation		Experience	
	Warm	Cold	Warm	Cold
Buying intention	3.47 (1.54)	3.39 (1.38)	2.62 (1.44)	2.91 (1.62)
Tastiness	4.50 (1.42)	4.26 (1.40)	3.26 (1.56)	3.85 (1.76)
Healthfulness	4.00 (1.10)	3.88 (1.18)	3.53 (1.40)	3.50 (1.35)
Sweetness	2.21 (1.27)	2.21 (1.49)	1.41 (0.89)	1.71 (1.14)
Sourness	3.03 (1.62)	3.32 (1.47)	2.50 (1.69)	2.74 (1.58)
Saltiness	1.21 (0.54)	1.41 (0.93)	1.24 (0.89)	1.32 (0.98)
Bitterness	5.06 (1.46)	5.50 (1.24)	4.88 (1.68)	4.82 (1.60)
Temperature	3.68 (1.32)	3.68 (1.39)	2.29 (0.63)	2.79 (0.91)
Freshness	4.06 (1.76)	3.71 (1.62)	3.06 (1.43)	3.50 (1.58)

The influence of physical warmth on expectations and experiences of black coffee. Various parameters are rated on a 7-point Likert scale ranging from 1 (not at all) to 7 (very much). Standard deviations are in parentheses.

Experiment 1 or 2. The results did not fit our hypotheses, possibly because of individual differences in the valence of sweetness and bitterness. Although sweetness is liked and bitterness is disliked in general, the degree of valence of sweet and bitter foods might be more varied than likable taste attributes (tastiness, healthfulness, and greater buying intention). For example, there are individual differences in how people attribute sweet tastes to a positive valence, and some may attribute sweetness to a negative valence (e.g., guilty feelings) (Kampov-Polevoy et al., 2006). Weaker valence matching may have attenuated the effects of temperature on sweet and bitter taste correspondence. We did not measure core affect (valence and arousal), which could improve understanding of putative emotional transfer. For instance, it is not clear whether thermal comfort corresponds to valence (Spence, 2020a).

Previous research has shown that warm and cold temperatures are associated with red and blue, respectively (Ho et al., 2014b). However, in our experiments, the colors of the hot/cold pad (green) and beverages (black for black coffee and green for Japanese green tea) were not associated with previously reported color temperatures. Thus, it seems that our findings are not attributable to color-temperature correspondence.

Differential Effects of Physical Warmth on Hedonic/Sensory Perceptions of Two Beverages

The effects of physical warmth on hedonic/sensory ratings were different between Japanese tea and black coffee, although we did not hypothesize a differential influence of physical warmth between the two beverages. The matching of warmth with healthfulness and perception of Japanese tea as healthier than black coffee might have influenced these results. The results of Experiment 1 showed that warmth (vs. coldness) and healthfulness were matched more frequently than any other attribute pair. Thus, warmth may exert more influence

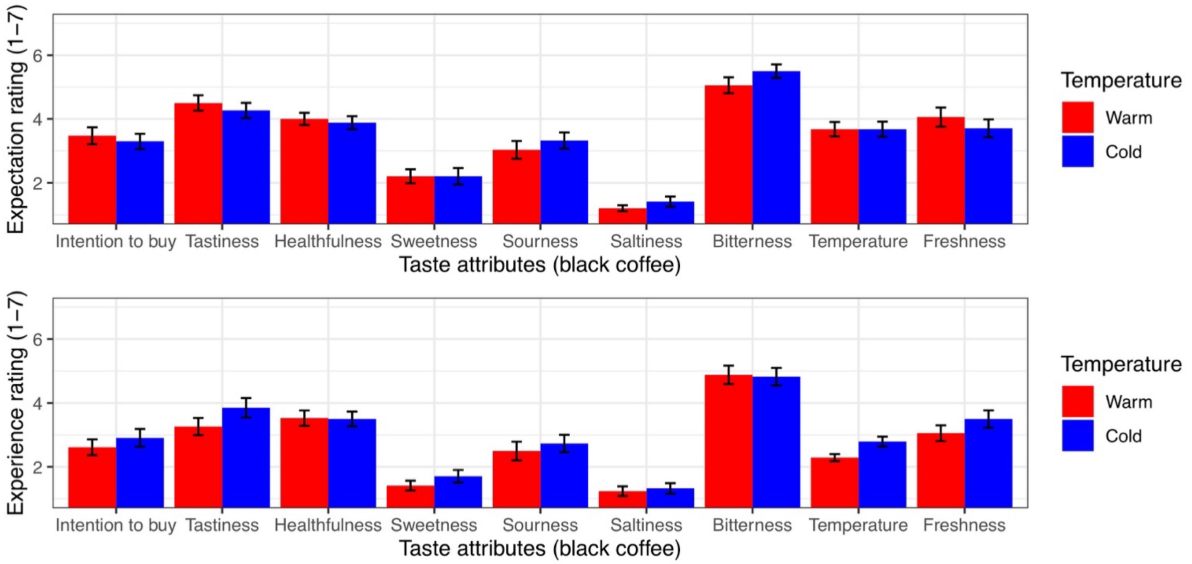

FIGURE 6 | The influence of physical temperature on the taste attributes of black coffee. The error bars represent standard error.

on perceived healthfulness than other attributes. The data from Experiment 2 suggested that Japanese tea is perceived to be healthier than black coffee. This result might explain the differential influence of warmth on the perceptions of Japanese tea and black coffee; warmth might increase the perception of healthfulness only when the drink is already regarded as healthy to some extent (e.g., Japanese tea).

Possible Applications of the Findings

Our findings have practical implications for industry. The results for Experiment 2a showed that physical warmth increased perceptions of healthfulness and buying intention. Thus, restaurant staff could recommend Japanese tea to customers wearing warm clothes. This could be especially effective for customers who are interested in a healthy lifestyle. Modifying the ambient temperature of the store to increase physical warmth might also be effective.

Limitations and Future Directions

A major limitation of this study is its small sample size (n = 35 for Experiment 2a, n = 34 for Experiment 2b, within-participants design). We did not conduct a sample size calculation for the experiments because no previous research has investigated the effect of extrinsic temperature on hedonic and sensory ratings. We hypothesized an influence of physical warmth on hedonic/sensory perceptions of the two beverages (Japanese tea and black coffee), but no significant effects were observed in Experiment 2b (black coffee). This might have been because of the small sample sizes in this study. Although we did not find any evidence for the effects of temperature on sensory/hedonic ratings of black coffee, this does not mean that the effects were non-existent. The directions of some of the sensory/hedonic attributes of black coffee were consistent with the hypothesis. For example, the mean freshness rating for black coffee was 3.50 at the cold temperature and 3.06 at the warm temperature. Previous research using relatively small sample sizes and a between-participants design did not find significant differences in sensory transference (Machiels, 2018). To detect possible small effects of physical warmth on sensory/hedonic ratings, further study is needed to replicate the current findings with larger sample sizes.

This study checked for the manipulation of physical warmth using subjective feelings of warmth. Although this procedure has been used previously with extrinsic temperature (Wortman et al., 2014; Zwebner et al., 2014; Motoki et al., 2018b, 2019b; Sinha and Bagchi, 2019), it remains unknown how manipulating warmth affects participants' actual physical temperature. Further studies should measure changes in participants' actual physical temperature after wearing a hot/cold pad.

An additional limitation was the possible mismatch between the measured temperature (temperature words) in Experiment 1 and the actual temperature (hot/cold pads) in Experiment 2. Participants in Experiment 1 may have perceived the temperature words to relate to a food item. Although previous research suggests a link between oral and physical experiences (e.g., Biggs et al., 2016), associations between food temperature and hedonic/sensory attributes might differ from those between physical temperature and hedonic/sensory attributes. This could explain the differences between the results of Experiments 1 and 2.

There were also limitations pertaining to the within-participants design. In Experiment 2, participants experienced hot and cold conditions and drank the same beverage. Thus, they may have been aware that temperature was a variable of interest in the study. Further studies should aim to replicate our findings using a between-participants design.

This study manipulated food-extrinsic temperature using physical sensation and a neck pad. However, ambient temperatures can be more easily manipulated by store managers than physical warmth. Ambient temperature influences food preferences (Zwebner et al., 2014; Motoki et al., 2018b). It remains unknown how ambient temperature influences expectations and experiences of food and drink and whether the effects of ambient temperature are similar to those of physical warmth. The interaction between ambient temperature and sample temperature might also have influenced the present results. The drinks were stored at room temperature, where warm (vs. cold) ambient temperatures might differentially influence hot and cold drinks. Warm (vs. cold) ambient temperatures might increase the preference for cold (vs. hot) drinks and accordingly influence ratings of taste attributes associated with pleasantness (e.g., tastiness, healthfulness). Ambient temperature may also have influenced the results of the word association task (Experiment 1). Further studies are needed to determine whether manipulating ambient temperature influences taste-temperature associations, as well as drinking expectations and experiences.

Individual differences in consumption patterns/preferences might also have affected the results. We did not investigate the participants' tea and coffee consumption patterns or preferences. Some of the participants might habitually drink hot (rather than room temperature) Japanese tea and black coffee. Additionally, personal preference for Japanese tea or black coffee may have influenced the results.

Cultural, demographic and individual factors should also be considered. Consuming (Japanese) green tea and non-hot coffee is considered normal in Japan. Thus, a similar study including participants from other cultures might yield different findings. Additionally, the age range of the participants was different between Experiments 1 and 2. The participants in Experiment 2 were all university students, and were younger than those in Experiment 1. Also, the proportion of male participants was higher in Experiment 2 than Experiment 1. These differences may have contributed to the different results between Experiments 1 and 2. Moreover, we did not collect smell or taste impairment data. Further studies should investigate the generalizability of our findings by manipulating cultural, demographic and individual factors.

CONCLUSION

This study investigated temperature–taste correspondence. The word *warm* (vs. *cool*) was matched more frequently with saltiness and positive attributes (tastiness, healthfulness, and buying intention). By contrast, the word *cool* (vs. *warm*) was matched more frequently with sourness and freshness. Further experiments showed that physical warmth (vs. coldness) increased healthfulness and buying intention of Japanese green tea, although no effects of physical warmth on sensory/hedonic perceptions were observed for black coffee. These findings provide evidence of taste–temperature correspondence and provide preliminary support for the influence of food-extrinsic warmth on taste attributes related to positivity.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of Tohoku University School of Medicine. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

KM: conceptualization, formal analysis, writing – original draft. KM and TS: data curation. KM and RN: funding acquisition. KM, TS, RN, and MS: investigation, methodology. MS: resources, supervision. TS, RN, and MS: writing – review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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A Dash of Virtual Milk: Altering Product Color in Virtual Reality Influences Flavor Perception of Cold-Brew Coffee

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It is well known that the appearance of food, particularly its color, can influence flavor perception and identification. However, food studies involving the manipulation of product color face inevitable limitations, from extrinsic flavors introduced by food coloring to the cost in development time and resources in order to produce different product variants. One solution lies in modern virtual reality (VR) technology, which has become increasingly accessible, sophisticated, and widespread over the past years. In the present study, we investigated whether making a coffee look milkier in a VR environment can alter its perceived flavor and liking. Thirty-two United Kingdom (UK) consumers were given four samples of black cold brew coffee at 4 and 8% sucrose concentration. They wore VR headsets throughout the study and viewed the same coffee in a virtual setting. The color of the beverage was manipulated in VR, such that participants saw either a dark brown or light brown liquid as they sipped the coffee. A full factorial design was used so that each participant tasted each sweetness x color combination, Participants reported sweetness, creaminess, and liking for each sample. Results revealed that beverage color as viewed in VR significantly influenced perceived creaminess, with the light brown coffee rated to be creamier than dark brown coffee. However, beverage color did not influence perceived sweetness or liking. The present study supports the role of VR as a means of conducting food perception studies, either to gain a better understanding of multisensory integration, or, from an industry perspective, to enable rapid product testing when it may be time-intensive or costly to produce the same range of products in the real-world. Furthermore, it opens potential future opportunities for VR to promote healthy eating behavior by manipulating the visual appearance of foods.

Keywords: virtual reality, augmented virtuality, mixed reality, coffee, food color, consumer perception

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INTRODUCTION

We eat with our eyes (Delwiche, 2012). Vision plays a fundamental role in the eating experience, as it evolved to facilitate foraging and feeding (Gehring, 2014; Spence et al., 2016). The visual appearance of food not only stimulates our appetite (Wang et al., 2004), but also influences our anticipated and actual eating pleasure (Hurling and Shepherd, 2003). Of all the visual aspects, the color of the food we eat has been especially studied in relation to flavor perception.

Color-Flavor Interaction

Crossmodal correspondences between color and flavor identification/perception have been well-documented in research (see Spence et al., 2010, and Spence, 2015 for reviews). Over the past 50 years, studies have shown that people consistently associate each of the basic tastes with specific colors; for instance, sweetness with red/pink, sourness with green/yellow, saltiness with blue/white, and bitterness with dark colors like black and deep blue (e.g., Favre and November, 1979; Spence, 2015; Woods and Spence, 2016). Such color–taste/flavor pairs are arguably the result of associative learning, when one learns to associate a specific color with a specific gustatory cue through repeated exposure. This would explain cross-cultural differences in color-taste/flavor pairings, for instance, light blue being associated with mint flavor for Taiwanese participants but raspberry for United States (US) participants (Shankar et al., 2010). Interestingly, new color-taste associations can be learned even with relatively brief exposure periods (e.g., four training sessions, Higgins and Hayes, 2019).

An extensive body of research has demonstrated how food color can drive perceptual changes in the tasting experience. On a basic level, increasing the color intensity of foods and drinks has led to higher taste/flavor intensity ratings (e.g., Johnson and Clydesdale, 1982; Norton and Johnson, 1987; Calvo et al., 2001). When it comes to specific tastes, red-colored drinks have been found to enhance sweetness detection (Johnson and Clydesdale, 1982), expectations (Wei et al., 2012), and perceived intensity (Pangborn, 1960; Clydesdale et al., 1992; Lavin and Lawless, 1998; Hidaka and Shimoda, 2014). Food color can also interfere with flavor identification, such as shown by Zampini and colleagues with lime- and orange-flavored beverages colored green or orange (Zampini et al., 2007). With a more complex beverage, Wang and colleagues have demonstrated recently that participants used rosé wine aroma and flavor terms to describe a white wine that had been dyed pink to match the color of an actual rosé wine (Wang and Spence, 2019).

More recently, human-computer interaction research has incorporated technology to alter the sensory input of given foods. For instance, Ranasinghe and colleagues created two such beverage delivery systems, the Virtual Lemonade and the Vocktail. The Virtual Lemonade uses colored LED lights to overlay a color on plain water, combined with electrically stimulated sour taste sensations on the user's tongue (Ranasinghe et al., 2017a). The Vocktail goes one step further, by combining colored lights and electrically induced tastes with scent delivery, to digitally alter the flavor of a given drink (Ranasinghe et al., 2017b).

The Use of Virtual Reality in Food-Related Research

Virtual Reality can be defined as a type of human-computer interaction where one interacts with a three-dimensional computer-generated environment presented *via* a stereoscopic head mounted display which tracks the location of the user's head (Crofton et al., 2019). Given the increasing popularity of VR, several studies have been conducted in the last decade to understand whether VR is suitable for use in food research.

The potential usefulness of this kind of research is supported by emerging evidence that the food-related decisions that people make in VR appear to replicate decisions that they make in the real-world. For example, Ung and colleagues exposed participants to both real-world and VR buffets, in order to investigate whether the nutritional value of foods selected by participants in VR paralleled the value of the foods that they selected in real-world contexts (Ung et al., 2018). There was a strong correlation between the nutritional values of food that participants served themselves in VR and real-world environments ($r \geq 0.75$). Similarly, participants exposed to both real-world and VR store environments made similar cereal product selection decisions in VR as in the physical environment (Siegrist et al., 2019). In the same vein, researchers placed parents in VR and real-world environments, in order to investigate whether the portions of a pasta-based meal that they chose for their children in VR were similar to the portions that they selected in the real-world (Persky et al., 2018). Results showed that there was a strong relationship between the portions that parents served in VR, and in the real-world. For example, a correlation of $r = 0.822$ was observed between the amount of real apple juice that a parent served and the amount of VR apple juice that they served. In terms of consumer testing, a comparison of beer tasted in a laboratory, in a real pub, or in a variety of immersive environments ranging from projection walls to VR headsets demonstrated that repeatability of hedonic scores for beer was better both in the real pub and in the immersive environments, compared to the central lab testing site (Sinesio et al., 2019). These findings suggest that the use of VR in food research is a useful and meaningful method as participants have been found to treat food the same way in both VR and the real-world. This is especially important given the increasing use of VR in food disorder therapy, either by altering participants' self-image or by introducing virtual food cues (see Clus et al., 2018, for a review).

Furthermore, a nascent body of literature examines how digitally introduced colors may influence taste perception. For example, Huang and colleagues examined how displaying different colors of tea (red or green) in VR influenced individuals' subsequent taste ratings of drinks in the real-world (Huang et al., 2019). Results of this study largely did not find any overall effect of color. However, the authors did suggest that there were some color-induced taste rating differences driven by individual color–food associations. More recently, Ammann et al. (2020) assessed whether changing the color of foods (two juices and a piece of cake) shown in VR influenced flavor identification. They demonstrated that seeing modified product colors in VR did in fact negatively impact flavor identification, and that flavor identification performance was not significantly different when participants did the study in VR vs. in real life, using food-coloring-modified products. Finally, even food-extrinsic changes in virtual environment have been shown to influence taste evaluations of different foods, such as a grenadine-based beverage tasting sweeter when consumed in a sweet-congruent environment compared to a bitter-congruent environment (Chen et al., 2020), or when cold brew coffee tastes sweeter when consumed in an environment with pleasant color and music, compared to one with unpleasant color and music (Nivedhan et al., 2020).

Color-induced gustatory effects have been found in studies using augmented reality (AR) technology. In contrast to VR, AR projects digital information (typically visual imagery) onto the physical world (Crofton et al., 2019), therefore plausibly providing a greater degree of realism in the entire eating scenario. For instance, Okajima and colleagues have constructed an AR "food changer" system to identify and modify the appearance of food *via* a sophisticated computer vision algorithm, either using a projector (Nishizawa et al., 2016) or a head-mounted display (Ueda and Okajima, 2019; Ueda et al., 2020). The findings of their experiments, which changed the color, saturation, and visual texture of various foods, found that there was a correlation between the color saturation and the rated sweetness in cake (Nishizawa et al., 2016); the mouthfeel, greasiness, and deliciousness of sashimi can be altered by its visual texture and color (Ueda and Okajima, 2019) and the moistness and deliciousness of sponge cake, as well as the watery taste in ketchup, can be altered by dynamically modifying the luminance distribution of the foods. However, the studies are limited by small sample sizes (four participants in the cake study, 12 participants in the sashimi study, and 13 participants each in the sponge cake and ketchup study).

In a demonstration of altering both color and smell, Narumi and colleagues created a MetaCookie+ system consisting of headset and aroma delivery system, which was able to track and alter the appearance and scent of a cookie in real time (Narumi et al., 2011). The researchers showed that, without changing the chemical composition of the food itself, 79% of participants experienced a change in the cookie taste using the pseudo-gustatory display. Going beyond taste perception, AR has also been shown to modify people's level of perceived satiety by altering the apparent size of the food consumed using real time-shape deformation (Narumi et al., 2012).

However, such custom AR technology requires a high level of technical expertise in computer vision, making it relatively infeasible in most sensory testing situations. In the current study, we created a simple yet convincing mixed-reality VR setup which allows for the simultaneous presentation of food stimulus in both virtual and physical reality.

Hypothesis Development and Contributions

To demonstrate how VR could be incorporated in flavor perception research, we decided to investigate a scenario which would be difficult to study in the real-world. Namely, we investigated the influence of visual appearance on the perceived flavor of black coffee. Since people have learned to associate a light brown color with milky coffee, we hypothesized that *a black coffee which appears to be light brown would be rated as tasting sweeter and creamier than one that appears dark brown*. If the hypothesis holds, then we could develop future applications where people can add "virtual creamer" to their coffee to cut down on calories while still maintaining the perception of creaminess. Moreover, this study is uniquely suited for VR because, in the real-world, it would be difficult[1] to make black coffee appear light brown without altering its taste.

From a theoretical perspective, this study is a proof of concept for using VR as a way to study the merging of virtual and actual sensory cues in the formation of our eating experience. Notably, unlike previous VR studies which separated virtual and real sensory cues (e.g., Huang et al., 2019, where participants first saw a color cue and then tasted the samples in a black screen), the present study enhances the realism of the situation by enabling the participants to simultaneously interact with the same object in both the physical and virtual environment. From an industrial perspective, this study demonstrates the possibility of performing rapid product testing with a consumer panel, in situations when it may be time-intensive or costly to produce products with the same range of visual features in the real-world.

MATERIALS AND METHODS

Participants

Thirty-two participants (5 women, 27 men) aged 18–38 years (M = 23.1, SD = 3.1) were recruited for the study from York St. John University. Participants were recruited at computer science labs on campus by word of mouth. The studies took place between 10 a.m and 6 p.m (13 participants took part before 1 p.m, 19 participants after 1 p.m). No further selection criteria were applied other than having normal senses of vision, smell, and taste. All participants gave their informed consent to take part in the study. The study was approved by the Research Ethics Committee of York St. John University.

Coffee Samples

Black cold brew coffee (Califa Farms) were used in the study. To test sweetness level as a possible moderator in color–taste influences, two sweetness levels were created with the addition of either 4% or 8% of sucrose by volume. The coffee was served in 30 ml samples.

Technical Setup

A room (4 m × 4 m × 2.3 m) with a table (0.9 m in diameter), mug, and straw was modeled in the Unity game engine (Unity Technologies) to mirror the physical setup in the experiment room (**Figure 1**). The color of the coffee was manipulated in VR such that it either appeared light brown or dark brown. A straw was placed in the mug so participants could consume the coffee while wearing the VR headset (HTC Vive Pro).

[1]Although high-concentration white food coloring apparently exists, which might make this scenario easier to test in the real world.

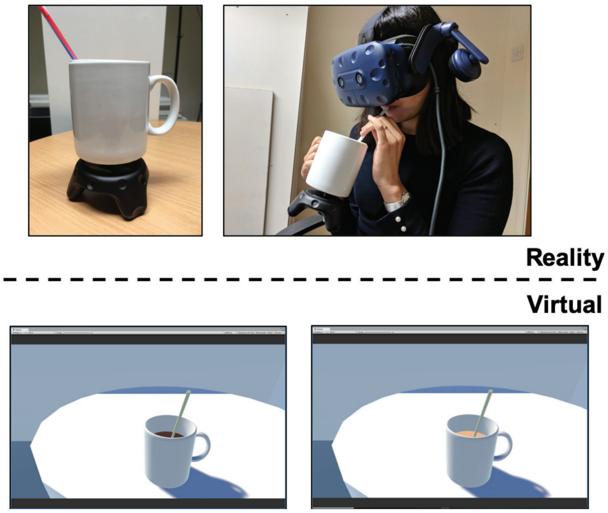

FIGURE 1 | Experiment setup. A virtual reality (VR) tracker (HTC Vive) was attached to the physical mug so that the movement of the mug would be aligned in VR and in real life. The bottom images demonstrate the two color conditions (light brown, and dark brown) of coffee appearance in VR.

In order to create a mixed-reality environment where the mug of coffee would move synchronously in VR and the physical world, a VR tracker (HTC Vive) was placed under the physical mug. This way, the movement of the mug was aligned such that when participants lifted the mug in the physical world, the mug also appeared lifted in VR. such that the mug could be tracked in the VR environment as well.

Procedure

A within-subject study with two virtually presented coffee colors (light brown, and dark brown) and two levels of sucrose in the physical coffee product (4, and 8%) was carried out. The study took place at a research laboratory at the Department of Computer Science at York St John University. Each participant was seated in front of a table. First, they read an information sheet and gave consent to partake in the study. Next, they rinsed their mouths with water and were instructed to wear the VR headset.

At the onset of each trial, the participant was instructed to pick up the mug from the table and take a sip from it. After tasting, participants were asked to orally evaluate their liking for the drink as well as its sweetness and creaminess on 1–9 scales (with 1 being not at all, and 9 being very much). These evaluations were reported verbally by the participants, and then recorded by the experimenter *via* a Qualtrics questionnaire. Participants then placed the mug back onto the table after giving their evaluation. In between trials, the experimenter switched out the coffee sample inside the mug. They also handed a cup of water to the participants, who rinsed their mouths with water between each trial. It should be stressed that participants wore the headset during the entire tasting session and never saw any of the actual coffee samples.

Each participant tasted all four color (light brown, and dark brown) and sweetness (4, and 8%) combinations. The order of conditions was counterbalanced across participants using a Latin Square Williams Design.

After tasting all four samples, participants removed their headsets and completed the rest of the Qualtrics questionnaire on a laptop. They answered questions regarding their VR experience (never used it before, < 1 h, 1–5 h, > 5 h), frequencies of drinking black coffee and of drinking milky coffee (daily, 4–6 times a week, 2–3 times a week, once a week, never), and preference for sweet and bitter foods (scale from 1 to 9).

Each experimental session lasted approximately 15 min and participants were debriefed afterwards.

Data Analysis

Data from all 32 participants were included in the analysis. After checking for data normality and multicollinearity between the measured variables (i.e., liking, sweetness, and creaminess), a repeated-measures multivariate analysis of variance (RM-MANOVA) was conducted with coffee color (light brown, and dark brown) and sugar level (4, and 8%) as within participant factors (SPSS, version 25). The model included liking, sweetness, and creaminess as measures. While our sample size is too small for in-depth demographic analyses, we reported summary statistics of the participants' VR familiarity, coffee drinking frequency, and preference for sweet and bitter tastes to communicate more information about the background of the participants.

RESULTS

To check for multicollinearity, Pearson's correlation coefficients were calculated between measures of sweetness, creaminess, and coffee liking. It revealed, as expected, that coffee liking is positively correlated with perceived sweetness ($r_{128} = 0.19$, $p = 0.034$) and with creaminess ($r_{128} = 0.26$, $p = 0.003$), and that sweetness and creaminess are positively correlated ($r_{128} = 0.35$, $p < 0.001$). To better understand the drivers of coffee liking, we found that creaminess is positively correlated with liking even controlling for sweetness ($r_{125} = 0.21$, $p = 0.019$), whereas sweetness is not correlated with liking after controlling for creaminess ($r_{125} = 0.11$, $p = 0.229$). Sweetness and creaminess are positively correlated after controlling for liking ($r_{125} = 0.32$, $p < 0.001$).

Participants' ratings for coffee samples in all conditions are shown in **Figure 2**. RM-MANOVA revealed a significant main effect of color [$F(3,29) = 3.13$, $p = 0.04$, *Wilks Lambda* = 0.76] and of sugar level [$F(3,29) = 55.01$, $p < 0.001$, *Wilks Lambda* = 0.15]. We did not observe a main interaction effect between color and sugar level [$F(3,29) = 1.35$, $p = 0.28$, *Wilks Lambda* = 0.88].

Univariate ANOVAs revealed a significant main effect of color on creaminess [$F(1,31) = 9.48$, $p = 0.004$, $\eta_p^2 = 0.23$], where the coffee was rated to taste 20% creamier when it appeared light brown compared to dark brown ($M_{dark} = 4.08$, $SE = 0.25$, $M_{light} = 4.88$, $SE = 0.19$, $p = 0.004$, *Hedges'* $g_{av} = 0.62$). Moreover, the color-induced change in creaminess was only

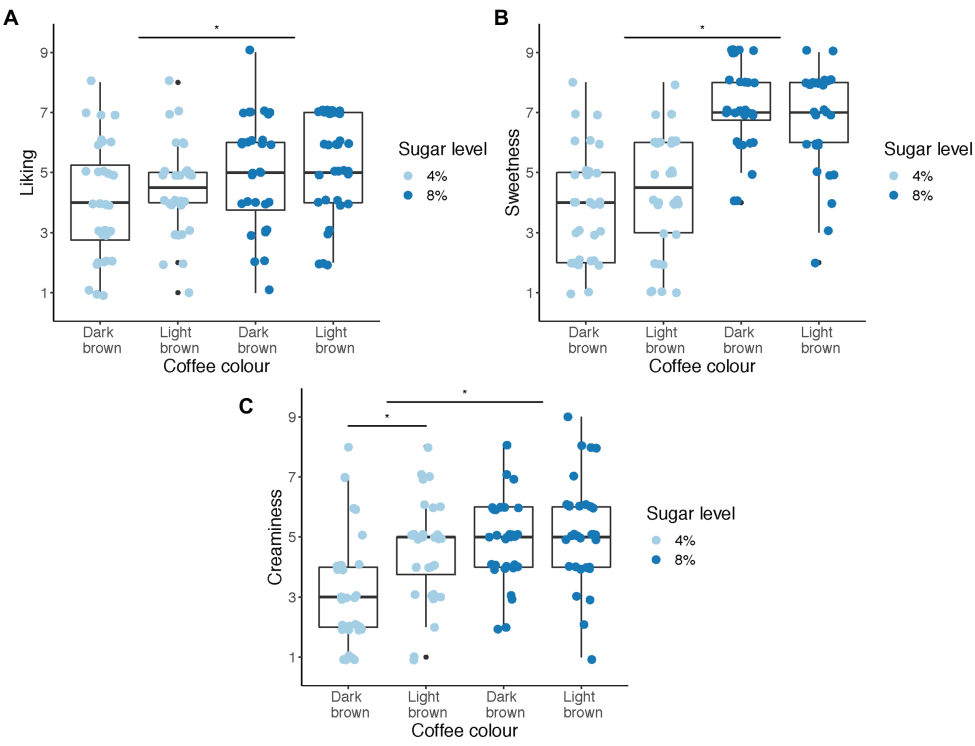

FIGURE 2 | Scatter and boxplots showing participant ratings of coffee liking **(A)**, sweetness **(B)**, and creaminess **(C)** under both VR color conditions (dark vs. light brown) and for both sugar levels (4% vs. 8%).

observed for the 4% sugar-added coffee (M_{dark} = 3.28, *SE* = 0.34, M_{light} = 4.88, *SE* = 0.24, p = 0.010, *Hedges' g*$_{av}$ = 0.87), and not for the 8% sugar-added coffee (M_{dark} = 4.56, *SE* = 0.29, M_{light} = 5.19, *SE* = 0.31, p = 0.348). In contrast, we did not observe an effect of color on liking [$F(1,31) = 1.08$, $p = 0.306$] or sweetness [$F(1,31) = 0.003$, $p = 0.958$].

In terms of sugar level, the 8% sugar-added coffee was liked more [$F(1,31) = 9.92$, $p = 0.004$, $\eta_p^2 = 0.24$] and rated as sweeter [$F(1,31) = 134.93$, $p < 0.001$, $\eta_p^2 = 0.81$] and creamier [$F(1,31) = 20.22$, $p < 0.001$, $\eta_p^2 = 0.40$] compared to the 4% sugar-added coffee.

An overview of the participants' background revealed very limited VR familiarity, with 19 out of 32 participants reporting they have never used VR before, six having used VR for less than an hour, four having between 1 and 5 h of experience, and three having over 5 h of experience. Black coffee drinking frequency was also very limited, with 27 out of 32 participants reporting never drinking coffee black, two reporting drinking black coffee once a week, one reporting 2–3 times a week, and two reporting daily consumption. Milky coffee drinking frequency was higher, with 14 out of 32 participants reporting never drinking milky coffee, five reporting drinking once a week, four reporting 2–3 times a week, three reporting 4–6 times a week, and six reporting daily consumption. In terms of food preference, preference for sweet foods (M = 6.66, SD = 1.70) was significantly higher than preference for bitter foods [M = 4.44, SD = 1.70, $t(31) = 4.48$, $p < 0.001$].

DISCUSSION

The results of the present study demonstrate that color cues from VR and gustatory cues from the real-world may be integrated to influence creaminess evaluation of black coffee, with coffee that appeared to be light brown rated as significantly creamier compared to coffee that appeared dark brown. This result is in line with previous evidence of color-gustatory bias (see Spence et al., 2010, for a review), but with the novelty of using VR to assess food stimuli that are otherwise difficult to set up physically.

Given the changes observed in creaminess when coffee color was changed in VR, the question naturally remains whether we might expect a similar degree of change if the color of the coffee were physically altered in real life. As mentioned in the introduction, there has been a body of studies demonstrating consistency between consumer ratings and behavioral tasks performed in real life vs. in VR (Persky et al., 2018; Ung et al., 2018; Siegrist et al., 2019; Sinesio et al., 2019; Ammann et al., 2020). Therefore, we have some confidence that our findings in VR would translate to a real-world experience. Moreover, it might be possible to validate our findings in real life in the future, by either making light brown coffee appear darker with food coloring, or, using high-concentration white food coloring (unbeknownst to the authors at the time of conducting the research originally) to lighten black coffee. Granted, both methods would require extensive pre-testing to ensure that no additional flavors or textures are introduced by the food coloring. That said, we can compare our current findings with previous studies showing the effect of beverage color on rated taste intensities in sucrose solutions or in fruit beverages (e.g., Johnson and Clydesdale, 1982; Clydesdale et al., 1992; Lavin and Lawless, 1998; NDom et al., 2011). Moreover, in terms of coffee-specific results, while we are not aware of any studies manipulating coffee color (without changing its components), there is evidence demonstrating that changing the color of the coffee cup can influence the taste of the coffee (Van Doorn et al., 2014; Carvalho and Spence, 2019). As seen in **Table 1**, our effect size (*Hedges' g_{av}* = 0.62) is roughly in line with the range of effect sizes observed in previous studies involving the manipulation of color, although we should qualify that this is only a very approximate comparison, since none of the color-bias studies analyzed have measured mouthfeel.

Furthermore, it is important to note that the color-induced change in creaminess evaluation was only observed for 4% sugar coffee and not for the 8% sugar coffee. There are several plausible reasons for why we did not observe any color-induced changes in creaminess in the 8% sugar coffee. Since sweetness and creaminess were highly correlated, it is possible that participants could have experienced a ceiling effect where the 8% coffee was rated as creamy even in the dark-brown VR condition. This is especially plausible since higher sugar level could increase perceived creaminess by increasing the viscosity of the coffee (Frøst and Janhøj, 2007; Wagoner et al., 2019). Alternatively, there might have been a contrast effect, whereby the 8% sugar coffee did not match consumer expectations in the dark brown VR condition, and disconfirmation of expectations resulted in a higher creaminess rating in the dark brown condition than participants would have otherwise given (Piqueras-Fiszman and Spence, 2015). Regardless, the fact that color-creaminess effects are dependent on the product itself demonstrates that participants' creaminess ratings were driven by more than just color cues.

Moreover, while we observed a color-induced change in creaminess, altering coffee color in VR did not significantly alter perceived sweetness or liking. This is possibly because, in everyday life, coffee that appears light brown, i.e., milky coffee, is not necessarily also sweetened. Therefore, participants had no reason to associate a lighter brown color with sweetness whereas milky coffee is more clearly associated with creaminess. Furthermore, as we did not apply strict selection criteria commonly used in sensory studies (e.g., asking participants to fast or avoid eating strongly flavored foods 2 h before the study), it is possible that we could have obtained more precise results had these stricter guidelines been followed.

From a methodological view, the experimental procedure outlined here can be easily applied in psychological research as well as market research and new food research and development. Through the use of a commercially available HTC Vive tracker, we were able to create a heightened sense of reality in VR by enabling participants to simultaneously see the food in VR while touching and tasting it physically. This goes one step beyond previous research in VR eating experiences, which either do not include a model of food in VR (e.g., Sinesio et al., 2019), or if they do, only provide a static model of the food that does not track the motion of the physical food in the real-world (e.g., Huang et al., 2019). Our research also extends previous AR experiences, because our relatively simple technological setup is easily accessible [compared to the deep learning visual learning algorithms used in Ueda and Okajima (2019)] and offers a range of motion [compared to limited to the space of the projective systems as in Nishizawa et al. (2016)]. Furthermore, the strength of our system lies in using real foods in a mixed reality setup, since the digitalization of chemical input, such as shown by The Virtual Lemonade or Vocktail (Ranasinghe et al., 2017a,b) is still far from convincing (see Spence et al., 2017, for a review). To summarize, in terms of psychological research, we can use this system to study multisensory integration by presenting tailored combinations of digitally introduced audiovisual information and physically introduced chemosensory information. From an industry perspective, this VR system would enable the rapid testing of product and packaging visual appearances, without having to produce the same range of visual features in the real-world. Furthermore, we can use the VR system to evaluate the relative influences of product, packaging, and environmental features on consumer food perception, preference, and eating behavior.

Nevertheless, we should point out that the study has several limitations. One obvious limitation is the relatively small sample

TABLE 1 | Effect size analyses of previous studies demonstrating the effect of color (either food-intrinsic or extrinsic) on taste perception.

Study	Design	N	IV	Food-intrinsic or extrinsic color	DV	Effect size
Present study	Within-subjects	32	Coffee color (light or dark brown)	Intrinsic	Creaminess	Hedges' g_{av} = 0.62
Carvalho and Spence (2019), study 1	Between-subjects	82	Cup color (white or pink)	Extrinsic	Sweetness	Hedges' g_s = 1.17
Carvalho and Spence (2019), study 1	Between-subjects	82	Cup color (white or pink)	Extrinsic	Acidity	Hedges' g_s = 1.27
Lavin and Lawless (1998) study 1	Within-subjects	74	Fruit beverage color (light or dark red)	Intrinsic	Sweetness	Hedges' g_{av} = 0.30
Lavin and Lawless (1998) study 1	Within-subjects	74	Fruit beverage color (light or dark green)	Intrinsic	Sweetness	Hedges' g_{av} = 0.22
NDom et al. (2011)	Between-subjects	24	Fruit beverage color	Intrinsic	Taste	Hedges' g_s = 0.83

In order to compare between effect sizes of between and within subjects studies, we calculated Hedges' g_s (between-subjects design) and Hedges' g_{av} (within-subjects design), as recommended by Lakens (2013). We could only calculate effect size for those studies where either t-values or the combination of means and standard deviation/error were reported.

size tested (N = 32), although this is in line with previous VR and color studies [N = 50 per cell (study 1) and N = 25 per cell (study 2) in Ammann et al. (2020); N = 41 in Chen et al. (2020)]. Another demographic issue is the admittedly uneven gender distribution of mostly men, due to the fact that we collected a convenience sample from computer science courses. Therefore, it is unclear to what extent our findings on coffee color and creaminess can be generalizable to the wider population.

Furthermore, a limitation of the current study is that we only recorded the participants' subjective coffee evaluations, which could have been influenced by response bias and demand effects. That said, the fact that we observed different color-creaminess effects with different sugar levels suggests an expectations effect (Piqueras-Fiszman and Spence, 2015) where color cues only played a role when the coffee was not already perceived as creamy due to its high sugar content. In the future, VR-food studies can be improved by collecting behavioral data, such as discrimination testing or drinking speed/quantity, to get a better understanding of color-induced perceptual effects. Another idea is to simultaneously collect biometric data such as electrodermal conductance, heart rate, or electroencephalography (EEG) to better understand the participants' emotional experience while simultaneously interacting with food in the virtual and physical world.

Thinking more broadly, a variety of research projects already use VR to create facsimiles of infeasible or impossible situations, often for therapeutic purposes, in order to better understand how people react to these situations. For instance, VR in widely used in the treatment of eating disorders in the form of exposure therapy (see Clus et al., 2018, for a review), by presenting virtual food stimuli or by altering the patients' own body image. Our novel methodology of simultaneously presenting both digital and physical food cues therefore introduces a way for researchers to combine audiovisual information coming from digital sources with chemical information coming from the food itself in the physical world. In other words, this combination makes it possible for participants to see one thing while eating another, all the while believing they are eating what they are seeing. Some future applications of this technology could be to enable multisensory eating scenarios whereby participants could reduce their sugar/salt/fat intake with "virtual seasoning" (see Wang et al., 2019, for some ways to enhance sweetness without adding sugar), or learn to familiarize themselves with new foods. For example, VR may be a way to introduce more vegetables for children by changing the visual appearance to be more similar to those of more acceptable foods, such as suggested by Petit et al. (2019) for baby carrots to appear like French fries. Of course, any such research is predicated on first acquiring an understanding of whether longer term use of this VR method would lead to sustained changes in food-based perceptions, and how best to transition from experiencing foods with VR into lasting "real-world" food preferences and behaviors. Nevertheless, in the context of the increasing popularization and accessibility of VR technology, this research could therefore be a first step towards using VR in combination with eating scenarios to encourage healthier eating behavior and more sustainable food choices in the general population.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://osf.io/etu59/.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Research Ethics Committee of York St John University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

QW: Conceptualization, methodology, formal analysis, visualization, and writing – original draft preparation. RM and SW: Investigation, writing – review, and editing. DZ: Conceptualization, methodology, software, writing – review, and editing. All authors contributed to the article and approved the submitted version.

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What's the Story With Blue Steak? On the Unexpected Popularity of Blue Foods

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Is blue food desirable or disgusting? The answer, it would seem, is both, but it really depends on the food in which the color happens to be present. It turns out that the oft-cited aversive response to blue meat may not even have been scientifically validated, despite the fact that blue food coloring is often added to discombobulate diners. In the case of drinks, however, there has been a recent growth of successful new blue product launches in everything from beer to tea, and from wine to gin, arguing that coloring food products blue is more than simply a contemporary fad. In fact, the current interest in blue food coloring builds on the color's earlier appearance in everything from blue curacao to blue-raspberry candyfloss (cotton candy), and thereafter a number of soft drinks. Over the years, the combination of blue coloring with raspberry flavoring has also appeared in everything from bubble-gum to patriotic pop rocks (popping candy in The United States). Ultimately, it is the rarity of naturally-blue foods that is likely what makes this color so special. As such, blue food coloring can both work effectively to attract the visual attention of the shopper while, at the same time, being linked to a range of different flavors (since this is one of the few color-flavor mappings that are essentially arbitrary) depending on the food format in which it happens to appear. Note also that the basic descriptor "blue" covers a wide range of hues having a range of different associations, hence eliciting different reactions (be they positive or negative). While blue was once associated with artificiality, a growing number of natural blue food colorings have come onto the market in recent years thus perhaps changing the dominant associations that many consumers may have with this most unusual of food colors.

Keywords: blue, food coloring, digital consumption, multisensory flavor perception, gastroporn

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INTRODUCTION

There is a famous anecdote about an experiment once conducted on a group of unsuspecting diners who were served a meal of steak, chips, and peas under dim illumination. Partway through the meal, the lighting was returned to normal levels of illumination, revealing to the guests that the steak they were eating was, in fact, blue, the chips green, and the peas red. Revolted by the realization, a number of the guests were apparently immediately sick. After reading about this story as a young researcher (one who was becoming increasingly interested in the impact of food coloring on the perception of consumers), I was very pleased eventually to track down what I believed to be the original citation for this anecdote, namely an article written by Wheatley (1973). First published in the trade publication *Marketing*, the article was subsequently republished 2 years thereafter in the fragrance industry newsletter, *Dragoco Report*, published by a German perfume manufacturer (Wheatley, 1975).

In recent years, my colleagues and I, as well as many other researchers have more or less accurately reported on this study as if the events described by Wheatley had actually taken place (e.g., see Thesen et al., 2004; Zampini and Spence, 2012, p. 740; Spence and Piqueras-Fiszman, 2014; Spence, 2017a; Bruno and Pavani, 2018; p. 89). The story also appears elsewhere in the academic press on food coloring (e.g., Kostyla and Clydesdale, 1978, p. 303; Cardello, 1994, p. 267, 269; Kennedy et al., 2005; Kappes et al., 2006, p. S590; see also Blackman and Kvaska, 2011)[1], as well as having been widely covered in the popular press. For example, Eric Schlosser, best-selling author of *Fast Food Nation* (Schlosser, 2001a), did much to popularize the blue steak story, devoting three sentences to the "experiment," in an article that appeared in *The Atlantic* (Schlosser, 2001b). Meanwhile, other mentions in the popular press that I have come across include: Fleming (2013), Poon (2014), Wollan (2016, p. 72), Nobel (2017), and Jahnke (2018).

But what if the events described by Wheatley (1973) never actually took place? This the discomforting suggestion that has recently been raised in an intriguing article by Joel Harold Tannenbaum, writing in *Gastronomica* (Tannenbaum, 2020). In a careful historical piece of gastronomic detective work, Tannenbaum has uncovered some facts about Wheatley that suggests it is unlikely that she was the one conducted the original blue steak experiment, if experiment is even the right name for what might more rightly be called an anecdote; An anecdote, moreover, that on subsequent retelling, has taken on something of the standing of an "urban myth" (see Tannenbaum, 2020). We will return later to the question of why this story, in particular, should have resonated down through the following decades.

Given the almost half century that has passed since Wheatley's (1973) article first appeared in print, it is hard to know, in hindsight, whether it refers to an actual event/experiment, and if so, it was one that was witnessed/conducted by Wheatley herself, or whether instead she is merely retelling a story heard elsewhere. Wheatley writes that: *"All perception of color is relative in two main ways. It is relative to memory and experience and it is relative to context. An experiment was carried out to illustrate the first of these two facts. Several people were collected round a table in a special form of lighting which showed the food on the plates in front of them but not its color. After they had consumed some of the meal normal lighting was resumed and the subjects found that the steak was blue, the peas red and the chips green. Almost all were violently sick."* Wheatley continues: *"There was no pause for rationalization, the brain instinctively told the body to reject such 'unnatural' food, yet it is very likely that the reaction of young children to the same experiment would be far less extreme. They would not have had time to build up the very strong color associations of adults."* (Wheatley, 1973, p. 26, 28).

Tannenbaum (2020), in his commentary, helpfully provides a little background—Jane Wheatley (a "she" often referred to as a "he" —including by myself *mea culpa*) was apparently an editorial writer at the magazine in which the article first appeared. What is more, the text itself does not provide any statistics (nor sample size, etc.), and given her background and future career path (as a successful editor), it would seem unlikely that Wheatley herself conducted the blue steak experiment that she so famously reports. Rather, she would appear simply to have been recounting a story that she had heard, or read about, elsewhere. The main focus of Wheatley's article is to highlight the various ways in which packaging color can be used by marketers. That being said, the article also uncritically recounts the suggestion from Max Lüscher, a Professor of Psychology from Basle University (Lüscher, 1969), that homosexuals adjust their TV sets to give a magenta cast or tint! This suggestion apparently being reprinted in a British Bureau of Television Advertising booklet – *The physiology and psychology of color* (Townsend, 1969; see Wheatley, 1973, p. 28, 67).

Whether or not the blue steak story provides an accurate representation of people's response to blue meat, the more important question here concerns the consumer's relationship with blue foods more generally? Is blue a desirable or disgusting color in food? It is worth noting that there have been several hundred published studies of the impact of food color in the years since Moir's (1936) first scientific publication on the topic (see Spence et al., 2010; Spence, 2015b, for reviews)[2]. While not all have demonstrated an impact of food color on people's sensory-discriminative or hedonic responses, there are now sufficient rigorous peer-reviewed studies out there to show that coloring a food or, more frequently, a beverage (given that it is simply easier to do the latter), can result in changes in the perceived identity and/or intensity of taste/flavor (see also Vanderbilt, 2015). Changing the color of a food can also have an impact on people's hedonic responses as well. Chylinski et al. (2015) have even provided evidence to support the view that blue coloring is more associated with a crunchy (rather than creamy) texture as compared to red in a creamy yogurt with almond bits (though see Christensen, 1983). As such, there can be little doubting that the color of food affects us. What is, though, special about the blue steak story is the almost visceral aversive response that can apparently be elicited be an "off-colour" in animal protein[3].

Here, it is important to distinguish between the role that is played by color in setting our taste/flavor expectations on the one hand, and separately (though undoubtedly connected) the effect that coloring foods has on our taste/flavor perception (see Piqueras-Fiszman and Spence, 2015; Spence, 2015b, 2019b). The assumption underpinning much of the contemporary research on color-related taste and flavor expectations is that they influence, and hence modify, the experienced taste/flavor of food

[1]Wheatley's name seemingly gets more different spellings than Shakespeare: She becomes "Weathley" in Bruno and Pavani (2018, p. 153), and "Wheately" in Thesen et al. (2004), Kappes et al. (2006), and Schlintl and Schienle (2020).

[2]Moir (1936) reported how easily his/her colleagues were fooled by the miscolouring of table jellies and other cakes and confections by mixing-up the typically-occurring colours (e.g., colouring orange or lemon jelly green, and pineapple or apricot jelly red).

[3]The question of off-colour in plant-based imitation meat products has recently come to the fore. According to Tim Geistlinger, vice president of research and development at *Beyond Meat*, one of the leading companies now making plant-based protein products, consumers are not ready for chlorophyll-tinged hamburgers. He was quoted as saying: *"There's no meat that's green unless it's going bad."* (Vanderbilt, 2015). A British Pathé newsreel from 1959 apparently confirms the displeasing impact that green meat has (see also Tysoe, 1985, p. 13, Tannenbaum, 2020).

and drink should the latter be given that color. However, it should be acknowledged that there may be some rare situations in which the experience on sampling a colored food is not always determined simply by the expectations that are associated with that color. One such situation might be when we have reason to doubt whether the color is real (e.g., as in the case of augmented reality and virtual reality tasting experiences; see Ueda et al., 2020; Wang et al., 2020a; Xu et al., 2021).

Given the replication crisis that has been convulsing the psychological sciences in recent years it is certainly worth carefully questioning many of the more newsworthy findings that are taken as fact in the world of pop psychology (see Della Sala, 1999). After all, a dispiriting number of social psychology findings have been questioned in recent years (Resnick, 2016). What is more, the world of food psychology has also had its own dodgy data scandal to deal with, leading to the retraction of many of the articles by former leading food research Brian Wansink (see Resnick and Belluz, 2018; Lee, 2019). And that is before we get to the various oft-cited examples of marketing interventions that famously never actually happened. For instance, just take James Vicary's claim to have induced a cinema audience to drink more Coke and buy more popcorn (by 18 and 58%, respectively) simply by subliminally flashing up the words "COCA-COLA" and "EAT POPCORN" at the start of a cinema feature. It subsequently turned out that Vicary had made the entire story up (Karremans et al., 2006; Samuel, 2010, Chapter 3)!

On the Origins of the Blue Steak Story

Oftentimes, those interested in understanding where a particular factoid or anecdote came from create citation trees to help trace back the development of the idea (e.g., Sivak, 1996; Spence, 2015a). Unfortunately, however, the citation tree in the case of the blue steak experiment stops squarely with Wheatley (1973), since neither of the references that are mentioned in her article (namely Lüscher, 1969; Townsend, 1969) mention the blue steak experiment. In fact, the likely source of her story has recently been traced back to Cheskin's (1951) book *Colors, and what they can do* first published in 1951[4]. There, Cheskin, a famous marketer in the middle decades of the twentieth century (Samuel, 2010) describes a meal with a group of people that matches pretty-closely to Wheatley's account. The same story, note, also appearing in several of Cheskin's subsequent books (e.g., see Cheskin, 1957, 1967, 1972). Given the popularity, and widespread dissemination, of Cheskin's writings (Samuel, 2010), and the similarity to Wheatley's description, this would seem to be the most plausible source for the latter's description.

Writing half a century ago, Watson (1971, p. 66–67) argued that: "*We have a deep-seated dislike of blue foods. Take a trip through a supermarket and see how many blue ones you can find. They are rare in nature and equally rare in our artificial hunting grounds. No sweet manufacturer ever successfully marketed a blue confection, and no blue soft drink or ice cream appeared on sale for very long.*" Watson was presumably not much of a fan of fairground treats, otherwise he would presumably have been familiar with the popular blue-raspberry (and pink-vanilla) cotton candy that had been a common feature of the fairground since at least the early 1950s, and possibly before (see Swarns, 2014). Once again, in this case, Watson also fails to provide any empirical support for his claim. He may well simply have been parroting Cheskin's general line on the unpalatability of blue foods.

In another anecdote about blue food, this time reported by Tysoe (1985, p. 13): *"Blue food, for instance, is regarded as bizarre and unnatural. Color experts Tom Porter and Byron Mikellides, of Oxford Polytechnic's department of architecture, report that "a group of young children taking part in a test with dyed vegetables became decidedly ill after eating harmless, blue-colored potatoes.""* However, whether or not the experiment described by Wheatley (1973) actually took place, and whether or not we choose to describe it as an "experiment," anecdote, or merely an urban myth, the more fundamental question is whether the general claim that coloring food blue is off-putting is correct or not.

Blue Food: Desirable or Disgusting?

There is, however, no simple answer to the latter question. This is because there is no unique meaning associated with color in food (and blue is presumably no exception in this regard). It really is all a matter of the form or substrate in which that food coloring appears. One can, I suppose, think of this as a version of Elliot's "color-in-context theory" (e.g., Elliott, 2019; see also Fechner's Aesthetic Association Principle from 1866, and recently translated into English by Ortlieb et al., 2020). Consider here only how redness in some fruits – think strawberries is associated with sweetness, whereas in the chile fruit it may be associated (rightly or wrongly) with spiciness instead (see Spence, 2018a)[5]. In both cases, redness is associated with ripeness (see Foroni et al., 2016), but how that ripeness expresses itself (as spicy or sweet) differs markedly between fruits.

Of course, as well as any literal crossmodal associations between colors and flavors (presumably based on associative learning) which may guide our flavor expectations, it is also worth noting that the visual appearance of food can take on a more symbolic meaning. This is perhaps especially clear in the case of the achromatic colors white and black, linked to purity/cleanliness and mourning, respectively (e.g., see Huysmans, 1884/1926; Weineck, 2006; Carter, 2011; Harris, 2011; Spence and Piqueras-Fiszman, 2014; Piepenbring, 2016; Spence, 2018d, 2020a; Strand, 2020). Furthermore, there is also a growing literature on the existence of more abstract crossmodal correspondences between color patches, or combinations of colors, and basic tastes and aromas (e.g., see Wan et al., 2014b; Spence et al., 2015; Woods and Spence, 2016; Woods et al., 2016; Spence, 2020b). In the case of abstract colors, it is not always altogether clear whether they are associated with tastes and flavors because of the colors of the source foods themselves, the packaging, brand color (think Coca-Cola red)[6],

[4]I am indebted to Willa Paskin for tracking this down for an episode of *Slate*.

[5]According to Carter (2011): *"Red: to hunter-gatherers, red could denote both ripe fruit and poisonous berries. Today, it's a colour often used to signify sweetness."*

[6]In terms of packaging, there is also the distinctive blue of Pepsi (Cooper, 1996), and KP Nuts, not to mention the blue sachets that were once included in bags of crisps (Wan et al., 2014b).

or may have a more emotional (see Spence, 2019b), or symbolic connotation instead.

Was Blue Always an Unappealing Food Color?

Blue can undoubtedly set expectations regarding the likely taste, but does this color actually impact consumption/elicit an aversive response? F. T. Marinetti famously colored white wine blue, orange juice red, and milk green in the early decades of the twentieth century (Marinetti, 1932/2014; see also Anonymous, n.d.). While the motivation remains rather opaque, given the Futurists' general mindset, one might assume that the idea was to discombobulate people simply by miscoloring drinks rather than any specific association with blue. Meanwhile, according to Tannenbaum (2020, p. 32): *"During World War II, the American horror novelist Shirley Jackson served meals consisting of blue steaks and red potatoes to baffled dinner guests at her home in Bennington, Vermont (Oppenheimer, 1988 : 108)."* Blue mashed potatoes may also have been served to children in the UK (as part of patriotic red, white, and blue dishes, mirroring the colors in the flag) to celebrate the end of the Second World War (though, thus far, I have been unable to track down any documentation to back up this particular claim). Britain's first celebrity chef, Fanny Cradock, was also fond of presenting her mashed potatoes in vivid colors such as purple and blue on her TV shows from the 1950s onwards (Ellis, 2007). Not everyone was a fan, though. Chris McManus of Bedford College, London is quoted in Tysoe (1985, p. 13) as saying: *"What we like for mashed potatoes is very different from what we like for clothes to wear. What would you make of green mashed potatoes or green meat? It means it's off."*

There have also been a number of documented (albeit anecdotal) examples of famous individuals intentionally coloring foods blue so as to deliberately disconcert their dinner guests (e.g., Hitchcock and Gottlieb, 2003). For instance, Hitchcock reported how he used to use blue food dye to taint the food when hosting dinners at London's Trocadero back in the 1960s. As the famous director put it: *"And all the food I had made up was blue! Even when you broke your roll. It looked like a brown roll but when you broke it open it was blue. Blue soup, thick blue soup. Blue trout. Blue chicken. Blue ice cream."* (Hitchcock and Gottlieb, 2003, p. 76). And in 1964, Hitchcock invited Cary Grant, his wife Dyan Cannon, and some other guests to his Bel Air home for a Christmas party. The evening started with Windex-blue martinis. Cannon (2011) writes:

> "Two butlers brought large, covered plates to the table. Hitch gave them a nod, and they removed the covers to reveal slabs of prime rib. The beer smelled wonderful, but it looked awful. It was blue. Bright, turquoise blue. Then along came the side dishes: blue broccoli, blue potatoes, blue rolls 'Do you think it's safe to eat?' I whispered to Cary. 'The color may be off-putting, but I'm sure it's perfectly fine,' Cary said sanguinely. He was wrong. By the time the night was over, the two of us had worn a groove in the carpet between the bed and the bathroom."

I certainly know from my own experience how unappealing blue foods can be, after having been one of the guests at a particularly memorable conference dinner (and how often does one say that?) at the *Art and the Senses* meeting held here in Oxford in August, 2006. We were served a blue soup accompanied by the sound of Miles Davies Blue (Spence et al., 2011, p. 208). A few years later, together with top Spanish chef Maria Jose San Román, we served pizza smothered in blue tomato sauce to members of the audience at a Spanish gastronomy conference that was about as popular as one might expect – i.e., not at all (see San Román and Spence, 2009). However, beyond these anecdotal examples, what do the scientific studies of the consequences of miscoloring foods blue show?

In one early study, Christensen (1983) presented participants ($N = 29$) with a soy analog bacon strip, an American-style cheese, as well as three other foods (margarine, orange juice, and gelatine), that they had to rate in terms of flavor intensity/quality, aroma intensity/quality, and texture. The normally-colored bacon was perceived as having a more intense flavor than when abnormally colored bright blue instead. There was, however, no impact of blue food coloring on aroma intensity for either the bacon or cheese. That said, cooking and browning the bacon apparently reduced the color difference substantially. In a conference poster, Sakai (2011) has also reported the lowering in appetizing ratings of sushi that was colored blue, something that I have also seen with my own eyes in a demonstration that I was involved in for a TV show in 2013 (see Nobel, 2017).

A more recent Japanese study reported that coloring a soup blue was unappealing to female participants (Suzuki et al., 2017). In particular, it was shown to lead to decreased ratings of palatability and appetite when compared to a normally-colored white or yellow soup. Meanwhile, Schlintl and Schienle (2020) recently published a study in which female participants were presented with images of an array of sweet foods, including chocolate-chip cookies, cupcakes, and cream cake displayed in either their normal color or else digitally colored blue, red, or black and white. Half of the participants were informed that red color in food was supposed to increase appetite, while blue color in food was supposed to suppress it. Both groups of participants then viewed the food images in the different colors and rated how much they would like to eat the food. Those foods that were colored blue (but also those that were colored red) were rated as less appealing than the original food images. However, there was no significant effect of the placebo manipulation in this study. The examples cited thus far should be sufficient to make clear that blue is sometimes an off-putting color in food however, it need not be. It really depends on the food format in which it appears, as we will see below.

It is perhaps also worth noting how all of the anecdotes and studies reviewed in this section, involved participants who saw the blue food coloring prior to their consuming/evaluating the foods concerned. By contrast, one unique feature of the blue steak story is how the true color of the food was only revealed part-way through the meal (Wheatley, 1973). I am unaware of any researchers having repeated this temporal manipulation specifically with blue foods, though related research suggests that relevant information/experimental manipulations that happen to be presented after (as opposed to before, or concurrently) with a tasting experience generally tend to have less of an impact on taste/flavor perception (e.g., Lee et al., 2006; Shankar M. et al., 2010; Wang et al., 2020b).

Where Did the Blue-Raspberry Association Originate?

Raspberry-flavored blue candyfloss (cotton candy) has been a feature of the fairground for a number of decades (e.g., Spence et al., 2020). According to Park (2016), in 1958:

> "The same year that the Food Additives Amendment became law, an April 7 article in a periodical called The Billboard: Outdoor Amusement Directory mentions a 'new blue-raspberry flavor for snow cones' promoted by a Cincinnati company called Gold Medal, which to this day sells shaved-ice Sno-Kones and popcorn machines for concession stands and snack vendors. In addition, Gold Medal was going 'all out in pushing two new flavors for the floss (cotton candy) operator, grape-purple and blue-raspberry.'
> In either 1970 or 1971, the blue raspberry ICEE took its place alongside red cherry as a signature flavor of the brand. It had an artificial raspberry flavor but was colored by FD&C Blue No. 1."

Hence, the blue-raspberry association would first appear to have been introduced into the marketplace in the format of candyfloss (cotton candy) at the fairground (Park, 2016; Rupp, 2016). Thereafter, the crossmodal association was likely reinforced in the minds of consumers by the widespread introduction of soft drinks such as Icee Slush Puppie, Kool-Aid, blue Jolly Rancher raspberry-flavored drink, and thereafter, the Gatorade energy drink (see **Figure 1**). The combination of blue coloring with raspberry flavoring also appears in Hubba Bubba gum and patriotic pop rocks (popping candy) in The United States (Greenspan, 2009; Furdyk, 2020), though pop rocks were only introduced to the marketplace in 1974. Blue tomato ketchup (along with purple and green varieties) also made an appearance in the early 2000s (see Vanderbilt, 2015).

On the Meaning of Blue in Transparent Drinks

Research conducted by my students and I a little over a decade ago, suggested that there were salient cross-cultural differences in the flavor expectations elicited by blue drinks (Shankar M. U. et al., 2010). Two groups of young adult participants, one from the UK and the other from Taiwan, were shown pictures of the same clear blue drink along with drinks of five other colors (see **Figure 2**). The participants were asked what flavor they expected the drinks to have. The results revealed that while the majority of the British participants expected the blue drink to taste of raspberry, the majority of the Taiwanese participants expected that it would taste of mint instead. The latter association presumably being with blue-colored mouthwash (see Parise and Spence, 2012).

Here, though, it is important to note that the interpretation of color in beverages can also be influenced by the context, specifically the glassware or drinking vessel in which it is shown. Indeed, the mint mouthwash interpretation (association) may have been primed in the Taiwanese participants in Shankar M. et al.'s (2010) study by the fact that the drinks were shown in the kind of plastic cups that one often comes across in hotel bathrooms. In our subsequent research, we have been able to demonstrate that these color-flavor expectations are modulated by the type of glass in which a drink happens to be displayed (see Wan et al., 2014a, 2015, 2016) (see **Figure 3**).

In 2015, as one of the experiments conducted at The Science Museum in London, and also online as part of their "Cravings" exhibition more than 5,000 people from around the world were, once again, shown drinks of six different colors and asked to pick which looked the sweetest (Velasco et al., 2016). In this case, the results revealed that the red drink garnered 41% of the votes followed, in second place, by blue (28%), and purple in third place (18%). Here, it is perhaps interesting to consider whether people expected the blue drink to be sweet because that is the gustatory association that they have with blue, or rather because the color blue is associated with raspberry flavor, and it is the latter that is considered sweet.

On the Early Use of Blue

However, going further back in time, the first commercial blue-colored food product was probably curacao (a drink, note that also comes in orange, green, amber, and clear). The product from the Dutch island of the same name was first made in 1896, achieved international recognition when a Dutch company Bols made a blue-colored version of curacao that became internationally recognized, as the color behind many a kitsch cocktail (Martineau, 2010). According to one online source: *"Bols says they can't prove they invented the blue version, but they did start making it somewhere between 1920 and 1933."* (Senior and Co, n.d.). According to the latter website, the color of the drink may just have been inspired by the azure color of the waters and sky surrounding this Caribbean island. Hence, in this case, the color association is, in some sense, symbolic, rather than based on a specific colored-flavored source object. The distinctive orange taste of this clear blue alcoholic drink is due to the Laraha oranges that are used to make it.

Over the last few years, various other alcoholic drinks have also been launched into the marketplace, including *Blumond*, a blue sparkling wine made from a mixture of curacao, peach and prosecco (Marchetti, 2017) and the *Gïk* sweetened blue wine brand (Hohenadel, 2016). A naturally-blue French white Chardonnay wine *Vindigo* came onto the market in 2018 (Edkins, 2018). At the same time, various blue-colored gins have also been released (e.g., the London Gin Company's Original Blue, Carter, 2011; Edgerton blue spice gin; Kiely, 2015; and the blue Magellan gin colored with iris flowers)[7], not to mention a blue beer (Abashiri Beer's Okhotsk Blue Draft; Anonymous, 2014). Here, though, one should perhaps also be aware of the consequences of miscoloring drinks blue on people's ability to monitor their consumption of alcohol that has been documented to have, at least in the short term (Remington et al., 1997). As such, there is perhaps more ambiguity over the flavor-associations of clear

[7]Perhaps ironically, in the 19th Century, low-end gin was referred to as 'blue ruin' in the UK because of the complexion of those who drank too much of the stuff (Jackson, 2019; see also https://www.victorianlondon.org/entertainment/blueruin.htm).

FIGURE 1 | Yellow, red, and blue: how would you expect them to taste? (Photo from Kathyn Russell Studies, coutesy of Getty Images).

blue drinks these days than perhaps there was a few decades ago. As such, the context (or glassware) in which a clear blue drink appears may be critical to constraining the flavor expectations it generates nowadays.

On the Historical Association With Blue Coloring

Over the course of history, blue had various different associations. For instance, according to Stewart (2011, p. 58): *"The woad blue smeared by ancient Britons on their skin before battle acts as a natural antiseptic against future wounds."* (see also Finlay, 2002). Aquamarine blue was very highly prized in the world of painting (see Stewart, 2011; see also Pastoureau, 2000). In the Medieval period, edible precious materials were desired for their eye appeal (Woolgar, 2018)[8]. In the context of food, Woolgar (2018, p. 18) writes that: *"Elite cooks were trained to produce color, and if the recipes are a sure guide, then in some environments color was highly sought after and could be an element in a great many dishes. There were recurring features. Certain dishes may usually exhibit particular colors – but there might equally be change over time, in quite a bewildering way: for example, the well-known case of 'mawmenny' (a minced meat, in a sauce of wine or almond milk, with spices). In the first part of the fourteenth century in England, this was colored blue; by late fourteenth century, it was commonly yellow; and by the 1420s, it was an orange-red."* In the Medieval period, a blue color would therefore appear to be an unusual, desirable, and also temporary color in food.

Haslehurst's (1791/1814) kitchen manual provides instruction on how to create blue coloring using indigo. Rietz (1961) listed indigo, campeachy, violet, and cudbear as potential botanical sources of blue food coloring. There is, then, no simple answer to our response to blue. In the Victorian era, meanwhile, the color blue was apparently associated with poison (Carter, 2011; see also Walford, 1980; Downham and Collins, 2000; Burrows, 2009)[9].

Why Might Blue Be Undesirable in Food?

Over the years, several different theories have been put forward in order here to explain why blue should be an undesirable food color. They include the suggestion that:

(1) Blue is a rare appearance property of the food we consume, and this is the reason we are suspicious of it (e.g., Greenhalgh et al., 2009; Ossola, 2016). As Wollan (2016, p. 51) notes: *"Blue is a rarity among plants and animals."* She goes on to highlight how many of the things that appear blue to us

[8] Woolgar (2018, p. 6) notes how one fifteenth-century cookbook described dishes of food pulps, that is, pottages and broths, as a "blue mush" (blawe mose). An Anglo-Norman culinary collection, from the fourteenth century, also directs the cook that "the colour shall be blue" (Woolgar, 2018, p. 8). Another famous book the *Forme of Cury*, provides instruction on how to make blue food, using a lichen – orchil, that could be red or blue depending on the acid/alkali balance.

[9] In the 19th Century, copper was sometimes added to perk up palid pickled green vegetables (Wilson, 2009; Wollan, 2016, p. 54), while a golden yellow colour was added to margarine to make it look more like butter (Petersen, 1895; Masurovsky, 1939).

FIGURE 2 | The six drinks shown to participants in the UK and Taiwan in a cross-cultural study of the flavor expectations elicited by color reported by Shankar M. U. et al. (2010).

do so only because of a trick of diffraction—the scattering of light—that is the case for bird feathers, sky, ice water, and butterfly wings. Consistent with such a view, according to a recent press article, no one has yet managed to grow a blue rose (Leafe, 2019; Quest-Ritson, 2019) – *Die* blaue Blum, being a famous notion from German romantic poet and novelist Novalis (Mukhamadiarova et al., 2018).

(2) Blue is a rare color in food, and therefore when we see a food that has been colored blue, our mind immediately assumes that the coloring must be artificial rather than natural (see Smithers, 2008; Fleming, 2013; Spence, 2015c). Note also that brighter colors, and this includes brighter shades of blue, also tend to be associated with artificiality (e.g., Licata, 2015). Indeed, research from Korea suggests that foods displaying higher chroma are preferred, while chroma tends to be reduced as fresh produce ages (see Lee et al., 2013). Blue No. 1 (E133 Brilliant Blue) used, for example, to achieve the blue color in curacao happens to be the only permitted food dye that crosses the blood-brain barrier (Wollan, 2016; see also Hansen et al., 1966; Kobylewski and Jacobson, 2010).

(3) Blue in food looks very much like mold (see **Figure 4**) and we are programmed to find food that has gone off/unappealing (Piqueras-Fiszman et al., 2014; Staff Writer, 2015; see also Lee et al., 2013). According to Mühl and von Kopp (2017, p. 7): *"We instinctively recoil from food that has the 'wrong' color."* while Schlintl and Schienle (2020) suggest that toxic or spoiled food often looks blue, black, or purple.

There are, however, problems with all three of these accounts. While (1) may, in general be true, i.e., such foods are indeed rare, it is worth noting that rarity can actually act as a stimulant to desire – think only of truffle (see Stewart, 2011, p. 56, also links the rarity of ultramarine blue paint to the white Alba truffle in terms of their rarity). Though it is unclear whether the very rare

FIGURE 3 | The four different glasses in which colored drinks (having one of seven colors) were presented to participants in a series of cross-cultural studies designed to assess the impact of glassware on the flavor expectations set by colored drinks in a study by Wan et al. (2014a).

bright blue lobsters are valued any more highly because of their distinctive color (Parkinson, 2016) (see **Figure 5**). Hence, rarity can either be negatively or positively valenced in the context of food.

While (2) was presumably once true it isn't obviously any more, given the rise in the number of natural blue food dyes – think pea flower, Blue Magik, iris flower, Jagua blue, etc. (e.g., Newsome et al., 2014; Brauch et al., 2016; Elgart, 2018; see Spence, 2018b, for a review). It is, though, worth noting that many of the new sources of natural blue food coloring are not without their limitations. For instance, Blue Majik can leave an undesirable taste in the mouth, reminding one commentator of bitter fishy seaweed notes (Music, 2017). Meanwhile, there is apparently an insufficient global supply of spirulina-based blue pigment to meet the needs of the food industry (Wollan, 2016). Problems with the heat and light stability of a number of the newer blue food colorings have also been reported (Jespersen et al., 2004). Indeed, the pH instability of pea flower, means that its use is limited largely to novelty foods, such as color-changing dishes, drinks, and noodles (Blake, 2017b; see also Spence, 2019a, on the range of color-changing foods that have come onto the market in recent years).

(3) Does not seem obviously true given that the blue-green moldy veining in blue cheese—think Blue Stilton, Stichelton, or Gorgonzola—are desirable attributes to many consumers. And, according to Nolan (2013), moldy foods have actually become fashionable at the higher end of modernist cuisine. For instance, the Mugaritz restaurant served a moldy apple (Adúriz et al., 2019, p. 294). That said, chefs do not appear to like using blue in the dishes they serve. This is perhaps because there is no culinary purpose for the appearance of this color other than to create eye-catching gastroporn (see Spence, 2018b). At the same time, however, the marketing and Instagrammable appeal of blue and unicorn- and rainbow-colored foods would appear to show no signs of letting-up (see Blake, 2017a,b).

On the Recent Resurgence of Unusually-Colored Produce

While chefs rarely introduce blue coloring into the foods they serve nowadays, it would not seem inconceivable that the contemporary consumer interest in unusually-colored produce has been sparked by the molecular/modernist chefs who have been deliberately miscoloring some of the foods they serve for years (see Piqueras-Fiszman and Spence, 2012; Nolan, 2013; Spence and Youssef, 2018). Whatever the explanation, there has been something of an explosion of unusually-colored fresh produce in the supermarket aisles in recent years. UK supermarkets have started to stock everything from black garlic to orange, and yellow raspberries, and candy-striped beetroot (Anonymous, 2008; Carter, 2011). One can see the (re-)introduction of such unusually-colored produce as pine berries (white strawberries), red bananas, and purple potatoes (such as the Purple Majesty variety; Poulter, 2011), as playing to a consumer-curiosity in unusually-colored natural produce. Purple and blueish potato chips have also made an appearance in recent years (e.g., *Tyrrells* brand in UK).

The recent encouragement for consumers to eat a multi-colored diet perhaps also draws attention to the color of purple and blue foods[10]. Blue and purple fruits and vegetables have also

[10]According to the traditional Japanese food philosophy *Washoku*, every meal should contain five colours. The term Washoku literally means the harmony of food, a way of thinking about what we eat and how it nourishes us. According to

FIGURE 4 | Blue lobsters are exceedingly rare. This one of the blue foods that is though to be a sign of good luck for the fishermen who catch them. There is no mention that blue lobsters are unappealing. Though note that only the inedible carapace is blue, the flesh is white. Parkinson (2016) (photo from the Science Photo Library).

become more desirable in recent years due to the association with higher levels of anti-oxidants (Carter, 2011). Purple majestic potatoes are higher in anti-oxidants than the white variety, as are blueberries (though, the latter are perhaps more purple when mashed). Part of the increase in the appeal of purple and blue-ish produce is, therefore, likely attributable to the healthy associations that these colors now have (see also Macrae, 2011; Poulter, 2011; De Graaf, 2016)[11]. The high levels of natural antioxidants and anthocyanins found in blue corn have also started to attract attention of researchers (Herrera-Sotero et al., 2017). As such, one might expect the consumers' response to atypically-colored foods such as blue potatoes to change as the years go by (see Paakki et al., 2016; see also Leksrisompong et al., 2012), and further support for the health benefits of blue and purple foods becomes more widely known. I would argue that the suggestion that one sometimes comes across that purple and blue are simply, and specifically unappealing colors in food (e.g., Jahnke, 2018), is simply no longer true nowadays.

It is, though, interesting to consider how the distinctive colors we associate with particular vegetables (such as white potatoes and orange carrots), could so easily have been otherwise. According to Gillian Kynoch, head of development and innovation Albert Bartlett's Purple Majesty potato variety, the reason why (in the west, at least) we tend to think of potatoes as being white lies with Sir Walter Raleigh (Carter, 2011), who brought white potatoes back to Europe, despite the fact that purple is a common color amongst traditional potato varieties in the northern part of South America he visited (Salaman, 1949)[12]. As Hisano (2019) has also noted, over the last century or so the food industry has also played an important role in standardizing the color of fresh produce – thus ensuring that we now think of bananas as yellow (not red) and oranges as always being bright orange, not green.

Washoku, the five colors to be included in each meal: black, white, red, yellow, and green (Nobel, 2017).

[11] At the other extreme, of course, some people go for diets of only one colour, or of any colour except white foods (e.g., Rodale, 2017).

[12] Though, it should be remembered that Cortes independently brought potatoes back to Spain, and from there they rapidly spread to other Mediterranean countries (see Tannahill, 1973).

FIGURE 5 | It has been suggested by some that our aversion to blue-green foods comes from the fact that moldy foods often take on this appearance (figure courtesy of Peter Dazeley/Getty Images).

Carrots originated in Afghanistan and Iran with purple, red, white, and yellow varieties of this root vegetable initially all being common. According to Carter (2011), the orange variety only became popular in the 17th Century when this color was deliberately cultivated as a symbol of the House of Orange, and the struggle for Dutch Independence (cf. Banga, 1963; Dalby, 2003; Macrae, 2011; Greene, 2012, p. 81). However, according to other commentators, the popularity of orange carrots may have more to do with the fact that they do not dye the dish in which they were cooked in the way that purple carrots do (see Spence and Piqueras-Fiszman, 2014). It is somewhat ironic, therefore, to read that an ancient purple carrot variety is now finding a new role as a natural coloring (Associated Press and Cone, 2009). There are also increasingly-popular purple sweet potatoes that may have a role to play as a natural food dye too (Barclay, 2013).

Carrots of blueish nature (often called "purple," but in fact covering wide portions of blue-ish spectrum (e.g., see Schifferstein et al., 2019, **Figure 3**) are taken by consumers to indicate intense taste (there may be something similar going on here with the dark and unusual colors of some varieties of heritage tomato that have started to become much more popular) and despite their current low familiarity, and hence high artificiality, are rated as much more "attractive" than white or white-green carrots, and are rated as attractive as yellow carrots.

Blue: An Imprecise Descriptor of Food Color?

Innocent Drinks' Bolt from the Blue, launched in 2018, rapidly became one of their most successful new product launches ever. The drink contains guava, lime, apple, coconut water, blue spirulina + vitamins is described as blue (see **Figure 6**). There has been quite some online debate about whether the drink in more green than blue (Jewell, 2019). Notice here how finding an ambiguous color for one's product can undoubtedly help generate lots of discussion, and hence free publicity, on social media. However, the more general point here is that many different hues are, rightly or wrongly, described as blue. As such, this one descriptor "blue" covers a wide range of different shades, from Oxford to Cambridge blue (cf. Schloss et al., 2011), and from the blue of so-called blue potatoes (which are more purple) to blueberries (which are perhaps more purplish when mashed). There is, of course, also the blueish-purple of a rare steak served blue/bleu (Dixon, 2013), not to mention the very artificial-looking light-white turbid blues that are seemingly favored by the food artists (Poon, 2014; Ivanova, 2015). As such, our association with blue foods likely depends on which particular shade of blue one is talking about.

One other observation relating in the ambiguous naming of blue foods comes from the case of "dark" (red-blueish) cabbage in Germany. According to a reviewer, in Northern Germany, this type (and treatment) of cabbage is called "Rotkraut" or "Rotkohl" (red kraut or red cabbage), whereas those living in the south, especially Bavarians, call it "Blaukraut." It's always the same type of cabbage, and the color does not differ, yet those living in the North describe it (and thus presumably perceive it) as red, whereas those in the South perceive it as blue. The garnish is apparently very popular and liked across Germany, thus suggesting that taste (and familiarity) can sometimes beat the mere color property.

What's the Relationship Between the Resurgence of Blue Food Coloring and Our Increasing Digital Consumption of Food Images?

Let me end though with the dishes of biochemist and self-proclaimed "mad scientist" Kurare (Rose, 2015). He has created psychedelic udon noodles using fluorescence chemicals such as new coccine and riboflavin (see **Figure 7**). While visually stunning, I would argue that they are not appetizing. Ultimately, therefore, one might consider whether the recent resurgence of brightly, one might even say surreally-colored foods would have taken place had it not been for the increasing amount of visual food consumption that occurs by means of our digital technology (Lavis, 2015)? I would also argue that the deconstruction of dishes by modernist/molecular chefs in recent decades has also helped to encourage consumers to think more creatively about the color of the foods they prepare/consume (see Spence and Youssef, 2018; del Moral, 2020).

At the same time, there is also a sense in which people need repeated opportunities to appreciate more challenging material. Carbon and Leder (2005) demonstrated how people may come to appreciate those stimuli that may initially seem relatively uncommon, innovative, and unfamiliar via the Repeated Evaluation Technique. As such, one might wonder whether repeated exposure to blue foods, along with increased elaboration by consumers, might also lead to their increased acceptance in the future. This kind of approach might also lead one to question whether the single-shot evaluation procedure so often used food research in this area might not necessarily be all that useful when it comes to predicting future appreciation.

What Does Blue Taste Like? Synaesthetic Blue Tastes

Pantone declared Classic Blue (19-4052) its color of the year for 2020. According to Fixsen (2019): *"To augment the 2020 reveal, Pantone included a twist of its own: As part of its marketing campaign, the company partnered with several brands to develop the smell, sound, taste, and texture of Classic Blue. The resulting package included a swatch of suede-like fabric from the Inside, a musk-and-sea-salt-scented candle, a blue, berry-flavored jelly, and a three-minute audio track titled 'Vivid Nostalgia*[13]*.'"* This campaign seems almost synaesthetic in suggesting that blue color has a specific taste/flavor. Potentially relevant here, several synaesthetes have mentioned that they associate certain tastes with a blue-colored concurrent. For example, according to Jaime Smith, a professional sommelier living in Las Vegas, a white wine like Nosiola has a *"beautiful aquamarine, flowy, kind of wavy color to it."* (quoted in Carlsen, 2013). Meanwhile, the synaesthetic artist Kandinsky also mentioned a synaesthete for whom certain taste inducers give rise to blue color concurrents: *"As far as tasting colors is concerned, many examples are known where this explanation does not apply. A Dresden doctor tells how one of his patients, whom he describes as 'spiritually, unusually highly developed,' invariably found that the certain sauce had a 'blue' taste, i.e., it affected him like the color blue."* (Kandinsky, 1977, p. 158; see also Marks, 1978). I would, however, argue that synaesthetic colored-taste concurrents are of little relevance for understanding blue food coloring's relevance to the regular consumer (Spence and Youssef, 2020).

Blue Plates, Trays, Lights, and Glasses

The appetite-suppressing effects of blue in relation to food apparently extend beyond the food itself. Over the years, it has been suggested that everything from blue plates (see Spence, 2018c, for a review; though see also Schlintl and Schienle, 2020)[14] to blue trays (Crumpacker, 2006)[15], and from blue lighting (Cho et al., 2015) to blue dieting spectacles (sold by Yumetai, a Japanese company; Anonymous, 2009) may help to reduce people's food consumption. That said, to date, the evidence supporting such claims would appear to be weak or anecdotal at best. What is more, there are other studies suggesting that high-contrast blue plateware may actually help elderly hospital patients to eat significantly more (not less; Adams, 2013; Spence, 2017b). The latest research suggests that neither blue food nor blue plates necessarily reduces appetite any more than coloring food red, thus confusing matters further (Schlintl and Schienle, 2020). Children have also been reported to consume more, and thus prefer, to eat from colored, rather than white, plates (Brunk and Møller, 2019). Overall, therefore, the evidence supporting the claim that presenting a food against a blue background suppresses appetite currently appears to be rather weak too.

CONCLUSIONS

There is a tension between those commentators/researchers, on the one hand, who want to paint blue as an appetite suppressant (Suzuki et al., 2017), and the food marketers, and Instagrammers who sense the appeal of blue foods (e.g., Hohenadel, 2016; Elgart, 2018), or at least captures visual attention effectively on the shelf

[13]You can listen to the Audio UX track Vivid Nostalgia at https://www.youtube.com/watch?v=SVa6eQ1oRt8. It is, however, important to highlight the distinction between our preference for different colours in a food vs. a non-food context. While blue and green are typically chosen as the favourite colours generally-speaking. In a food context, these two colours are much more likely to appear at the bottom of the list of preferred colours (see Spence, 2019b).

[14]According to the media-friendly synaesthete Jamie Wannerton: *"You serve me food on a blue plate — it just totally messes up the eating sensation."* (Carlsen, 2013). Though note that it has been suggested that blue plates might increase food consumption in the elderly, many of whom have problems seeing, due to enhanced contrast with typically pale hospital food (e.g., see Adams, 2013).

[15]According to an unsubstantiated anecdote reported by Crumpacker (2006, p. 143): "*…the term blue plate special became popular during the Great Depression because restaurant owners found that diners were satisfied with smaller portions of food if it was served on blue plates.*"

FIGURE 6 | Innocent Drinks launched their Bolt from the Blue in 2018. It has been one of the companies most successful new product launches ever. Who says that blue-colored food and drink products would never sell? Though some have argued the drink is more green than blue (see Jewell, 2019) (Copyright Innocent Drinks).

or increasingly on the screen (e.g., Garber et al., 2008; Spence, 2016). Is it simply a matter of unusually-colored food being off-putting (e.g., Cardello, 1996; Greenspan, 2009; Ossola, 2016)? Or is there something special about blue, or about unusual color specifically in meat (Vanderbilt, 2015)? As yet, while there is undoubtedly plenty of anecdotal evidence, there is little robust scientific evidence that coloring food blue is any different that coloring food black or purple, say (see Spence, 2020a). If the question is narrowed down, to ask specifically about blue animal protein, the story isn't much clearer/different either.

According to the research summarized here, the associations we hold with, and hence our response to, color in food very much depends on what that food is, and perhaps when historically we are looking at it. Hence, there is likely to be no simple answer to the question of whether blue food is aversive, and if so, how universal that aversion might be. Nevertheless, blue is a special color in the world of food due to its rarity relative to other colors. Rare colors (like blue) capture our attention more effectively in a given context, and at the same time are less likely to have any well-established favor associations. A case can, I think, be made that the recent resurgence of blue foods is intimately linked to our digital consumption of food images.

Ultimately, therefore, there is no single meaning of blue in food. The context, or food format, in which it appears is crucial to determining its meaning. Given the rarity of naturally-blue foods, this means that it is primarily added as a coloring and hence the

FIGURE 7 | Neon blue noodles created by Kurare. While such visually-captivating dishes generate a lot of interest online. How appealing are such dishes really?

link between color and flavor is essentially arbitrary (which is not the case for the majority of other food colors). Nevertheless, the majority of consumers nowadays would appear to associate this color in a drink or confectionary product with a sweet fruit flavor (e.g., Shankar M. U. et al., 2010; Velasco et al., 2016). Most often this would appear to be raspberry, of for those who kitsch cocktail loves out there, then the association is with sweet orange due to the popular Blue bols curacao. However, the explosion of new blue drink products in the marketplace in recent years likely means that the flavor associations with this most unusual of food-colors is likely to be more context, format, or glassware dependent than it was, even just a few decades ago.

As for the blue steak story that we started with, that would appear to be nothing more than a much-publicized urban myth. As to why this particular story has proved so popular down through the decades, it might be argued that myths tend to stick when they "sound right," when they fits our naïve expectations, and/or when we want them to be true (see also Tannenbaum, 2020). Certainly, for those wanting to stress the importance of color to the experience of food and drink then the blue steak example presents what appears to be perhaps the strongest of all support that has been reported to date. As is so often the case, further research will be needed to get to the bottom of the question of whether eating blue meat really does elicit a pronounced aversive reaction in consumers nowadays, as has been so often suggested in the literature in the past.

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Virtual Terroir and the Premium Coffee Experience

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With its origin-centric value proposition, the specialty coffee industry seeks to educate consumers about the value of the origin of coffee and how the relationship with farmers ensures quality and makes coffee a premium product. While the industry has widely used stories and visual cues to communicate this added value, research studying whether and how these efforts influence consumers' experiences is scarce. Through three experiments, we explored the effect of images that evoke the terroir of coffee on the perception of premiumness. Our results revealed that online images that resembled the broad origin of coffee (i.e., a farm) could influence premiumness expectations of coffee (Experiment 1). Similarly, a virtual reality environment that depicted this broad origin (vs. a control but not a city atmosphere) could enhance the perception of coffee premiumness for non-expert consumers (Experiment 2) and the enjoyment of the experience for coffee professionals (Experiment 3). Importantly, we found that congruence between the coffee and the virtual reality (VR) atmospheres mediated how much non-experts enjoyed the experience (Experiment 2). VR atmospheres also influenced expectations of sweetness and acidity for non-experts (Experiment 2). These findings serve as a steppingstone for further exploration of the effects of congruence between visual cues and product/brand attributes on premiumness expectations and perception, and more generally on consumer experience. From a practical standpoint, this study provides insights into key aspects for the development of immersive virtual product experiences.

Keywords: premiumness, consumer experience, virtual reality, atmospheres, coffee, terroir, origin

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1. INTRODUCTION

In the last decades, the specialty coffee industry has expanded internationally and has experienced a significant rate of growth (Morris, 2017). As of 2018, the global specialty coffee market was valued at more than USD 35 billion in revenue, and it is expected to reach USD 85 billion by 2025 (Globe Newswire, 2019). The key factor that grants specialty coffee the status of a premium, much sought-after product lies in the close relationships that coffee companies develop with farmers through the valorization of the coffee's origin, traceability, and potentially the improvement of the production process (Perez et al., 2017). The combination of these factors results in unique flavor profiles. According to the World Intellectual Property Organization (2017), specialty coffee consumers are willing to pay higher prices for coffee, and in exchange, they want to know the origin of the beans and how they were farmed. Therefore, the specialty coffee industry strives to communicate the origin-centric value of coffee in order to improve premiumness perception and thus, increase the willingness of consumers to pay higher prices for the coffee and experiences around it (Perez et al., 2017).

To show that their coffee is a premium product, companies use different cues to convey information about the origin of the coffee. They create flavor profiles linked to the origin of the coffee, which are accompanied by detailed information and stories about the farmers and the terroir (Sanz-Uribe et al., 2017). Additionally, in their websites and packaging, companies present a plethora of images of the terroir and the people that take part in the production (Yeretzian et al., 2017; Gerard et al., 2019). Nevertheless, the outcome of many of the above-mentioned efforts is unclear. To our knowledge, there is no conclusive evidence that indicates that the images about the coffee origin augment the perception of product premiumness and overall experience around coffee. More generally, research on the effect of congruence between visual cues associated with the place of origin and a given product on specialty coffee premiumness perception and experience is scarce. Therefore, there is an opportunity to both understand how images with specific contents, as well as origin congruence, may influence the specialty coffee experience.

In this study, we investigate this topic and go beyond by using virtual reality (VR) as a tool to analyze how atmospheric cues associated with terroir may influence the premium coffee experience. Today, new technologies like VR can create immersive experiences by detaching people from the physical reality, and thus "transporting" them into a virtual environment (Animesh et al., 2011; Gabisch, 2011). In particular, in Experiment 1, we examined whether online images (e.g., photographs on a website) with different levels of congruence with the broad origin of coffee can influence premiumness expectations in coffee. In Experiment 2, we went beyond 2D images and explored whether VR atmospheres that portray the broad origin of coffee can influence how non-expert consumers experience the coffee. In Experiment 3, we extended our investigation to professionals as they appear to rely less on extrinsic cues (e.g., D'Alessandro and Pecotich, 2013; Lee et al., 2018).

2. THEORETICAL BACKGROUND

2.1. Premiumness and Terroir

While there does not seem to be a clear-cut consensus regarding the definition of premiumness, it has been suggested that superior quality is an indispensable element of premium products (Quelch, 1987; Pombo and Velasco, 2020). The literature also seems to agree that premium products add value to the consumer and demand premium prices (see Vigneron and Johnson, 2004; Miller and Mills, 2012; Ko et al., 2019 for reviews on premiumness and luxury goods). Indeed, Quelch (1987) suggested that premium products command the highest quality distribution channels and premium prices that are linked to the performance of the products (see also Lyons and Wien, 2018; Velasco and Spence, 2019 for a review).

For specialty coffee, high quality is a sine qua non-element that is closely associated with the place it comes from (Jackson, 2013). For food and drinks, the concept of origin is especially important since it can convey cultural meaning and lead to the formation of identities, which adds value beyond its purely utilitarian function (Bech-Larsen et al., 2007). The specialty coffee industry, in particular, aims to leverage its connection with the origin of the coffee and its producers to differentiate itself and gain a competitive advantage against the commodity coffee industry (Perez et al., 2017).

For coffee, the concept of terroir is highly relevant in order to analyze the effects of place of origin. Terroir refers to the terrain where a food product comes from that gives it its unique characteristics (Barham, 2003). Terroir is more than a mere geographical link between product and land. It relates to the idea that products are a unique expression of different environmental and sociocultural characteristics of a specific place (Vaudour, 2002). However, it is worth noting that while the specialty coffee industry strives to capitalize on traceability and the use of terroir, it is a relatively young industry (Sepulveda et al., 2016; Perez et al., 2017). Consequently, several consumers know little about the origin of coffee, or they do not see its relevance.

The use of terroir can serve as an indicator of authenticity (a dimension often included in luxury products) with specific geographic heritage (Kuznesof et al., 1997; Beverland, 2006), and it can inhibit the perception of commoditization (Demossier, 2004). The use of terroir can also influence the perception of quality (Heslop et al., 2010) and consumers' willingness to pay higher prices (Livat and Vaillant, 2006; Schamel, 2006; Spielmann et al., 2014; Moulard et al., 2015). Spielmann et al. (2014) suggested that these effects occur mainly because indications of origin provide information and signal quality and authenticity. Highlighting the value of terroir has the potential to enhance product premiumness expectations and perception (Caniato et al., 2009). Research in the wine industry provides evidence that the use of terroir can increase the perception of premiumness (Spielmann and Babin, 2011; Moulard et al., 2015). A useful body of literature to understand why the use of images of terroir might influence perceptions of premiumness in these products is that of schema congruence.

2.2. Enhancing Premiumness Associations Through Congruence With Terroir Images

As Douglas and Hargadon (2000) stated, schemas are a "cognitive framework that determines what we know about the world" (p. 154) acquired through previous experiences. These schemas make it possible to make sense of future unfamiliar experiences since they influence information processing and comprehension. Furthermore, congruence relates to the "extent to which a brand association shares content and meaning with another brand association" (Keller, 1993, p. 7). Keller argued that congruent new information is more easily learned and recalled, which determines the cohesiveness of the product-experience image. According to Lee and Labroo (2004), stimuli congruent with a brand or product reduces uncertainty since they share a common meaning, so the product is recalled more easily, becoming semantically predictive (e.g., an advertisement featuring a thirst-quenching beverage in a sporting event). Throughout this paper, we use the terms congruence and fit interchangeably.

Based on these concepts, consumers' previous knowledge about the origin of coffee represents the schema. We construe that schema congruence arises from the interaction and shared common meaning of place of origin between the schema and stimuli that portrays the terroir of coffee. Congruence may generate a cohesive mental image between the new experience and a schema, resulting in basic positive evaluations in terms of familiarity, acceptability, and liking (Mandler, 1982). Consumers prefer the reduced levels of uncertainty brought by congruence as less uncertainty facilitates the processing of new information (Schwarz, 2004). Consequently, the higher degree of fluency that arises in the case of congruence triggers more favorable product evaluations (Winkielman et al., 2015; see also Tofighi et al., 2020 for a more recent example of congruence on brand perception).

Another concept that can serve to analyze the effect of images of a product's terroir on product evaluation is situational appropriateness. It refers to how well a food or beverage product fits the situation in which it is supposed to be consumed (Giacalone and Jaeger, 2019b). Research on this concept suggests that consumers not only evaluate products based on their preferences but also on the situations in which they were meant to be used. Giacalone and Jaeger (2019a) found that perceived situational appropriateness is an essential criterion of product evaluation that can explain over 70% of product choice variance. There are multiple ways in which brands can relate a product with its corresponding terroir, including names, labels, and visual cues through multiple channels. For example, companies can use brand names, labels, and certifications (e.g., AOC, PDO, PGI, TSG) to indicate the provenance of their products (Leclerc et al., 1994; Aichner, 2014). Considering the strong emphasis of terroir products around experiences, hedonic consumption, and knowledge, Charters et al. (2017) suggested that using images about the product and, importantly, its place of origin (landscape, architecture, history, culture) is critical for brands to heighten consumer experiences and create ties to the products and places. Indeed, Häubl and Elrod (1999) highlighted the positive effect of congruence between brand names and country of production on quality perception. In that sense, congruence between visual cues and a product may facilitate premiumness associations. Given that quality is a crucial dimension of brand premiumness, product-origin congruence might lead to higher premiumness perception. Hence, we expected images that more closely resemble the origin of a product to create a higher perception of premiumness. More formally, we hypothesized as follows:

H1: Higher (vs. lower) congruence between a given product and visual cues of terroir will result in a higher perception of premiumness.

In addition to the potential effects of visual cues that relate to the origin of products on the perception of coffee premiumness, terroir may influence intent to purchase. As evidenced in the tourism literature, images about a specific location can directly and indirectly—through trip quality, perceived value, and satisfaction—influence intentions to revisit and recommend destinations (Chen and Tsai, 2007). Such images can also influence seek for knowledge and feelings toward the destination (Hosany et al., 2006). As Willems et al. (2019) found, VR images of destinations can generate consumer engagement and increase intent to purchase. Thus, we expected that higher congruence would influence consumers' willingness to buy a product. More formally, we proposed the hypothesis as follows:

H2: Higher (vs. lower) congruence between a given product and visual cues of terroir will increase the intent to purchase the product.

Furthermore, we expected the effects of congruence to influence the overall product experience. Visual cues can trigger mental simulation of experiences (Elder and Krishna, 2012), and the use of terroir can imbue more context to these experiences as it can transport consumers to the place of origin (Vaudour, 2002; Charters et al., 2017). For instance, the use of terroir can generate a strong sense of involvement with a product, which in turn can enhance the overall experience and trigger a desire to "become one" with the place (Beverland and Farrelly, 2010). Evoked experiential contexts like terroir can help consumers develop emotional connections with products (Piqueras-Fiszman and Spence, 2015; Charters et al., 2017; Motoki et al., 2020a). Moreover, the use of terroir can provide consumers with connecting experiences with products, the makers, and the place (Smith Maguire, 2010). Taken together, the potential effects of the use of terroir can increase how much consumers enjoy experiences associated with specific products. Thus, we proposed the hypothesis as follows:

H3: Higher (vs. lower) congruence between a given product and visual cues of terroir will increase the enjoyment of the overall experience of the product.

2.3. Opportunities in Evoking Terroir Through Immersive Technologies

The concepts of presence and telepresence are critical to understand immersive experiences. Presence relates to the perception or sense of being in an environment, where the surroundings have a direct effect on the senses, and telepresence relates to the experience of presence via a communication medium (Steuer, 1992). Moreover, in his seminal paper, Steuer (1992) defined VR as a "real or simulated environment in which the perceiver experiences telepresence" (p. 75). In other words, VR refers to a mediated experience of presence. VR, compared to desktops and mobile phones, can induce more positive emotions and greater psychological and behavioral engagement in destination-based experiences (Flavián et al., 2020). Therefore, VR can be a useful tool for the specialty coffee industry to communicate the concept of terroir and create unique experiences (see also Mollen and Wilson, 2010).

Given the possibilities VR brings to consumer contexts, there has been a growing number of articles on VR in sensory and consumer science in recent years (Spence et al., 2016; Sinesio et al., 2018; Stelick et al., 2018; Andersen et al., 2019; Hannum et al., 2019; Petit et al., 2019; Picket and Dando, 2019; Chen et al., 2020). VR is becoming an effective tool for companies to develop immersive brand experiences with the potential to transport consumers to specific locations an allow them to "live" stories (see also Rogers, 2018). Creating immersive experiences based on real scenarios revolving around terroir in VR can increase consumer engagement and involvement with products and brands (Zandstra et al., 2020). At a low level, VR experiences can foster consumers' desire to continue engaging in these experiences. At a high level, VR can be a crucial tool for companies to more effectively convey the meaning and personality of their brands and help consumers grasp issues related to their products (Hollebeek et al., 2020). Moreover, companies can use VR to develop consumers' emotional connections with brands and products (Harris et al., 2020). As Chirico and Gaggioli (2019) found, the emotions and sense of presence elicited by immersive 360-degree videos are comparable to those elicited by real-life environments. Given the nature of the product and the focus on the stories about terroir and people, the specialty coffee industry may capitalize on VR to tell stories about coffee terroir and farmers to better convey the value and differentiation they add to a product most people consider a mere commodity. In this paper, we tested the effect of congruence in different means that can be used to exhibit terroir. More specifically, we used online 2D images (Experiment 1) and 360-degree VR atmospheres (Experiments 2 and 3).

3. EXPERIMENT 1: COFFEE-IMAGE CONGRUENCE AND EXPECTATION OF PREMIUMNESS IN NON-EXPERTS

The aim of Experiment 1 was to explore whether variations in visual cues used to describe and promote coffee online could be used to manipulate the fit between these cues and the coffee. We began with online images in a product information communication context as it is a common way the industry uses to promote specialty coffee and is one of the first lines in non-expert consumers' evaluation of the coffee. Given the importance of origin in specialty coffee, the variations in the visual cues were done in terms of broad origin, specific origin, and labels, as well as the images themselves, as they can be used to portray different degrees of closeness to the origin of the coffee presented (Leclerc et al., 1994; Aichner, 2014; Charters et al., 2017). Moreover, using different cues, rather than one, can facilitate premiumness associations (Leclerc et al., 1994; Häubl and Elrod, 1999; Aichner, 2014). We sought to uncover whether these factors independently, or interactively, could drive any effect on the fit and premiumness expectations of coffee. We evaluated this as one could also hypothesize that just denoting the country of origin (and assuming that not all consumers know details about the specificities of the origin) could also impact the fit and premiumness expectations. Moreover, we wanted to uncover whether, despite incongruencies between the origin stated in the coffee description and the image, any potential effect of the factors on fit and expectation of premiumness remained. Additionally, the experiment aimed to analyze the effect of this potential fit on premiumness expectations of coffee in non-experts. This experiment also guided the generation of stimuli for the subsequent studies.

3.1. Methods

3.1.1. Participants

A total of 770 individuals (516 female, age range 18–74, $M = 36.5$ years, $SD = 13.5$) participated in the experiment.[1] Participants were recruited from Prolific Academic. All participants were native English speakers and were based in the UK. In Experiment 1, we focused on non-experts. Individuals who participated in this experiment were remunerated with GBP 1.00. This and all the experiments reported in this manuscript were implemented on Qualtrics and complied with the World Medical Association's Declaration of Helsinki. Before beginning each experiment, participants provided their consent to take part in the experiment.

3.1.2. Apparatus and Materials

The stimuli consisted of descriptions of four different specialty coffees along with a photograph and potentially a label of the photograph. The descriptions and photographs of the coffees were selected from those traded by Nordic approach, a green coffee sourcing company based in Oslo, Norway, in the online green coffee marketplace Cropster Hub. The coffees selected were from Burundi, Kenya, El Salvador, and Honduras. The stimuli were created from the combination of three factors (*broad origin*, *specific origin*, and *label*), which we expected to yield different levels of fit, and the four coffees. Based on the abovementioned literature on terroir, the factor broad origin could take the value of *farm* or *city*, indicating whether the photograph was from a coffee farm or a city. The factor specific origin could take the value *from origin* or *not from origin*, where the former meant the image matched the origin of the coffee in the description. The factor label could take the value of *label* or *no label*, indicating whether the image was labeled with the information about the specific region and country of the image. The factor broad origin was chosen as it could easily portray something close to the terroir of the coffee (farm) vs. something further away from it (city), and as such, we expected it to have the largest effect.

Information about origin can be presented in multiple ways. In this experiment, we were interested in the terroir images themselves. Note, however, that we explored how cues of origin typically used by the specialty coffee industry (e.g., labels) would influence consumer experiences. Even though non-experts may be unfamiliar with coffee-producing countries, the factor-specific origin allowed us to create levels of complete (in)congruence and to analyze how disruptive the stimuli with labels from origin and not from origin were. It also permitted us to analyze which cues would be the most relevant when signaling premiumness. The factor label was chosen as we wanted to know if just looking at a picture portraying nature was enough to influence expectations or if more information was needed. In this experiment, we were interested in generating different levels of congruence while

[1]The required sample size for Experiments 1 and 2 were determined using GPower 3.1.9 (Faul et al., 2007) using an alpha level of 0.05 and 0.95 ($1 - \beta$) statistical power. The analysis indicated sample sizes of 640 and 150, for Experiments 1 and 2, respectively, were required. Moreover, recent research on sensory and consumer science studies (Velasco et al., 2018; Motoki et al., 2020b) use similar sample sizes.

maintaining relative closeness to the origin. Hence, both the farm and the city images were from coffee-producing countries.

All the photographs of the farms were extracted from Cropster Hub, and they were from the specific farms of each of the coffees used in the experiment. The images of cities were from the region where the coffee was produced, and they were taken from Nordic approach's database or free-to-use images. The combination of the three factors and four different coffees resulted in 32 different stimuli. The final stimuli presented to participants consisted of the description of a specific coffee (i.e., name of the farm, specific place of origin, country of origin, the coffee's flavor notes) along with an image placed to the left of the description with or without a label in the lower-left corner. The description was presented in black Arial font, size 18, with a white background. Each stimulus had dimensions of 1362 × 596 pixels and a resolution of 150 dpi (see **Figure 1**). The complete set of stimuli can be found in OSF at https://osf.io/5vne6/.

We measured premiumness expectations along four dimensions, by adapting Ko et al.'s (2019) luxury dimensions to premium product perception: quality, authenticity, willingness to pay a premium price, and also general premiumness. Participants answered to these dimensions by indicating their level of agreement to a series of statements using five-point Likert scales ranging from 1 (*Strongly disagree*) to 5 (*Strongly agree*). In addition, participants were asked to indicate how well they believed the image fit the coffee through a five-point Likert scale ranging from 1 (*Not well at all*) to 5 (*Extremely well*). See **Supplementary Figure 1** for an example of the questionnaire.

To get a sense of the profile of respondents and their relationship with specialty coffee, we included questions regarding their coffee consumption habits and motivations, the factors they considered most important when purchasing coffee, and how familiar they were with specialty coffee and with each of the countries of origin of the coffees presented. See **Supplementary Table 1** for a description of participants' profile.

3.2. Experimental Design and Procedure

The experiment followed a 2 (broad origin: farm vs. city) × 2 (specific origin: from origin vs. not from origin) × 2 (label: label vs. no label) between-subjects design. Each participant evaluated the four different coffees and was randomly assigned to one of the eight groups. They provided their consent before taking part in the experiment and then proceeded to indicate their age and gender. Afterwards, participants answered the questions regarding their relationship with specialty coffee. Participants later saw each stimulus one at a time and responded to the questions regarding premiumness and the degree of fit between the image and the coffee. The order of the stimuli and premiumness items was randomized. The experiment lasted for approximately 5 min.

3.3. Analyses

A mixed analysis of variance (ANOVA) with broad origin, specific origin, and label as between-subjects factors and coffee as within-subjects factor—to control for any difference in perception related to the coffee being evaluated—was conducted to evaluate our dependent variables (fit and premiumness). The measure of effect size for all the ANOVAs was the partial eta squared (η_p^2). All the statistical analyses were conducted using R software (R Core Team, 2020). Whenever the interaction terms were significant, Bonferroni-corrected pairwise comparisons were conducted.

Note that premiumness consisted of the average of the four items used to measure it. To check the consistency of the premiumness variable, Cronbach's alpha was computed, yielding a value of 0.75 (95% confidence interval [CI]: 0.74, 0.77), which exceeded the recommended threshold of 0.70 (Nunnally, 1994).

3.4. Results and Discussion

3.4.1. Fit Between Visual Cues and Coffee

The analysis confirmed the effectiveness of the fit manipulation (**Figure 2**). The analysis revealed that all main effects and interactions were significant (**Table 1A**). As for the main effects, farm images (M = 2.72, SD = 1.09) presented higher fit with the coffee than city images (M = 2.08, SD = 1.05). Moreover, the images from the specific origin of the coffee (M = 2.45, SD = 1.11) presented higher fit than those not from the specific origin (M = 2.36, SD = 1.13). Surprisingly, the stimuli without labels (M = 2.49, SD = 1.11) presented higher fit ratings than those with labels (M = 2.33, SD = 1.12). As expected, broad origin was the factor with the largest effect size.

To further analyze the effects of the significant two-way interactions, pairwise comparisons were conducted. First, when the visual cues were not from the specific origin, farm images (M = 2.75, SD = 1.10) presented higher fit than city images (M = 1.97, SD = 1.03; $p < 0.001$), and when the cues were from the specific origin, farm images (M = 2.69, SD = 1.09) also presented higher fit compared to city images (M = 2.18, SD = 1.07; $p < 0.001$). Second, when the images were not labeled, those portraying farms (M = 2.86, SD = 1.08) presented higher fit than those portraying cities (M = 2.12, SD = 1.02; $p < 0.001$). Similarly, when the images were labeled, those with farms (M = 2.59, SD = 1.09) presented higher fit than those with cities (M = 2.03, SD = 1.09; $p < 0.001$). Lastly, when the images were labeled, those from the specific origin (M = 2.41, SD = 1.12) were rated as having higher fit than those not from the specific origin (M = 2.25, SD = 1.12; p = 0.003). However, there was not a significant difference between images from the specific origin and not from the specific origin when they were not labeled (p = 0.968).

To further investigate the effects of the significant three-way interaction (**Figure 3**), two separate ANOVAs for the label and no label conditions were conducted. In the former case, the analysis revealed significant main effects of broad origin, $F_{(1,3069)} = 110.0$, $p < 0.001$, $\eta_p^2 = 0.035$, and specific origin, $F_{(1,3069)} = 8.14$, p = 0.004, $\eta_p^2 = 0.003$, as well as a significant interaction effect of broad origin and specific origin, $F_{(1,3069)} = 26.5$, $p < 0.001$, η_p^2 = 0.009. Subsequent pairwise comparisons of the latter showed that within the labeled images from the specific origin, those that portrayed farms (M = 2.54, SD = 1.11) had higher fit than those that portrayed cities (M = 2.27, SD = 1.12; $p < 0.001$). Similarly, from the images with labels and not from the specific origin, those that depicted farms (M = 2.65, SD = 1.07) presented higher fit than those that portrayed cities (M = 1.83, SD = 1.01; $p < 0.001$).

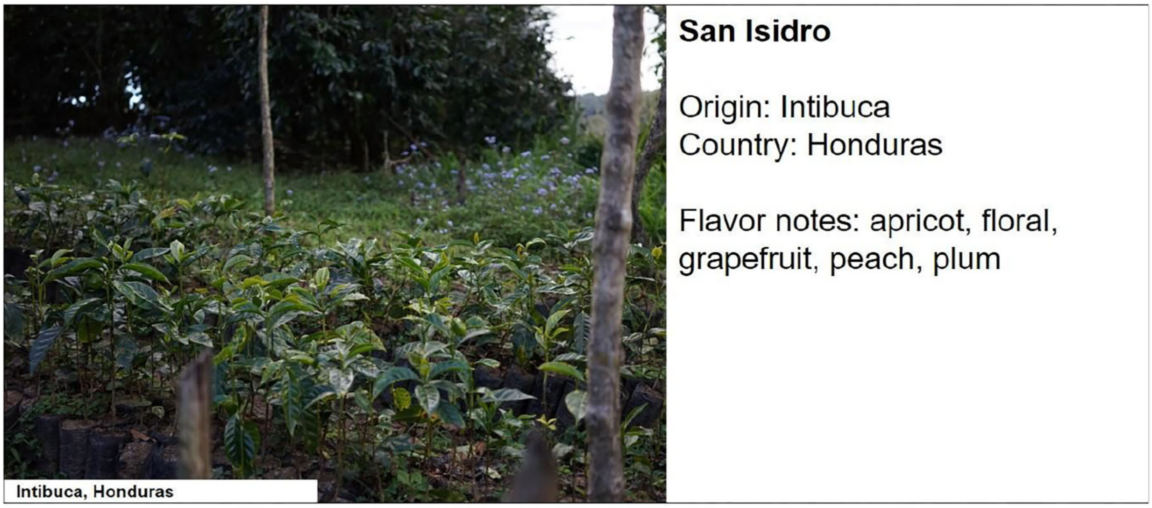

FIGURE 1 | Example of stimuli used in Experiment 1. The factors broad origin, specific origin, and label take the values of farm, from origin, and label, respectively.

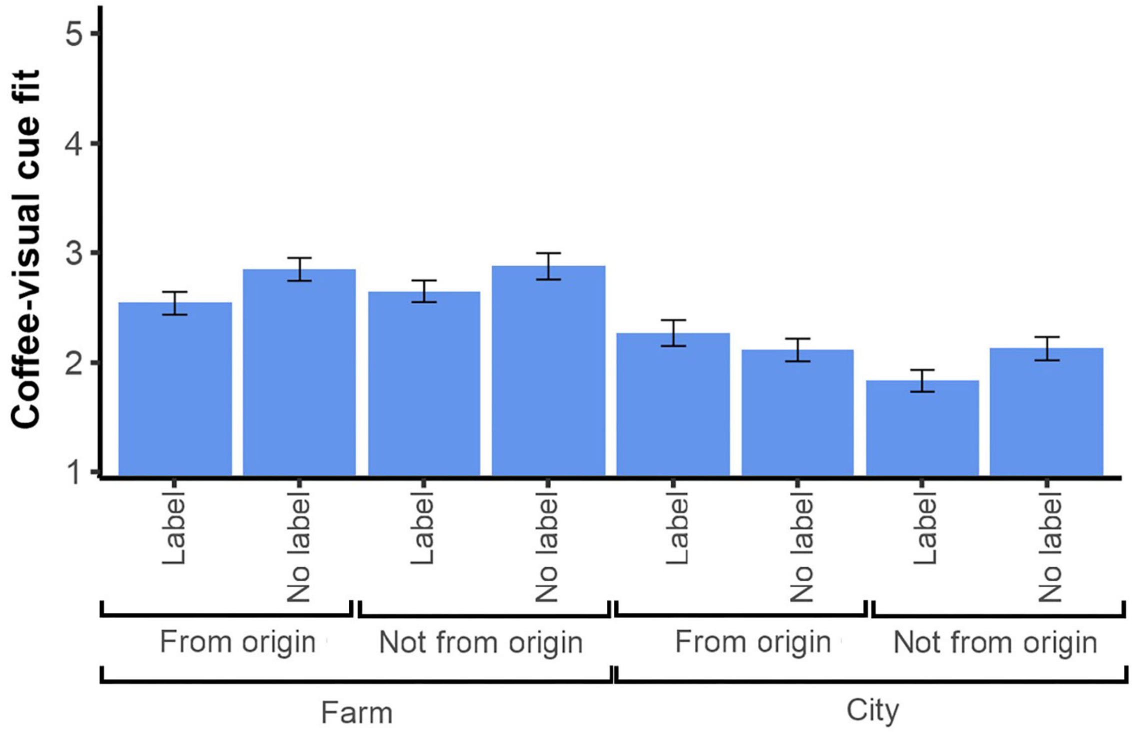

FIGURE 2 | Mean fit ratings between visual cues and coffees in Experiment 1. Ratings of fit on a 1–5 scale. Error bars: 95% CI.

Under the no label case, the ANOVA revealed a significant main effect of broad origin, $F_{(1,3069)} = 180.0$, $p < 0.001$, $\eta_p^2 = 0.055$.

Broad origin appeared to be the most important factor in the manipulation of fit. It is natural to assume that non-experts may not necessarily be able to distinguish when the image (whether from a farm or a city) is not from the specific origin if it does not have a label, which, as the results showed, did not affect the fit. It is interesting to note that the fit ratings of all groups of stimuli were below the midpoint of the scales, likely indicating that participants did not have strong associations between the coffee and the visual cues resembling its origin. One possibility is that participants regarded coffee

TABLE 1 | Analysis of variance (ANOVA) results on fit **(A)** and premiumness **(B)** for Experiment 1.

Factor	(A) Fit			(B) Premiumness		
	F	p	η_p^2	F	p	η_p^2
Coffee	**2.74**	**0.042**	**0.003**	**14.96**	**<0.001**	**0.014**
Broad origin	**280.33**	**<0.001**	**0.085**	**15.18**	**<0.001**	**0.005**
Specific origin	**6.05**	**0.014**	**0.001**	0.14	0.706	<0.001
Label	**21.12**	**<0.001**	**0.007**	0.63	0.426	<0.001
Broad origin × Specific origin	**13.24**	**<0.001**	**0.005**	**6.71**	**0.010**	**0.002**
Broad origin × Label	**6.62**	**0.010**	**0.002**	0.26	0.610	<0.001
Specific origin × Label	**5.14**	**0.023**	**0.002**	3.16	0.076	0.001
Broad origin × Specific origin × Label	**11.96**	**<0.001**	**0.004**	**3.86**	**0.050**	**0.001**

Bold values indicate the statistically significant effects at p < 0.05.

as an undifferentiated product, and the images provided little specific meaning.

3.4.2. Expectation of Premiumness

The three-way ANOVA (**Table 1B**) revealed a significant, albeit small, main effect of broad origin (farm vs. city) such that coffees with images portraying farms (M = 3.35, SD = 0.78) resulted in higher premiumness ratings than those portraying cities (M = 3.25, SD = 0.68). The analysis also showed a significant two-way interaction between broad origin and specific origin. Pairwise comparisons revealed that when the visual cues were not from the specific origin, farm images (M = 3.39, SD = 0.81) were rated as more premium than city images (M = 3.22, SD = 0.66; $p < 0.001$). However, there was not a significant difference between farm and city images when they were from the specific origin ($p = 0.360$).

Furthermore, the ANOVA revealed a significant three-way interaction of broad origin, specific origin, and label. To further analyze its effect, two separate ANOVAs for the label and no label conditions were conducted. Under the label condition, the analysis revealed a significant main effect of broad origin, $F_{(1,3072)} = 6.54$, $p = 0.011$, $\eta_p^2 = 0.002$, and a significant interaction effect of broad origin and specific origin, $F_{(1,3072)} = 10.7$, $p = 0.001$, $\eta_p^2 = 0.003$. Subsequent pairwise comparisons showed that in the case of images with labels and not from the specific origin, those that portrayed farms (M = 3.37, SD = 0.79) presented higher premiumness than those that portrayed cities (M = 3.17, SD = 0.69; $p < 0.001$). However, there was not a significant difference between farm and city images when they were from the specific origin and were labeled. Under the no label case, the analysis only revealed a significant main effect of broad origin, $F_{(1,3072)} = 8.98$, $p = 0.003$, $\eta_p^2 = 0.003$.

The results of Experiment 1 suggested that the fit between visual cues and coffee can be manipulated through indications of the terroir of the coffee, more specifically images varying in terms of the broad origin portrayed (farm or city), whether they are from the specific origin of the coffee or not, and whether they have labels indicating this specific origin. These findings seemed to indicate that visual cues of terroir can influence expectations of the product. These results provided support for hypothesis H1 and served as an initial step for further exploration. Since the broad origin factor (farm vs. city) had the most prominent effect on fit and premiumness expectations in a product information communication setting, in the subsequent experiments we aimed to evaluate whether the broad origin could also influence the coffee experience. For these experiments, we used VR atmospheres as they can provide a more immersive experience of contexts (congruent and incongruent with the terroir) than 2D images. Hence, VR atmospheres of a city and a coffee farm were used as stimuli for subsequent experiments.

4. EXPERIMENT 2: COFFEE-VR ATMOSPHERE FIT, PREMIUMNESS PERCEPTION, AND SENSORY EVALUATION WITH NON-EXPERTS

The goal of Experiment 2 was to investigate whether different VR atmospheres, varying in their level of fit with specialty coffee, would influence the perception of coffee premiumness. The selection of the visual stimuli was guided by the findings in Experiment 1, which indicated that broad origin (farm vs. city) was the main factor influencing fit and premiumness. Thus, the stimuli for Experiments 2 and 3 consisted of VR atmospheres of a city and a farm. In Experiment 2, we sought to understand the effect of more immersive visual cues close to the terroir of coffee (vs. far from the terroir) on consumers experiences in non-experts. Moreover, in this experiment, we wanted to widen the difference between the farm and the city in terms of their closeness to origin. We also explored whether such VR atmospheres would influence the perception of the sensory characteristics of the coffee. In this experiment, we moved on to actual coffee aroma evaluations, since it is a typical way in which consumers evaluate coffee prior to making purchasing decisions.

4.1. Methods

4.1.1. Participants

A total of 143 participants (39 males) took part in the experiment (age range 18–57, M = 26.0 years, SD = 7.2). The data corresponding to two participants was excluded from the analyses as they indicated in the questionnaire, they did not have a normal smell function. Hence, the final data consisted of observations from 141 participants. Participants were recruited through a behavioral studies platform at BI Norwegian Business School (Oslo, Norway), and they were compensated with NOK 30 for their time.

4.1.2. Apparatus and Materials

Participants were tasked to smell ground coffee from a small, white, resealable sample bag while exploring a VR atmosphere (**Figure 4A**). The bags contained approximately 20 g of Kiawamururu coffee from Nyeri, Kenya. The same coffee was used for the three atmospheres. The coffee had flavor notes of raspberries, red apples, and rose hips. To ensure quality and consistency, the coffee was previously ground, flushed

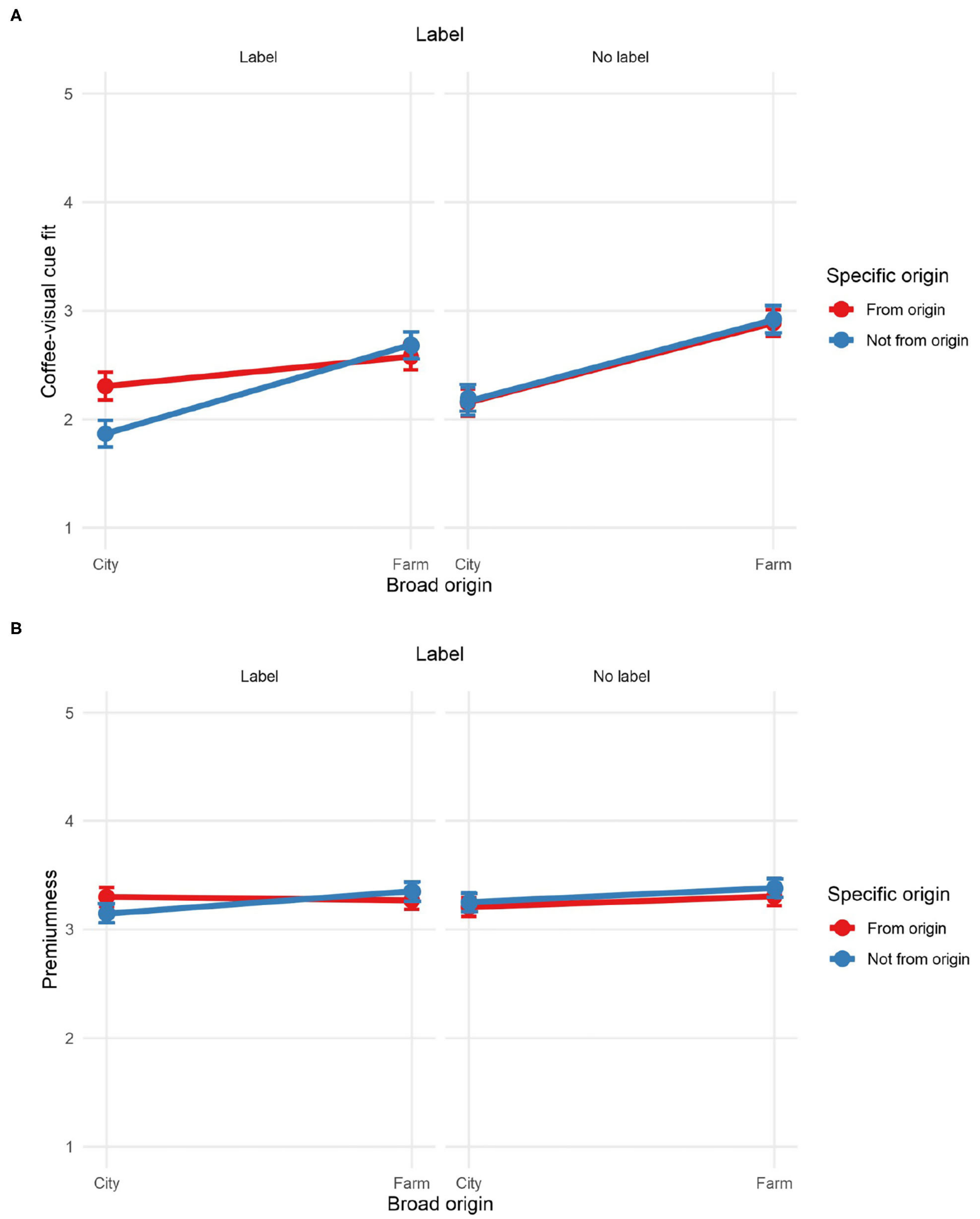

FIGURE 3 | Mean ratings of **(A)** fit and **(B)** premiumness in Experiment 1. Ratings of fit and premiumness on a 1–5 scale. Error bars: 95% CI.

FIGURE 4 | Panel **(A)** presents the instruments used in Experiment 2: Oculus GO virtual reality (VR) headset and sample coffee bag. The remaining panels show partial snapshots of the VR atmospheres used in Experiments 2 and 3: **(B)** farm, **(C)** city, and **(D)** control.

with nitrogen (to prevent oxidation), packaged, and sealed into the bags.

The stimuli for Experiment 2 consisted of high definition, 360-degree images—with no sound—of three different atmospheres corresponding to a farm, a city, and a control atmosphere (**Figure 4**). All the stimuli were presented in an Oculus Go VR headset. The capture of the farm was a coffee plantation in the Kangema Constituency of Kenya.[2] The image of the city was a capture of Times Square (New York City, United States)[3]. This atmosphere was chosen as we wanted to increase the level of incongruence between the atmosphere from the terroir vs. not from the terroir (farm vs. city). Finally, the control atmosphere consisted of a white room[4]. This atmosphere was chosen as a control as it is far from coffee contexts and relatively neutral. It is worth noting that the farm and the city atmosphere were real-life captures, while the control atmosphere was a computer-generated environment. Participants did not receive any prior information regarding any of the atmospheres (i.e., they were not told that the farm atmosphere was a coffee farm or that it was in Kenya).

In Experiment 2, we measured premiumness and fit as in Experiment 1, though here, participants were asked about the actual coffee aroma. Participants were asked to evaluate eight of the 10 sensory characteristics of the coffee, following the SCAA Arabica cupping form (Lingle and Menon, 2017), using slider scales from 0 to 100. The specific elements evaluated were aroma, flavor, acidity, sweetness, balance, and overall. Aftertaste and body were excluded from this experiment as they can only be evaluated by tasting the coffee. The experiment explored these characteristics as they are the ones that the specialty coffee professionals use when evaluating coffee (Lingle and Menon, 2017). We also asked participants to rate their willingness to purchase the coffee and their enjoyment of the overall experience using a slider scale from 0 to 100.

We included different control questions. Participants were asked to indicate the number of years they had lived in the city and the countryside and how familiar they were with specialty coffee with a five-point Likert scale ranging from 1 (*Not familiar at all*) to 5 (*Extremely familiar*).

Additionally, we included different control variables specific to VR. To measure the sense of presence in the VR environment, participants were asked to evaluate a series of statements on a five-point Likert scale ranging from 1 (*Strongly disagree*) to 5 (*Strongly agree*). More specifically, we used the five items of the Physical Presence sub-dimension of Makransky et al.'s (2017) scale. These five items measured physical realism, lack of awareness of physical mediation, consistency with real-world experiences, sense of being in the virtual environment, and captivation by the virtual environment.

[2]Extracted at second 46 of the 360-degree video "Come On In—Meet Coffee Farmer Samuel—360°" from the Fairtrade Association (https://youtu.be/LCmU-uK93wc?t=46).

[3]Extracted at second 30 from the video "EXTRA 5K 360 VR Video Times Square Manhattan New York Downtown Manhattan 2018 USA NYC 4k Jonnysbazar" (https://youtu.be/-UY0pzJdK7Y?t=30).

[4]Extracted from the video "White Room" (https://youtu.be/e6xduAUJUyg).

4.2. Experimental Design and Procedure

The experiment took place in the school's behavioral laboratory. First, participants provided their consent to take part in the experiment and later proceeded to indicate their age and gender and answer the control questions. Then, they were asked to stand up, were introduced to the Oculus GO VR headset, and were later asked to put the headset in on mode. Participants found themselves in the corresponding VR environment and after a few seconds to get familiar with the setting, participants received the bag of coffee. They were instructed to open the bag and smell the coffee as many times as they wished while they explored the atmosphere and assessed the coffee aroma. Note that participants were not able to see their hands or the coffee bag in the VR atmosphere. Once they finished, they removed the headset and returned the sample bag. Next they proceeded to answer the questions related to their premiumness perception, sensory characteristics, and intent to purchase the coffee, and their experience of the VR environment, using a desktop computer. The experiment lasted for approximately 10 min.

4.3. Analyses

The different dependent variables used in this experiment were analyzed by means of one-way ANOVAs. Tukey-corrected pairwise comparisons were conducted when significant effects were observed. Additionally, we conducted a serial mediation analysis since we were interested in the holistic experience and aimed to understand its underlying mechanism. We aimed to uncover whether the potential impact of the atmospheres on the enjoyment of the experience worked directly on this measure or indirectly through other aspects related to the experience. The analyses were conducted using R software (R Core Team, 2020), except the mediation analyses, which were performed with the PROCESS macro for SPSS (Hayes, 2012). The measure of premiumness resulted in a Cronbach's alpha of 0.84 (95% CI: 0.80, 0.89). The sense of presence measure consisted of the average of the five items of the physical realism sub-dimension in Makransky et al. (2017) scale, with a Cronbach's alpha of 0.82 (95% CI: 0.77, 0.86).

4.4. Results and Discussion

The summary statistics of all dependent variables are presented in **Table 2**.

4.4.1. Control Variables: Familiarity With the Coffee and Sense of Presence

The analysis did not reveal any significant effect of the VR atmospheres on the familiarity with the coffee (**Table 3**, **Figure 5A**). However, the analysis revealed a significant effect of the atmospheres on the sense of presence in the virtual environment (**Table 3**). Pairwise comparisons showed significant differences between the farm and control atmospheres ($p < 0.001$) and between the city and control atmospheres ($p < 0.001$) (**Figure 5B**). There was not a significant difference between the farm and the city atmospheres ($p = 0.625$). These results were expected as the city and farm atmospheres were more vivid, with

TABLE 2 | Descriptive statistics for Experiment 2.

	City (n = 48)		Control (n = 47)		Farm (n = 48)		Overall (n = 143)	
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Premiumness								
Quality	3.65^{ab}	0.79	3.40^{a}	0.97	3.94^{b}	0.81	3.66	0.88
Authenticity	3.85^{a}	0.90	3.57^{a}	0.99	4.00^{a}	1.05	3.81	0.99
Premiumness	3.44^{ab}	0.92	3.11^{a}	1.03	3.63^{b}	0.98	3.39	0.99
Willingness to pay a premium	3.06^{a}	0.93	3.04^{a}	0.98	3.40^{a}	0.96	3.17	0.96
Premiumness index	3.50^{ab}	0.70	3.28^{a}	0.84	3.74^{b}	0.78	3.51	0.79
Liking	4.15^{a}	1.03	4.17^{a}	1.03	4.38^{a}	1.00	4.23	1.02
Enjoyment of the experience	81.02^{a}	15.87	77.87^{a}	19.23	85.56^{a}	14.76	81.51	16.89
Intent to purchase	63.54^{a}	25.35	62.70^{a}	27.73	69.10^{a}	26.05	65.13	26.35
VR environment								
Coffee-VR atmosphere fit	3.35^{b}	1.14	2.26^{a}	1.26	3.60^{b}	1.05	3.08	1.28
Physical realism	3.40^{b}	1.16	2.66^{a}	1.17	3.81^{b}	1.10	3.29	1.23
Lack of awareness of physical mediation	3.46^{b}	0.97	2.94^{a}	1.17	3.29^{ab}	0.97	3.23	1.05
Consistency with experience in the real world	3.25^{b}	1.12	2.64^{a}	1.21	3.48^{b}	1.05	3.13	1.17
Sense of being in the virtual environment	3.75^{b}	1.12	3.00^{a}	1.34	3.96^{b}	1.13	3.57	1.26
Captivation by the virtual environment	3.38^{b}	1.08	2.66^{a}	1.31	3.48^{b}	1.13	3.17	1.22
Sensory evaluation								
Aroma	75.17^{a}	16.97	73.53^{a}	18.70	79.56^{b}	20.22	76.10	18.72
Flavor	70.58^{a}	17.68	71.28^{a}	17.49	73.77^{b}	20.29	71.88	18.46
Acidity	51.10^{ab}	21.10	43.28^{a}	21.58	54.42^{b}	22.50	49.64	22.09
Sweetness	44.40^{a}	22.23	56.23^{b}	22.18	53.06^{b}	20.49	51.20	22.07
Balance	65.21^{a}	18.73	63.49^{a}	17.91	68.79^{b}	16.61	65.85	17.78
Overall	73.10^{a}	16.28	72.15^{a}	15.21	77.48^{b}	16.92	74.26	16.21

Values within rows that do not share the same superscript letter are significantly different as per the Tukey-corrected pairwise comparisons (at $p < 0.05$).

more elements and colors than the control atmosphere, which consisted of a small, white room.

4.4.2. Coffee-VR Atmosphere Fit

The analysis revealed a significant effect of the atmospheres on the fit between the VR environment and the coffee (**Table 3**). Pairwise comparisons revealed significant differences between the farm and the control atmospheres ($p < 0.001$), and between the city and the control ($p < 0.001$) atmospheres. The difference in fit between the farm and city atmospheres was not statistically significant ($p = 0.538$) (**Figure 5C**). Contrary to our expectations, both the farm and the city atmosphere seemed to be a relatively congruent with the coffee experience compared to the control. Participants may not have found rich meaning in the farm atmosphere perhaps because they were just as equally suitable for the coffee or potentially because they might not have been aware it was a coffee farm. Non-experts may not be familiar with coffee farms, and their expectations of how they look like might differ greatly from reality.

4.4.3. Enjoyment of the Experience, Premiumness Perception, and Intent to Purchase

The ANOVA did not reveal a significant effect of atmospheres on the enjoyment of the experience (**Figure 5D**), failing to provide support to H3. However, a significant effect of the atmospheres on premiumness was observed (**Table 3**). Pairwise comparisons revealed a significant difference in premiumness perception between the farm atmosphere and the control ($p = 0.013$) but not between the farm and the city atmospheres ($p = 0.287$) (**Figure 5E**). Contrary to our expectations, these results only partially supported H1. The analysis did not reveal any significant effect of the atmospheres on intent to purchase (**Table 3**, **Figure 5F**), failing to provide support to H2.

Considering that the premiumness index involved a series of scales inspired by Ko et al. (2019), additional ANOVAs were conducted to assess the effect of the atmospheres on the individual components of premiumness and liking. The analyses revealed significant effects only on quality and premiumness, but not authenticity, willingness to pay a premium, or liking (see **Supplementary Table 2**). Significant differences were found

TABLE 3 | Analysis of variance (ANOVA) results for Experiment 2.

	F	*p*	η_p^2
Familiarity with the coffee	0.87	0.421	0.012
Sense of presence	**12.95**	**<0.001**	**0.156**
Coffee-VR atmosphere fit	**18.41**	**<0.001**	**0.208**
Premiumness	**4.15**	**0.018**	**0.056**
Intent to purchase	0.83	0.438	0.012
Enjoyment of experience	2.55	0.082	0.035
Aroma	1.33	0.268	0.019
Flavor	0.39	0.677	0.006
Acidity	**3.28**	**0.041**	**0.045**
Sweetness	**3.82**	**0.024**	**0.052**
Balance	1.10	0.335	0.016
Overall	1.48	0.232	0.021

Bold values indicate the statistically significant effects at p < 0.05.

between the farm and the control atmospheres in terms of the quality item (p = 0.029), as well as between the farm and the control atmosphere in the premiumness item (p = 0.008). It is possible that, despite perceiving the coffee as of higher quality and more premium under the farm atmosphere, participants still regarded coffee as an undifferentiated and ubiquitous product or that they are not greatly involved with the product category, resulting in no significant effects in value-related items (willingness to pay a premium and liking).

Furthermore, to look at the effect of the atmospheres and fit on the intent to purchase the product, we conducted a serial mediation analysis (Model 6 of Hayes, 2012; 10,000 bootstrap samples) with VR atmosphere coded as the independent variable, VR atmosphere fit, enjoyment of the experience, and premiumness as mediators; and intent to purchase as the key outcome variable (VR atmosphere → VR atmosphere fit → enjoyment of the experience → premiumness → intent to purchase). Those participants in the VR city atmosphere (vs. control, β = 1.07, t = 4.57, p < 0.001) and those in the VR farm atmosphere (vs. control, β = 1.32, t = 5.64, p < 0.001) reported significantly higher fit between the VR atmosphere and the coffee. Enjoyment of the experience was then regressed on VR atmosphere fit with a significant direct effect (β = 3.96, t = 3.39, p < 0.001). The effects of city (p = 0.66) and farm (p = 0.58) atmospheres were no longer significant, suggesting a full mediation. Moreover, we found significant direct effects of enjoyment of the experience on premiumness (β = 0.2, t = 6.25, p < 0.001). VR atmosphere fit also had a significant direct effect on premiumness (β = 0.16, t = 3.21, p = 0.002). The effect of premiumness (β = 8.93, t = 3.61, p < 0.001), as well as the effect of the enjoyment of the experience (β = 0.76, t = 6.77, p < 0.001), on intent to purchase were significant. The direct effects of VR atmosphere fit on intent to purchase was not significant (p = 0.07).

Finally, there were significant indirect effects of VR city atmosphere (vs. control, indirect effect = 0.80, 95% CI [0.17; 1.75] excluded zero) and VR farm atmosphere (vs. control, indirect effect = 0.98, 95% CI [0.20; 2.20] excluded zero) on intent to purchase through VR atmosphere fit, enjoyment of the experience, and premiumness, as mediators. Specifically, we found that the city and the farm atmospheres—as opposed to the control atmosphere—created higher VR atmosphere fit, which improved the enjoyment of the experience, subsequently increasing premiumness, and thereby positively affecting intent to purchase, giving partial support to H1, H2, and H3.

4.4.4. Sensory Evaluation

In terms of the perceived sensory characteristics of the coffee, the analysis revealed a significant effect of atmosphere on acidity and sweetness (**Table 3**, **Figures 5G,H**). Participants rated the coffee as more acidic under the farm atmosphere compared to the control (p = 0.036). Participants found the coffee sweeter under the control vs. the city atmosphere (p = 0.023).

Overall, the results of Experiment 2 showed that the farm and city atmospheres elicited a higher sense of presence compared to the control. Contrary to our expectations, both the city and the farm appeared to be contexts with relatively high congruence with the coffee experience. In other words, participants seemed to associate both environments with coffee. Furthermore, participants rated the coffee as more premium under the farm atmosphere compared to the control but not the city, which showed partial support to H1. The atmospheres indirectly influenced the intent to purchase and the enjoyment of the experience, through VR atmosphere fit and premiumness perception, giving partial support to H2 and H3, respectively. The results showed that atmospheric cues can affect the sensory perception of coffee, in terms of sweetness and acidity. In the next experiment, we sought to explore whether the VR atmospheres could also influence the coffee experience in coffee professionals.

5. EXPERIMENT 3: COFFEE-VR ATMOSPHERE FIT, PREMIUMNESS PERCEPTION, AND SENSORY EVALUATION WITH SPECIALTY COFFEE PROFESSIONALS

Specialty coffee has experienced a significant growth in interest that has resulted in a rising number of professionals in the field (Lingle and Menon, 2017). Specialty coffee professionals might evaluate products differently (cf. Spence and Carvalho, 2020). For this experiment,we elaborated our design based on previous research on beer and wine. The former suggests that the knowledge experts develop seems to enhance their recognition memory of beers, though this training does not seem to influence their perceptual abilities (Van Doorn et al., 2020). However, the wine literature suggests that experts tend to rely less on extrinsic cues when evaluating wines (D'Alessandro and Pecotich, 2013; Lee et al., 2018). Due to the specific characteristics that make specialty coffee professionals, we decided to conduct an experiment similar to Experiment

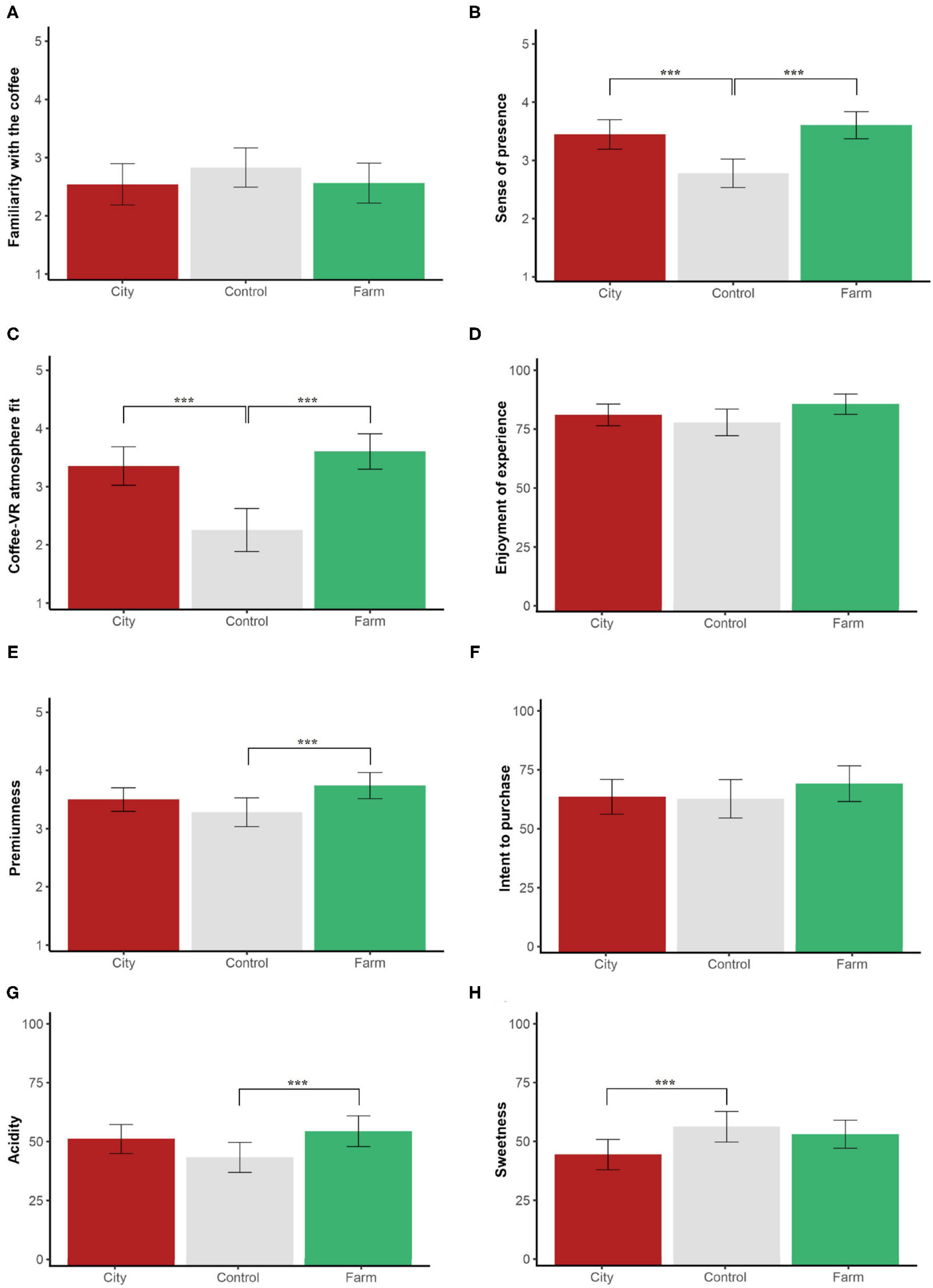

FIGURE 5 | Mean ratings of **(A)** familiarity with the coffee, **(B)** sense of presence, **(C)** coffee-virtual reality (VR) atmosphere fit, **(D)** enjoyment of the experience, **(E)** premiumness, **(F)** intent to purchase, **(G)** acidity, and **(H)** sweetness for Experiment 2. Ratings of **(A–C,E)** on a 1–5 scale. Error bars: 95% CI. Significantly different comparisons: ***$p < 0.01$.

2 only on this population, which would allow us to better understand non-expert consumers by comparing the results of both studies. Experiment 3 explores the effect of the different VR atmospheres on the premiumness perception and sensory evaluation of coffee by industry professionals. As explained in the theoretical background, non-experts form expectations differently compared to professionals. Thus, in this experiment, we moved on to taste with professionals as it is how they evaluate and test coffee.

5.1. Methods

5.1.1. Participants

A total of 34 individuals (21 males) participated in the experiment (age range 19–57, $M = 36.2$ years, $SD = 9.2$). Participants were recruited from Nordic approach, different coffee roasteries, and other companies in the specialty coffee industry. The pool of participants consisted of professionals working in the specialty coffee industry with expertise in specialty coffee quality and roasting (including certified cuppers and professional roasters) or at the minimum specialized knowledge and experience in cupping, coffee grades, and roasting.

Although other studies in consumer science involving participants with specialized knowledge have used similar sample sizes (Sauvageot et al., 2006; Valentin et al., 2007; Worch et al., 2010; D'Alessandro and Pecotich, 2013), we acknowledge this as a limitation at the outset. Despite this limitation, though, we decided to present this experiment as it provides relevant insights and a steppingstone for future studies.

5.1.2. Apparatus and Materials

In this experiment, participants were tasked to taste a sample of brewed coffee while exploring a VR atmosphere. Participants tasted approximately 100 mL of AA Muthuaini coffee from Nyeri, Kenya, at approximately 60○C from a standard clear glass. The brewed coffee was kept in a professional-grade thermal carafe and was poured into the glass immediately before each participant was going to taste it. Multiple batches of coffee were brewed during the duration of the experiment in order to ensure temperature consistency. The coffee had flavor notes of black currant, red currant, and lime, and it had a cupping score of 87. The cupping score is a measure of the quality of the coffee and ranges from 0 to 100. The score is obtained in standardized coffee tastings by professionals under controlled circumstances. A score above 85 indicates specialty coffees. The VR atmospheres were the same as those used in Experiment 2. However, to increase the generalizability of the analysis, the 360-degree images for the farm and the city conditions were extracted at slightly different points in time in the videos (at seconds 48 and 32, respectively).

We measured premiumness as in Experiments 1 and 2. Regarding the sensory evaluation, participants evaluated the 10 sensory characteristics from the SCAA Arabica cupping form. Aftertaste and body were added here since they can be evaluated by tasting the coffee. Participants also evaluated how much they enjoyed the drinking experience and how likely they were to purchase the coffee. Finally, they also rated their sense of presence in the atmosphere as in Experiment 2.

5.2. Experimental Design and Procedure

The experiment took place in Nordic Approach's office in Oslo, Norway. The procedure was as in Experiment 2, except that in this case, participants were given a glass with brewed coffee to taste instead of ground beans to smell. Similar to Experiment 2, participants did not see their hands or the cup of coffee in the VR environment. After they tasted the coffee and explored the VR atmosphere, they removed the VR headset and proceeded to complete the questionnaire in their smartphones (**Figure 6**).

5.3. Analyses

The analyses performed were the same as in Experiment 2. The measure of premiumness resulted in a Cronbach's alpha of 0.80 (95% CI: 0.69, 0.91), and the sense of presence resulted in a Cronbach's alpha of 0.74 (95% CI: 0.60, 0.88).

5.4. Results and Discussion

Descriptive statistics showed small differences in the various components of premiumness, sensory characteristics, and sense of presence across the different atmospheres (**Table 4**).

5.4.1. Control Variables: Familiarity With the Coffee and Sense of Presence

Similar to Experiment 2, the analysis did not reveal any significant effect of the VR atmospheres on the familiarity with the coffee (**Table 5**, **Figure 7A**). However, unlike non-experts, there were no significant differences among the atmospheres in terms of sense of presence for coffee professionals (**Table 5**, **Figure 7B**).

5.4.2. Coffee-VR Atmosphere Fit

The analysis revealed a significant effect of the atmospheres on the fit between the coffee and the VR atmospheres (**Table 5**). Pairwise comparisons showed a significant difference in fit between the farm atmosphere and the control ($p = 0.002$). However, there was not a statistically significant difference between the farm and city atmospheres ($p = 0.266$) (**Figure 7C**).

5.4.3. Enjoyment of the Experience, Premiumness Perception, and Intent to Purchase

The ANOVA revealed a significant effect of atmosphere on the enjoyment of the experience (**Table 5**). Pairwise comparisons showed a significant difference between the farm and the control atmospheres ($p = 0.023$) (**Figure 7D**), partially supporting H3. However, the analysis did not reveal any significant effect of the atmospheres on premiumness or on intent to purchase (**Table 5**, **Figures 7E,F**). These results failed to support hypotheses H1 and H2, in specialty coffee professionals.

Similar to Experiment 2, we also conducted a serial mediation analysis (Model 6 of Hayes, 2012; 10,000 bootstrap samples) (VR atmosphere → VR atmosphere fit → enjoyment of the experience → premiumness → intent to purchase). However, contrary to Experiment 2, the effects of VR city atmosphere (vs. control, indirect effect = 0.53, 95% CI [−0.53; 1.55] included zero), and VR farm atmosphere (vs. control, indirect effect = 1.03, 95% CI [−0.94; 2.60] included zero) on intent to purchase through VR atmosphere fit, enjoyment of the experience, and premiumness, as mediators were not significant. Those in the VR

FIGURE 6 | Instruments used in Experiment 3: Oculus GO virtual reality (VR) headset and brewed coffee.

farm atmosphere reported significantly higher VR atmosphere fit than those in the control atmosphere (β = 1.83, t = 3.92, $p <$ 0.001). However, those in the VR city atmosphere did not report significantly higher VR atmosphere fit vs. the control (β = 0.95, t = 1.99, p = 0.06). Enjoyment of the experience was then regressed on VR atmosphere fit, but the direct effects were not significant (p = 0.16), as well as the direct effects of city (p = 0.20) and farm (p = 0.16) atmospheres. Neither VR atmosphere fit (p = 0.62), nor the enjoyment of the experience (p = 0.17) had any significant effects on premiumness. We only found direct effects of enjoyment of the experience (β = 0.39, t = 3.81, $p <$ 0.001) and premiumness (β = 14.36, t = 5.4, $p <$ 0.001) on intent to purchase.

5.4.4. Sensory Evaluation

Contrary to Experiment 2, the analysis showed no significant effect of the virtual atmospheres in any of the sensory characteristics of the coffee (**Table 5**).

The results of Experiment 3 seemed to indicate that there is a higher fit between coffee and atmospheric cues that evoke its terroir, compared to the control but not to the city. The atmospheric cues did not influence intent to purchase in specialty coffee professionals. Experts seemed to enjoy the experience significantly more under the farm atmosphere vs. the control. However, there were no significant differences in the perception of premiumness or any of the sensory characteristics of the coffee.

6. GENERAL DISCUSSION

In this study, we investigated the effect of visual atmospheric cues on the expectation and perception of premiumness, enjoyment of the experience, intent to purchase, and sensory evaluations of coffee in non-experts and specialty coffee professionals. We explored these effects using 2D online images and 360-degree VR atmospheres. We found that 2D visual cues evoking the broad origin of coffee (represented by a coffee farm) could influence premiumness expectations in non-expert consumers, supporting H1. Our results showed that VR atmospheres that portrayed the broad terroir of coffee, given by a farm (vs. a control atmosphere but not a city), could increase premiumness perception in non-experts—partially supporting H1—and the enjoyment of the experience in professionals—partially supporting H3. Moreover, for non-experts, both the farm and the city atmospheres indirectly increased the intent to purchase the coffee through coffee-VR atmosphere fit, enjoyment of the experience, and premiumness—partially supporting H2. Furthermore, these visual atmospheric cues influenced the sensory evaluation of coffee in non-experts in terms of sweetness and acidity.

In particular, we found that 2D visual cues that illustrated the broad origin of coffee presented high fit with the product and increased premiumness expectations. However, whether the image was from the specific origin of the coffee or not, and whether this image had a label indicating its location, had a negligible effect on fit and premiumness expectations. This being said, the relevant factor was that the images presented something that resembled the broad origin of the coffee (e.g., a coffee farm). Since non-experts may not be able to differentiate between images of urban or rural areas of countries that produce coffee, the location represented in the image did not influence premiumness expectations. Even with indications that the images were not from the specific origin of the coffee, other things equal, this discrepancy did not affect the fit and premiumness expectations.

TABLE 4 | Descriptive statistics for Experiment 3.

	City (n = 11)		Control (n = 10)		Farm (n = 13)		Overall (n = 34)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Premiumness								
Quality	4.18[a]	0.87	4.40[a]	0.52	4.15[a]	0.90	4.24	0.78
Authenticity	3.64[a]	0.92	4.00[a]	0.82	4.31[a]	0.95	4.00	0.92
Premiumness	4.18[a]	0.60	4.60[a]	0.70	4.15[a]	1.07	4.29	0.84
Willingness to pay a premium	3.82[a]	1.33	3.60[a]	0.97	4.23[a]	0.73	3.91	1.03
Premiumness index	3.95[a]	0.84	4.15[a]	0.47	4.21[a]	0.78	4.11	0.71
Liking	4.18[a]	0.75	4.60[a]	0.52	4.23[a]	1.01	4.32	0.81
Enjoyment of the experience	69.91[ab]	15.10	56.70[a]	25.44	79.92[b]	17.93	69.85	21.33
Intent to purchase	70.45[a]	17.56	68.10[a]	11.35	73.69[a]	22.78	71.00	17.97
VR environment								
Coffee-VR atmosphere fit	2.73[ab]	1.19	1.70[a]	1.25	3.46[b]	0.97	2.71	1.31
Physical realism	3.82[a]	0.98	2.70[a]	1.25	3.46[a]	1.20	3.35	1.20
Lack of awareness of physical mediation	3.18[a]	1.25	2.90[a]	0.99	2.38[a]	0.96	2.79	1.09
Consistency with experience in the real world	3.18[a]	1.25	2.80[a]	1.32	2.77[a]	1.01	2.91	1.16
Sense of being in the virtual environment	3.73[a]	1.01	3.30[a]	1.34	3.46[a]	0.88	3.50	1.05
Captivation by the virtual environment	3.36[a]	1.43	2.20[a]	1.23	2.77[a]	1.01	2.79	1.27
Sensory evaluation								
Aroma	75.82[a]	8.27	68.10[a]	14.69	74.23[a]	19.84	72.94	15.27
Flavor	75.64[a]	11.89	71.70[a]	14.35	77.85[a]	14.82	75.32	13.62
Aftertaste	68.18[a]	23.91	70.30[a]	16.45	75.77[a]	17.24	71.71	19.14
Acidity	77.82[a]	14.62	70.10[a]	12.95	81.00[a]	10.80	76.76	13.18
Sweetness	72.45[a]	20.68	72.10[a]	19.08	76.92[a]	14.28	74.06	17.56
Body	71.45[a]	19.06	70.70[a]	14.27	72.31[a]	19.51	71.56	17.45
Balance	74.18[a]	9.84	72.90[a]	10.72	74.54[a]	18.16	73.94	13.46
Overall	74.36[a]	14.83	75.70[a]	10.95	79.31[a]	14.27	76.65	13.35

Values within rows that do not share the same superscript letter are significantly different as per the Tukey-corrected pairwise comparisons (at $p < 0.05$).

Our results revealed differences among the VR atmospheres in terms of sense of presence. As one may expect at present, we found that atmospheres that portrayed the real world (i.e., the farm and the city), vs. computer-generated images (the control white room), triggered significantly higher sense of presence. These differences are not surprising since both the farm and the city atmospheres provided a richer experience, in terms of vividness, than the control atmosphere. More specifically, the difference in vividness is related to higher depth (Steuer, 1992), which is a key determinant for telepresence (Kim and Biocca, 1997; Willems et al., 2019). The control atmosphere consisted of a white, 3D computer-generated model of a small room. On the other hand, the other two atmospheres were high definition images of the real world with a wider variety of elements and details, as well as varied gamut of colors.

Telepresence is a crucial part of the online consumer experience (see Mollen and Wilson, 2010 for a review). Several studies have shown that telepresence can increase consumers' perception of product knowledge, attitudes, and intent to purchase (Klein, 2003; Suh and Chang, 2006; Animesh et al., 2011; Algharabat, 2018). Fiore et al. (2005) suggested that the sense of presence is related to the ability to provide sensory information about the product that might be particularly relevant for the evaluation of coffee in virtual environments.

6.1. Premiumness Associations

Following the concept of schema congruence, our a priori expectation was that the farm atmosphere was the most congruent with the coffee as they shared the common meaning of terroir or origin of the coffee (Mandler, 1982; Keller, 1993). Having said this, both the farm and the city atmospheres seemed to be somewhat congruent with the coffee as both presented significant differences compared to the control but not against each other. It is possible that consumers' schema related to coffee was not sufficient to share meaning with the farm atmosphere. Most people have never been to a coffee farm,

TABLE 5 | Analysis of variance (ANOVA) results for Experiment 3.

	F	p	η_p^2
Familiarity with the coffee	0.79	0.464	0.048
Sense of presence	2.11	0.138	0.120
Coffee-VR atmosphere fit	**6.88**	**0.003**	**0.308**
Premiumness	0.40	0.676	0.025
Intent to purchase	0.27	0.766	0.017
Enjoyment of experience	**3.95**	**0.030**	**0.203**
Aroma	0.73	0.489	0.045
Flavor	0.56	0.574	0.035
Acidity	2.12	0.137	0.120
Sweetness	0.27	0.766	0.017
Balance	0.04	0.959	0.003
Aftertaste	0.49	0.617	0.031
Body	0.02	0.977	0.001
Overall	0.43	0.655	0.027

Bold values indicate the statistically significant effects at $p < 0.05$.

and in effect, not sampled coffee in such a context. Moreover, people may have different expectations about how a coffee farm looks like. Furthermore, based on the concept of situational appropriateness (Giacalone and Jaeger, 2019b), it is possible that the city atmosphere was congruent with the coffee since coffee is more often consumed in city contexts.

Nevertheless, non-experts rated the coffee as more premium only under the farm atmosphere compared to the control. It is possible that despite participants' limited knowledge of coffee's terroir, some of them made associations between the coffee and something with nature that looked like a place where it may come from. As previous research has shown, indications of a product's origin can be associated with quality traits (Spielmann et al., 2014). Hence, they may have expected the coffee to be of high quality, which is a component of premiumness.

In the case of the control atmosphere, consumers might not have drawn any association with the coffee, which resulted in a lack of both (in)congruence and relevance. Studying the suitability between sponsors and events, Fleck and Quester (2007) suggested that congruence derives from two sources, namely expectancy and relevance. When unexpectedness is coupled with enough relevance to retain meaning, the resulting effect of moderate (vs. high or low) congruence is the most impactful (see also Gillespie et al., 2018; Zdravkovic et al., 2010). In our study, the lack of congruence and relevance from the control atmosphere could have led to the poorest evaluations of the coffee.

Another possible explanation can be derived from the curiosity hypothesis (Berlyne, 1966). The experience of the city atmosphere likely matched most consumers' expectations about coffee very closely, as it is a regular place for consumption, which may not have been remarkable and not have affected their hedonic state. However, the farm atmosphere may have been a surprise, or slight deviation from expectations, in the regular coffee experience, and could have resulted in increased curiosity and hence, a modestly higher degree of arousal (Schifferstein et al., 1999). More recently, as Hill et al. (2016) found, curiosity can generate more positive evaluations of products experiences and indirectly increase intent to purchase.

Contrary to the findings in non-experts, we did not find any effect of atmospheric cues in the perception of premiumness of coffee or its sensory evaluation in coffee professionals. It is likely that, given their specialized knowledge, coffee professionals examined more objective attributes of the coffee and could discriminate intrinsic factors relevant for the assessment of the coffee from irrelevant extrinsic cues (Lee and Lee, 2009). Furthermore, experts can use origin cues to weigh the quality of products for which origin is highly relevant, such as wine (D'Alessandro and Pecotich, 2013; Warman and Lewis, 2019). However, in our case, participants received no prior information regarding the coffee (e.g., origin, notes) or the atmospheres (e.g., location or whether they had some relationship with the coffee or not) that allowed them to make a product-origin match and make such assessments. Hence, it is likely they relied on an independent evaluation of the coffee without considering the atmospheres.

6.2. Enjoyment of the Experience

Product experiences are the sum of multiple factors, including the sensory elements of the products, associated emotions, and the meaning communicated to consumers (Hekkert and Schifferstein, 2008). The enjoyment of these experiences will be determined not just by the properties of the product itself, but by sensorial, emotional, cognitive, pragmatic, lifestyle, and relational dimensions (Gentile et al., 2007; De Keyser et al., 2015). On this line, Reinoso Carvalho et al. (2016) found that participants reported liking the sound-beer (congruent) tasting experience more when their attention was drawn toward both the beer and the music, as a single multisensory experience. This suggests that when people are asked to evaluate the experience as a whole, rather than the individual parts of it, congruence may influence enjoyment. Furthermore, meaning in the form of product/brand values and associations, as well as relationships and past experiences play a key role in product experiences. For instance, in a study exploring the drinking experience of beer, Gómez-Corona et al. (2017) found that the cognitive dimension is more salient for craft beers than for industrial ones and that consumers engage with the former through intellectual experiences and inquire about them (including their origin).

The context in which a product is consumed is another important factor for its experience. As Meiselman (2008) suggested, product experiences also relate to the interaction between a product and specific contexts and situations, which can influence the emotions people experience while consuming a product. More appropriate scenarios for food consumption can trigger more positive emotions (Torrico et al., 2020). Thus, the same product can be experienced differently depending on the context and situation.

Related to the present study, we did not find significant effects of the VR atmospheres on the enjoyment of the experience in

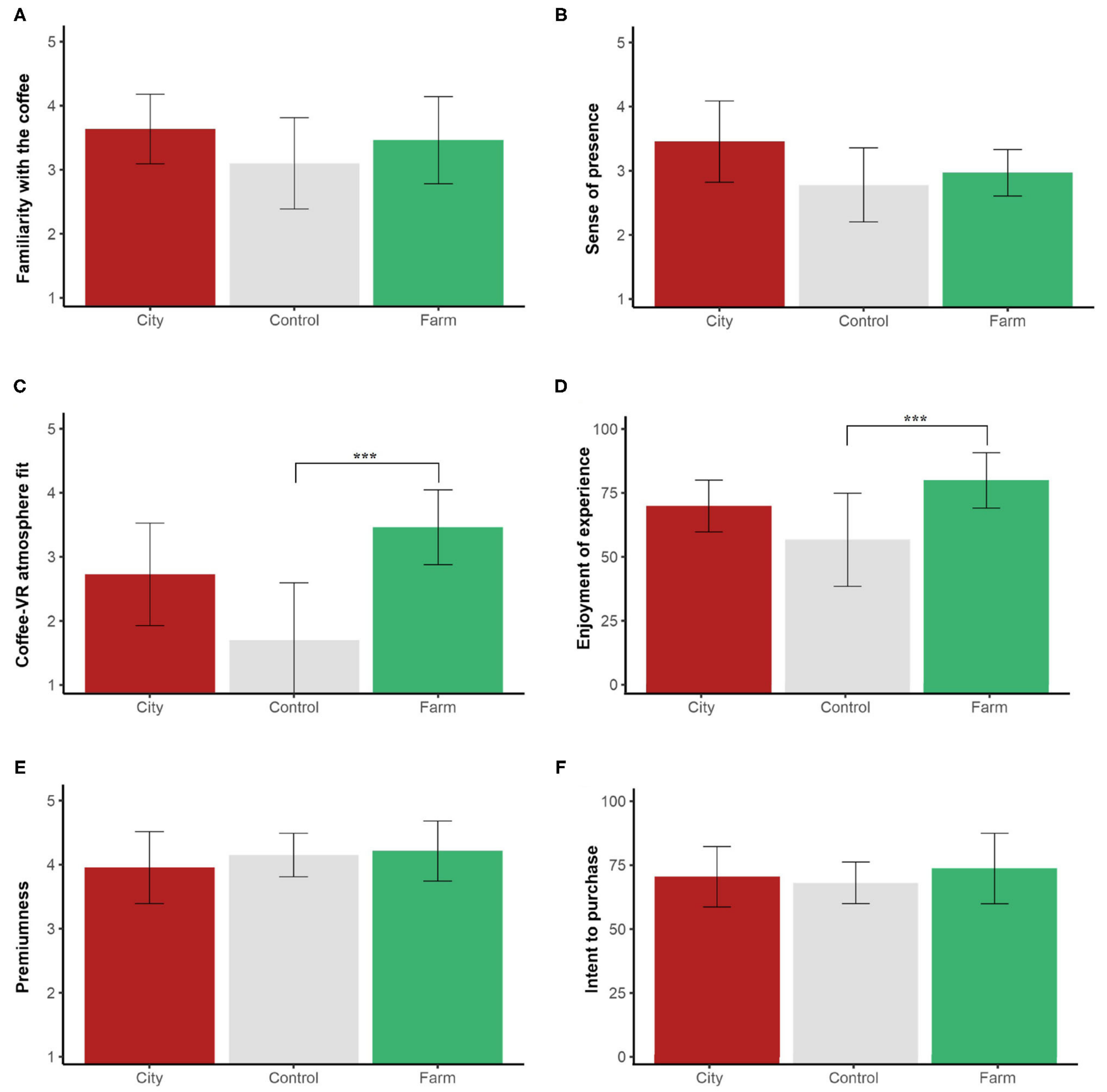

FIGURE 7 | Mean evaluations of **(A)** familiarity with the coffee, **(B)** sense of presence, **(C)** coffee-VR atmosphere fit, **(D)** enjoyment of the experience, **(E)** premiumness, and **(F)** intent to purchase for Experiment 3. Ratings of **(A–C,E)** on a 1–5 scale. Error bars: 95% CI. Significantly different comparisons: *** $p < 0.01$.

non-experts. Consumers' knowledge of the value of the coffee's origin may be limited, so an atmosphere related to the terroir of coffee would not have much significance. Thus, consumers may have seen the coffee as a commodity product in isolation and not made a connection with the atmosphere to form an experience with rich meaning. Consumers may need to have a minimum degree of knowledge about the value of terroir in order to make sense of semiotic meanings of sense of place and frame consumption experiences (Smith Maguire, 2010; Charters et al., 2017). On the other hand, coffee professionals reported significantly higher ratings of enjoyment of the experience under the farm atmosphere compared to the control but not to the city. It is possible that the knowledge of coffee professionals about the value of terroir in coffee imbued the farm with greater context and meaning, so they did not see the coffee as a product in isolation but more as a holistic experience related to their specialized knowledge, which made it more enjoyable. These results are consistent with Wen and Leung (2021), who found consumers with higher levels of wine knowledge tend to appreciate virtual wine tours and the wine itself more than those consumers with lower levels of knowledge. The city could have also provided context and meaning to the experience, albeit a more routinely experience of drinking coffee in an everyday scenario that is not associated with the origin of the coffee and less so with specialty coffee.

6.3. From Visual Cues to Purchase Intent

The serial mediation results revealed that the city and farm atmospheres (vs. control) had significant positive effects on intent to purchase through VR atmosphere fit, enjoyment of the experience, and premiumness, in non-experts, partially supporting our three hypotheses. First, we found that VR atmosphere fit fully mediated the effect of the atmospheres on the enjoyment of the experience. Indeed, several studies have highlighted the importance of the characteristics of the contexts in which food is consumed for its enjoyment and evaluations (Meiselman et al., 2000; Edwards et al., 2003; Köster, 2003; Petit and Sieffermann, 2007; Piqueras-Fiszman and Jaeger, 2014a,b). For instance, Piqueras-Fiszman and Jaeger (2014a) suggested that higher perceived appropriateness between a product and the context in which it is consumed can elicit more positive emotions. Our results with non-experts also confirm the role of fit between product and place of origin on product's evaluations (Häubl and Elrod, 1999; Chen and Tsai, 2007; Johnson et al., 2016; Spielmann, 2016) and indicate that the enjoyment of the experience is positively related to these evaluations.

In the case of coffee professionals, the effect of the atmospheres was not mediated by the fit between the coffee and the VR atmosphere, which as mentioned before, confirms the importance of the meaning of the atmospheres themselves coupled with previous knowledge. Furthermore, we found that VR atmosphere fit, as well as enjoyment of the experience mediated the effect of the atmospheres on the expectation of premiumness. These results are in line with previous studies showing the positive impact of fit and enjoyment of the experience on premiumness perception (Creusen et al., 2018). Finally, we observed direct effects of premiumness and enjoyment of the experience on intent to purchase.

Overall, it is likely that the congruence between the coffee and the atmospheres reduced the cognitive effort required to make sense of the premium experience, leading to a higher enjoyment and subsequently to better product evaluations that in the end increased intent to purchase. These results bring support to previous research that highlighted the interest of using images about a specific location to nudge toward higher intent to purchase (Hosany et al., 2006; Chen and Tsai, 2007). Moreover, they are consistent with previous studies that have shown the essential role of marketing experiences on intent to purchase (Schmitt, 1999; Babin and Attaway, 2000; Turley and Milliman, 2000), in particular in the luxury sector, where experiences play an important role in the perceived quality of the product (Vigneron and Johnson, 2004; Christodoulides et al., 2009; Hung et al., 2011). As Lee et al. (2015) suggested, consumers derive value from luxury goods from hedonic and symbolic attributes, besides quality benefits. Moreover, cues about the origin of the product convey important information in luxury goods (Godey et al., 2012). The perceived level of fit between a brand and its origin will influence affective behaviors toward the brand and subsequently intent to purchase (Siew et al., 2018).

6.4. Sensory Evaluation

While taste refers to what happens in the tongue, consumers can attribute taste qualities to odors mainly because odors are associated with tastes when they are experienced in tandem by eating (Stevenson et al., 1999). Moreover, consumers use attributes or descriptors related to other senses to describe olfactory stimuli due to the multiple crossmodal correspondences between the senses (Velasco et al., 2014; see also Deroy et al., 2013). This relationship between taste and smell allows consumers to form tastes expectations of food and beverage products by smelling them. In our study with non-experts, we obtained unexpected findings regarding the sensory evaluation of coffee aromas. Participants found the coffee more acidic under the farm atmosphere compared to the control. Moreover, they evaluated the coffee under the city atmosphere as significantly less sweet compared to the control. The results in the evaluation of sweetness may have arisen due to the varying degrees of sensory complexity of the different atmospheres.

In the farm atmosphere, it is possible that a sensation transference effect was at play and predominant colors in the atmospheres influenced participants' tastes perception (Cheskin, 1957; Chen et al., 2018). Indeed, Chen et al. (2020) found that sweet-congruent (i.e., round shapes and red colors) VR environments can increase the perception of sweetness of beverages (i.e., grenadine juice). In our case, it is possible that participants associated the high amount of green color with expectations of acidity of the coffee. Research suggests that there is a color-basic taste crossmodal correspondence between green and sourness/acidity (Spence et al., 2015; Saluja and Stevenson, 2018) that can influence drinking experiences (Spence et al., 2014; Carvalho and Spence, 2019).

A potential explanation for the lower sweetness ratings in the city atmosphere is that the latter, although only visual, evoked the perception of loud background noise or perhaps sensory overload, thus reducing the perception of sweetness. Several studies have highlighted that visual cues can facilitate mental simulation (Elder and Krishna, 2012; Cian et al., 2014; Xie et al., 2016; Petit et al., 2017, 2018; Palcu et al., 2019). In the same way, 3D images (VR and AR) appear to stimulate mental simulation (Choi and Taylor, 2014; Heller et al., 2019). Furthermore, as previous literature suggests, loud noises can affect the perception of sweetness (Woods et al., 2011; Stafford et al., 2013; Velasco et al., 2014; Yan and Dando, 2015; Lin et al., 2019; Xu et al., 2019).

7. LIMITATIONS AND RESEARCH PERSPECTIVES

One of the main limitations of the present study relates to the atmospheres used in Experiments 2 and 3. The response of participants, as well as the fit of the VR atmospheres with coffee, was likely to be dependent on the specific stimuli presented. For instance, some people might have had a special connection to a specific city presented, and others might have had special memories from farms. Expanding this study to explore atmospheres completely unrelated or negatively associated with coffee could yield interesting results. Moreover, while we explored different levels of fit with the stimuli, there was no control condition in Experiment 1. Exploring the effects of stimuli unrelated, or with no context, with respect to the coffee would provide a better control for the effect of origin cues.

It should also be noted that in Experiments 2 and 3, we only tested one coffee sample. Additionally, in Experiment 2, the task consisted of smelling the coffee, whereas the task in Experiment 3 was to taste the coffee. This provides consistent insights associated with different stages of the specialty coffee journey. However, to ensure that results are not coffee and origin dependent, future studies should involve coffees from different places of origin and incorporate smelling and tasting for both the non-experts and professionals.

Furthermore, different elements in the atmospheres could not be fully controlled. For example, the atmospheres diverged in lighting, colors, number of people, and proximity to these people, among other factors. Other elements not controlled for in the atmospheres were the overall hue and brightness of our different atmospheres, which could have affected participants' perception of product premiumness and intent to purchase, as well as experience enjoyment (cf. Spence et al., 2014). In our study, the coffee could have been evaluated better under the city atmosphere due to the colorfulness and increased color lightness in the city atmosphere compared to the farm. Several studies have highlighted the effect of colors on consumers' expectations and perceptions of packaged products (Gatti et al., 2014; Tijssen et al., 2017). For example, Paakki et al. (2019) suggested that more colorful products are more attractive and are preferred to less colorful ones. Motoki et al. (2019) also suggested that consumers prefer light-colored products compared to dark-colored ones. Future studies should be conducted to control for how the overall color space in the atmosphere can affect premiumness perception.

Despite the support of a prominent specialty green coffee sourcing company, recruiting coffee professionals was challenging, which resulted in a low sample size in Experiment 3. Nevertheless, our results serve as an initial step to study the effect of virtual atmospheric cues on the perception of premiumness, enjoyment of product experiences, and intent to purchase. Future studies can further explore differences between non-experts and professionals through studies with more statistical power. Extending this research to products for which terroir is crucial vs. other products for which it is less important could also provide exciting results. Moreover, further studies could explore whether highlighting the maker of a product has a greater impact than highlighting the place of production in manufactured products. Exploring the possibilities of using multisensory enabling technologies with other senses, such as touch, could also generate relevant insights (Petit et al., 2019).

8. IMPLICATIONS FOR INDUSTRY

The use of VR is still in its early stages in many industries, but its relevance and degree of implementation is growing (Boyd and Koles, 2019). Hence, it is imperative that practitioners are aware of key factors that make effective virtual experiences. Our findings are highly relevant and lead to interesting reflections for industry as they can help guide the creation of product-based VR experiences. Developers may aim to enhance the sense of presence of virtual experiences since it can influence their quality and enjoyment. As our results suggested, physical realism and consistency with the real world are critical aspects in generating a high sense of presence in these experiences. While VR can be used to develop non-worlds, developers and marketers should strive to create relevant connections between virtual experiences and their underlying products in terms shared meaning and appropriate contexts.

While our results did not reveal a significant difference between the farm and the city atmospheres, inexpensive versions of VR can be used to attract and introduce new consumers to specialty coffee and communicate the added value of terroir by engaging them in novel immersive experiences. These inexpensive solutions can make the coffee experience at home more enjoyable by portraying relevant scenarios, whether they are related to the origin of coffee or to consumption contexts.

DATA AVAILABILITY STATEMENT

The datasets generated and analyzed in this study can be found in OSF at https://osf.io/5vne6/.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of BI Norwegian Business School. The patients provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

FBE: conceptualization, methodology, formal analysis, investigation, writing-original draft, writing-review and editing, and visualization. OP: methodology, validation, formal analysis, resources, writing-review and editing, and visualization. CV: conceptualization, methodology, validation, formal analysis, investigation, resources, writing-review and editing, visualization, supervision, and funding acquisition. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.586983/full#supplementary-material

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Multisensory Experiences: A Primer

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We present a primer on multisensory experiences, the different components of this concept, as well as a reflection of its implications for individuals and society. We define multisensory experiences, illustrate how to understand them, elaborate on the role of technology in such experiences, and present the three laws of multisensory experiences, which can guide discussion on their implications. Further, we introduce the case of multisensory experiences in the context of eating and human-food interaction to illustrate how its components operationalize. We expect that this article provides a first point of contact for those interested in multisensory experiences, as well as multisensory experiences in the context of human-food interaction.

Keywords: multisensory experiences, human-computer interaction, technology, senses, psychology, marketing

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INTRODUCTION

Our life experiences are multisensory in nature. Think about this moment. You may be reading this article while immersed in a sound atmosphere. There may be a smell in the environment, even if you are not aware of it, and you may be drinking a cup of coffee or eating something, while touching the means through which you read the article. All these different sensory inputs, but perhaps more, influence the experience that you have about reading the article. But what if we could design such multisensory arrangement to create a given, intended, experience?

In this article, we present a primer on multisensory experiences. This term is interdisciplinary and used in multiple research and practice fields, ranging from psychology, through marketing, to human-computer interaction (HCI). Although researchers from such fields have referred to multisensory experiences, there is still no conceptual article focusing exclusively on the term itself, and its implications. After presenting a primer on multisensory experiences, the role of technology in them, and their implications for individuals and society, we move on to discuss an example of multisensory experiences in the context of eating and the growing field of human-food interaction (HFI). At the outset, we would like to clarify that this is not an extensive review of multisensory experiences. Instead, we present a perspective article in which we define the concept and our position about it. We aim to make this article an accessible first point of contact for anyone interested in multisensory experiences and their role in HFI.

What Are Multisensory Experiences?

We recently defined multisensory experiences as "…impressions formed by specific events, whose sensory elements have been carefully crafted by someone." (Velasco and Obrist, 2020, p. 15, see **Figure 1**). For instance, to create the impression of an object, say, a sunflower, colors, textures, and smells can be considered in a specific event (e.g., an art exhibition, Vi et al., 2017). The senses, and their corresponding functioning, are thus situated at the center of the formation of the impression of the object, *even* in the absence of a real object. We would like to note here, there is research that has suggested other concepts that can relate to, or involve, at least partly, multisensory experiences. These include, among others, multisensory enhancement (Marquardt et al., 2018), multisensory product

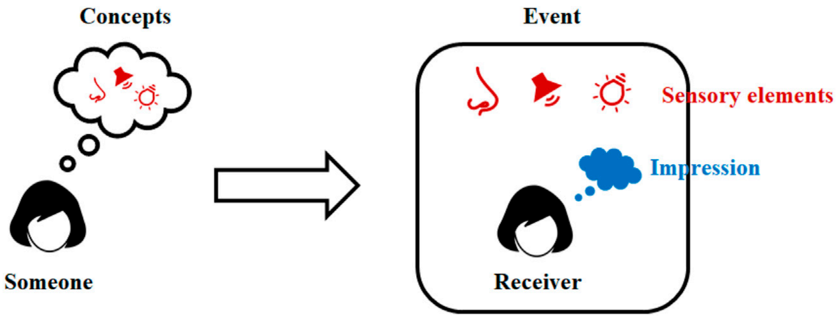

FIGURE 1 | Schematic representation of our definition of multisensory experiences. Multisensory experiences **(right of the arrow)** are impressions formed by specific events (black square), whose sensory elements (in this case represented by smell, sound, and light, in red) have been carefully crafted by someone **(left side of the arrow)** for a given receiver, capitalizing on concepts of multisensory perception (in the cloud). Note that, whilst most of people's experiences are multisensory per se, multisensory experiences are different in that there is intentionality in them. In other words, while, say, walking in a forest or jungle (event) involves a number of sensory elements, a multisensory experience, as we put forward, is carefully designed by someone. Take, as an example, a walk in the jungle that has been designed by a landscape architect to evoke specific impressions in a given receiver. Hence, when one refers to multisensory experiences, the "design" part is implied. For this same reason, multisensory experiences and multisensory experience design are often used interchangeably.

experience (Ferrise et al., 2017), and mulsemedia (e.g., Ghinea et al., 2014). Discussing all these concepts falls out of the scope of this article, however, future research should aim at reviewing and finding the conceptual links between them as some are aimed at describing experiences, technologies, and/or design frameworks.

When crafting an impression, through a given set of sensory elements, the someone who designs capitalizes on existing research and concepts from multisensory perception[1]. These include, though are not limited to, spatiotemporal congruence (e.g., Chen and Vroomen, 2013), semantic congruence (e.g., Doehrmann and Naumer, 2008), crossmodal correspondences (e.g., Spence, 2011; Parise, 2016), sensory dominance (Fenko et al., 2010), and sensory overload (Malhotra, 1984; see also Velasco and Spence, 2019, for a description of these concepts). In other words, the way in which sensory elements are integrated to a given event is inspired or based on research on sensation and perception, and more particularly, on research suggesting that the multisensory nature of information changes also cognitive processes such as like attention (e.g., Talsma et al., 2010) and memory (e.g., Shams and Seitz, 2008).

The Role of Technology in Multisensory Experiences

Multisensory experiences are increasingly changed and enabled through technology, thus, there is growing research on the topic in HCI (Obrist et al., 2017). For this reason, the sensory elements that are crafted in an event can be physical, digital, or a combination of both (mixed reality). In other words, multisensory experiences move along the reality-virtuality continuum, where they can go from fully real, through mixed reality, to fully virtual (see Flavián et al., 2019; Milgram et al., 1995, for reflections on the reality-virtuality continuum). Technology can change how events occur and, potentially, also become the event itself (e.g., technology as experience, McCarthy and Wright, 2004).

To clarify how technology relates to events in our definition of multisensory experiences, let us consider the following example. A group of friends have a new project of growing sunflowers and they want you to experience them and they have three options to do so: (1) Take you through their sunflower field without any technology, (2) Take you through the field with the aid of augmented reality (AR) to obtain information about the sunflowers, or (3) Take you through the field in virtual reality (VR). In the first, there may not be technology, in the second technology augments the experience, and in the third the experience is created through technology. In other words, technology can influence the event or become the means for creating the event itself.

There are multiple examples of multisensory experiences enabled through technology, which can further illustrate its role on said experiences (see emerging role on the chemical senses, smell, and taste, when designing multisensory experiences Maggioni et al., 2020; Vi et al., 2020). Situated towards the real end of the reality virtuality continuum, a multisensory experience of dark matter is created inside an inflatable dome enabling people to feel, hear, smell, taste dark matter next to staring into a simulation of the dark matter distribution in the Universe (Trotta et al., 2020). In mixed reality, an example is presented by Tennent et al. (2017), who created a digital version of a swing. Players wear a head-mounted display while sitting on a real, physical swing, having their sense of movement within a virtual environment exaggerated through the visual feedback. Finally, an example on the virtual end of the reality-virtuality continuum, is FaceHaptics presented by Wilberz et al. (2020), who developed a haptic display based on a robot arm

[1]Note that such concepts have been used in the context of multisensory integration research, which focus on the how and when our brains integrate information from different senses to produce a singular experience of the world around us (Calvert and Thesen, 2004; Spence, 2011).

attached to a head-mounted virtual reality display that provides localized, multi-directional and movable haptic cues in the form of wind, warmth, moving and single-point touch events and water spray to dedicated parts of the face not covered by the head-mounted display. Importantly, as technology develops, we may see a shift from multisensory experiences involving human-computer interaction, toward human-computer integration (Mueller et al., 2020).

In recent times, there has been a growing digitization of human experiences, accelerated due to the COVID-19 pandemic (Roose, 2020). Purely offline and 'real' experiences appear to be shifting faster to mixed and virtual reality experiences where both the physical and digital worlds merge. However, many of the senses are still left 'unsatisfied', making it clear that there is still much to be done to create multisensory experiences in an increasingly digital world (Petit et al., 2019).

Implications of Multisensory Experiences and How to Think About Them

The excitement about multisensory experiences in academia and industry, opens a plethora of opportunities but also needs to be met with responsibility. Hence, the excitement around multisensory experiences comes with a number of challenges and responsibilities. However, to the best of our knowledge, there is, to date, little discussion on the implications of multisensory experiences. Yet, there are multiple challenges associated with them, including, among others, how many businesses, individuals and communities who are not ready for a digital transition may be left behind. In addition, issues that are already in the public's eye, such as privacy, security, universal vs. exclusive access to technology, increased predictability, and controllability, will only become more and more salient.

Considering the aforesaid challenges and the definition of multisensory experiences, we recently postulated the three laws of multisensory experiences, which are inspired by Asimov's (1950) three laws of robotics. These laws focus on acknowledging and debating publicly different questions that are at the heart of the definition of multisensory experiences, namely, the why (the rationale/reason), what (the impression), when (the event), how (the sensory elements), who (the someone), and whom (the receiver), associated with a given multisensory experience. With this in mind, the laws indicate (Velasco and Obrist, 2020, p. 79):

I. Multisensory experiences should be used for good and must not harm others.
II. Receivers of a multisensory experience must be treated fairly.
III. The someone and the sensory elements must be known.

The first law aims to guide the thinking process related to the question: Why and what impressions and events we want to design for? The answer to this question, should always be: Reasons, events, and impressions must not cause any harm to the receiver, nor anyone else. Multisensory experiences should be used for good. The second law aims to make people reflect about the questions: Who are we designing for? Should we design differently for different receivers? The first question helps to identify the receiver and its characteristics. The final law seeks to address two questions. First, who is crafting the multisensory experience? Second, what sensory elements we select and why? With this law we call for transparency in terms of who designs, what knowledge guides the design, and what sensory elements are chosen to craft an impression. Although it is possible that not all information may be provided upfront to the receiver, they must have easy access to such information if they want.

MULTISENSORY EXPERIENCES IN THE CONTEXT OF HUMAN-FOOD INTERACTION

In this section we present multisensory experiences in the context of HFI, as a research and practice case. Multisensory experiences have been increasingly studied in the context of food (e.g., Velasco et al., 2018; Spence and Youssef, 2019). Among other reasons for this, is the fact that eating, and drinking are perhaps some of the most multisensory events of everyday life activities (e.g., Spence, 2017, Spence, 2020). Indeed, in the context of HFI research, multisensory human-food interaction (MHFI) is an active area of inquiry contributing to the field (Betran et al., 2019; see also Nijholt et al., 2016; Nijholt et al., 2018; Velasco et al., 2017). Here, we reflect on what multisensory experiences mean in the context of HFI.

What Are Multisensory HFI Experiences?

In the context of HFI, multisensory experiences refer to impressions formed by specific food-related events, whose sensory elements (e.g., intrinsic, and extrinsic to the food, see for example, Wang et al., 2019) have been carefully crafted by someone for a given receiver (e.g., diners). For instance, to create the impression of a taste, say "sweet", colors, textures, and specific smells can be considered in a specific event. The senses are thus situated at the center of the formation of the impression, even in the absence of the real object (e.g., sugar).

Moreover, when creating multisensory HFI, it is worth looking at the consumer journey associated with food. Inspired by the research on the customer journey (Lemon and Verhoef, 2016), that is, the stages of interaction associated with products and services that constitute the total customer experience, one may argue that food-related events include at least three broad levels, namely, pre-consumption, consumption, and post-consumption. The first level is the one in which people identify a need associated with food, search for food, and develop expectations about it. The second level is about decision making (e.g., deciding what to do about the food and interacting with it). The final stage is about what happens after consumption, which may involve everything from sharing the food event or experience, to discarding what remains after consumption. These are suggested as broad levels in the interaction with a given food, though one may look at the interaction in further detail, depending on the specific food and/or food context.

FIGURE 2 | Left traditional eating, right eating with a VR headset. **Left**—free stock picture. **Right** from "Tree by Naked" restaurant'.https://www.dw.com/en/tokyo-virtual-reality-restaurant-combines-cusine-with-fine-art/g-44898252.

By considering the different moments of experience with food (thus, different events), one may be able to create specific impressions more accurately in either one of the moments or the whole journey (Schifferstein, 2016).

Where Food Meets Multisensory Technology

The journey with food, and in general any consumer experience, is increasingly transformed by technology (Hoyer et al., 2020). There are numerous sensory elements that can be carefully crafted by someone throughout the consumer journey, to create a given impression. Such elements involve both intrinsic (internal) and extrinsic (external) properties of the food such as the aroma and atmospheric sound present in a given food interaction, respectively (e.g., Betancur et al., 2020). In addition, the sensory elements may be real or digital (see **Figure 2**), and as such, the experiences may occur at any level of the reality-virtuality continuum. In this case, concepts associated with multisensory food perception may be used as a base to craft the sensory elements, to deliver a given impression (e.g., Velasco et al., 2018).

There are multiple examples of multisensory experiences in the context of MHFI that can further help to illustrate what they mean in HFI. Situated on the real end of the reality-virtuality continuum, FoodFab capitalizes on 3D printing to control parameters of the internal structure of foods (infill pattern and infill density) and, thus, influence chewing time and, in turn, satiety (Lin et al., 2020). In mixed reality, an example is MetaCookie, a system that augments a cookie's flavor by digitally overlapping colors and textures, as well as specific aromas, on a plain cookie (Narumi et al., 2011). Finally, an example on the virtual end of the reality-virtuality continuum, is presented by Brooks et al. (2020), who developed a 'thermal display' that, through scents that evoke characteristic trigeminal sensation, integrates thermal sensations into virtual reality.

Responsible Design of Multisensory HFI

There is a broad and promising scope for multisensory experiences when it comes to HFI. As with any other design opportunities there are challenges and responsibilities to meet. Responsible design of multisensory HRI is even more important than many other application scenarios, as food is essential to any human being.

To illustrate the need for responsible design, think about the following example. A group of friends in Tokyo develop a multisensory intelligent system that uses 3D printers that carefully control food color, size, and sound, to create the impression of satiety and thus reduce both food consumption and waste. Probably, if the receivers of this system are children or adults, the specifications of the sensory elements might need to differ, as the reactions of these groups may vary. But now consider that this intelligent system was developed by, and based on the behavior of, people from Japan only, who come from an educated, industrialized, rich, and democratic society. If this system were used in a small community in an island in the pacific, would it evoke the same impression? Humans and intelligent systems can have biases, which need to be considered when designing experiences. In that sense, there is a need to not only treat receivers fairly by balancing their differences and giving them all the same opportunities, but also empower them through giving them a voice in multisensory experiences. In other words, receivers do not just passively receive, but can adjust experiences to their own needs (see Obrist et al., 2018).

DISCUSSION

We presented a primer to multisensory experiences. We elaborated on multisensory experiences, the role of technology in them, and their implications for individuals and society. In addition, we discuss the case of multisensory experiences in the context of eating and human-food interaction, to illustrate how to put the senses at the center of the experience design process.

We believe that we are just witnessing the first interdisciplinary research wave on multisensory experiences, as the scope for development is extensive. We have suggested, based on the example of HFI, that multisensory experiences can help tackle key challenges that humanity faces, such as those involved in space exploration (Binsted et al., 2008; Obrist et al., 2019). First, food is not only important for nutrition, but it also serves emotional and a social purpose in human contexts, dimensions which are key to the success of space travels (Szocik et al., 2018), as such, food experiences are vital for the success of space travels. Importantly, as space travelers experience changes in their senses in zero gravity and they are confined to a very specific context, such as that of a spaceship (Taylor et al., in press), multisensory food experiences can be designed to support those who venture to explore space.

It is important to mention that there are multiple questions and future directions that remain open and require further reflection. For example, with regards to carefully designing and engineering multisensory experiences, we need to think about what devices one may use for specific experiences; how to account for their different stimulation mechanisms and the reactions evoked; how can we ensure replicability and a seamless integration with experiences and users' interactions. Moreover, how can we predict experiences and personalize them based on individual and cultural differences? These are just some of many more questions that remain unanswered and need future explorations (see Saleme et al., 2019 on challenges in a diverse device ecosystem; and Maggioni et al., 2019 aiming for a device-agnostic design toolkit). We must remember that despite the current progress, we are still beginning to truly formalize this design space. We hope that this perspective article opens a wide discussion, within and across disciplines and thus helps shape its future.

It is reasonable to expect that technology will keep advancing and sensory delivery will become more accurate. In addition, our understanding of the human senses and perception will become more precise through large scale data from human-computer interaction and integration research. As such, there is the potential to systematize our definition of multisensory experiences, through adaptive, computational design. This is exciting but at the same time carries big questions on the implications of multisensory experiences as well as our responsibility in them. The three laws of multisensory experiences we presented can help to think about the implications of designing multisensory experience in the growing integration between the senses and technology (Mueller et al., 2020), but further debate is undoubtedly needed. We believe that, when it comes to human experience design, both researchers and practitioners should promote an ongoing public ethical discussion.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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REVIEW
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How Digital Food Affects Our Analog Lives: The Impact of Food Photography on Healthy Eating Behavior

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Obesity continues to be a global issue. In recent years, researchers have started to question the role of our novel yet ubiquitous use of digital media in the development of obesity. With the recent COVID-19 outbreak affecting almost all aspects of society, many people have moved their social eating activities into the digital space, making the question as relevant as ever. The bombardment of appetizing food images and photography – colloquially referred to as "food porn" – has become a significant aspect of the digital food experience. This review presents an overview of whether and how the (1) viewing, (2) creating, and (3) online sharing of digital food photography can influence consumer eating behavior. Moreover, this review provides an outlook of future research opportunities, both to close the gaps in our scientific understanding of the physiological and psychological interaction between digital food photography and actual eating behavior, and, from a practical viewpoint, to optimize our digital food media habits to support an obesity-preventive lifestyle. We do not want to rest on the idea that food imagery's current prevalence is a core negative influence *per se*. Instead, we offer the view that active participation in food photography, in conjunction with a selective use of food-related digital media, might contribute to healthy body weight management and enhanced meal pleasure.

Keywords: grounded cognition, food photography, social media, commensality, food intake, food porn

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INTRODUCTION

Obesity continues to be a major global problem for individual welfare (see Reilly, 2003) and a burden on national health care systems (see Wang et al., 2011). By 2030, half of the United States population will be obese (The Lancet Diabetes Endocrinology, 2020). In Europe, the obesity rate has been linearly increasing ever since the 1970s, without any indication of slowing down (WHO, 2016). Observational studies have shown that watching TV is associated with being overweight (e.g., Gore et al., 2003; Halford et al., 2004; for a review, see Boulos et al., 2012). Simultaneously, food is becoming an increasingly popular topic both in classical forms of media, such as cooking books and TV, as well as in new digital media formats on the internet, such as YouTube, Instagram, and other social media platforms (Petit et al., 2016; Spence et al., 2016). In 2014, Google reported food and cooking to be the fastest growing topic on YouTube (Kantchev, 2014).

In a recent survey of United States adults, 88% reported to eat while looking at a screen, and on average respondents reported having only five screen-free meals a week (Anderer, 2019). In general, the rise in food media's popularity may be a consequence of the decline of time dedicated to food preparation (also Prince, 2014; Spence et al., 2016), potentially leaving people psychologically unfulfilled and hungry (cf. also Murray and Vickers, 2009; cf. Dohle et al., 2014).

Mukbang, originating in South Korea, is a modern participatory digital food trend in which a host broadcasts eating large quantities of food while interacting with the audience (Pereira et al., 2019; Anjani et al., 2020). On Instagram and direct digital communication, it is also increasingly popular to participate actively in food content creation instead of mere passive consumption by taking photos of one's meals and sharing it with followers, friends, and family. To illustrate, the number of photos uploaded to Instagram every minute has increased by 17% from 2017 to 2019 (DOMO, 2017, 2019). Such active participation is also known as "user-generated content" (UGC).

Especially among adolescents, digital media (and social media specifically) have all but overtaken the traditional media of print and TV (Twenge et al., 2019). United States 12th graders spent approximately twice as much time online in 2016 than they did in 2006. Conversely, the share of 10th graders who read print every day has declined from 60% in the 1970s to 16% in 2016. Similarly, daily TV consumption has declined by an hour from the early 1990s to 2016. Research has yet to completely map out the implications of the ascend of these new and participatory digital media forms, including if and how they might affect the continued rise of obesity. Naturally, finding ways to utilize these media forms to facilitate, rather than hinder, healthy eating is of interest.

The recent outbreak of COVID-19 has increased this trend toward digitalization further. Among the chief restrictions caused by the pandemic have been limitations on people's social lives. A recent survey during the first wave of the pandemic around April 2020 found that social activities had decreased between 46.7 and 58%, and overall life satisfaction had decreased by 30.5% (Ammar et al., 2020b). Eating behavior and physical activity levels were also adversely affected, with a reported decrease in total weekly activity minutes by 33%, higher reported meal frequency, snacking, "out-of-control" eating, and more unhealthy food choices (Ammar et al., 2020a). Somewhat expected, the number of individuals who used digital technology for social purposes had increased by 24.8% (Ammar et al., 2020b). Eating is, in large part, a social affair (cf. Herman, 2017), therefore, it seems natural to assume that a non-trivial share of newly-digitized social interaction involved food. Indeed, a recent survey of people's motivations and experiences of lockdown-related online dining found that people gathered mainly for social reasons (Ceccaldi et al., 2020). The experience itself was reported as rather insufficient. We have possibly witnessed the largest experiment in digital commensality to date (cf. Spence et al., 2019). Hence, the question of how digital media affect eating seems more relevant than ever.

Food Photography

The term "food porn" was coined in the late 1970s to describe mouth-watering images of food that are "sensationally out of bounds of what food should be" (McBride, 2010). In other words, food images become pornographic when they showcase a visual decadence that is *entirely* removed from food's primary function – nourishment. The term has caught on and is nowadays used more generally for online viewing and sharing of appetizing food images (see Petit et al., 2016). However, not all scholars agree on this definition or even the notion that food photography could be pornographic in principle. Tooming (2021) conceptualizes pornography as a means to obtain sexual release. According to this definition, then, food images cannot be pornographic because they cannot afford the release, i.e., satiation.[1]

On the question of motivation, Tooming questions the precise source of pleasure when viewing food photography. The author, at least in part, dismisses anticipation as the source of pleasure in viewing food photography, as desiring the literally depicted food is both irrational (it is neither accessible and probably does not even exist anymore) and the activity does not seem to cause people to replicate the food, either (Prince, 2014). Neither is the pleasure purely visual. In his estimation, the pleasure in viewing food images is best described as *"reality-independent [gustatory] imaginings."* These "imaginings" are independent from reality insofar as they are not entirely bound to the actually depicted food (which might be a stylized mixture of inedible substances, see Chapin, 2016). We will return to these notions when discussing relevant experimental evidence.

While also defending the notion that food photography *could* have artistic merit, Tooming admits that most food photography on social media – maybe especially the popular ones – would probably not be considered art, or at least not good art, for it mostly appeals to universal, instead of learned or acquired, sensitivities (cf. Matthen, 2015). Regarding social media more generally, it is important to note that food companies invest heavily into the platforms and content to either influence consumers directly or gain detailed behavioral insight (Lewis, 2018). Here also, automated content contributions from bots play a role (cf. generally Daniel et al., 2019). While certainly important, we will not pursue these aspects of online food content quality in the review at hand.

The number of digital photos taken has increased over the past decades. On the year 2000, a reported 80 billion photos were taken, and by 2015, this number had grown to a trillion (Heyman, 2015). The increase is reportedly due to the spread of camera-equipped smartphones, with 75% of 2015's photos taken with such devices. According to a poll, 81% of the United States population owned a smartphone in 2019 (Pew Research Center, 2019). We assume that the figures in other developed countries are similarly high.

The explosion of content on food-related peer-review websites such as TripAdvisor and Yelp (Melumad et al., 2019) would

[1]We will review contrary evidence in later sections.

suggest that food photography – sometimes also referred to as "foodtography" (Coary and Poor, 2016) – is a widely prevalent activity. However, it can be controversial. Multiple restaurants, including well-known fine dining establishments, restrict food photography (Ensor, 2013; Stapinski, 2013; Willis, 2017). The restrictions vary and can include anything from a ban on flash-usage to disallowing any food or restaurant interior photography. There seem to be multiple issues. First, food photography causes an interruption in meal procedure and leaves the food to cool down, diminishing the experience of the diner herself. Second, photographing with a flash disrupts other's meal experience. Third, photos provide only a partial representation of the food – *"a picture on a phone cannot possibly capture the flavors"* (Willis, 2017) – resulting in inferior marketing for the restaurant. High-end chefs' critical stance toward food photography has not changed in recent years (Rawlinson, 2020).

A recent scientific publication by Yong et al. (2020) suggests a more mild prevalence of food photography. Investigating a group of healthy students (18–30 years old) at the University of Singapore under free-living conditions, the researchers report an average meal-time photography rate of about 5%, measured across a total of about 7,000 recorded meals. Meanwhile, only 23% of all study participants partook in *any* meal-time photography, who, in turn, photographed 16% of their meals. These findings seem to suggest that a minority of power-users capture most of the photographic content, at a rate of about one out of six meals. The employed Experience Sampling methodology reached a response rate of 76%, lending credibility to the results. Unfortunately, the study did not report the context of meal photography. Thus, it is impossible to draw any conclusions on whether the widespread reports of food photography's ubiquity are an overestimation or merely a matter of context.

One aspect that food photography is used for is cross-cultural communication. Food is an obvious human necessity. This fact makes food universally relatable and, consequently, a good vehicle for cross-cultural empathy (cf. Woolley and Fishbach, 2017). For example, people living away from their childhood region or country may feel nostalgic in relationship to specific food posted online (Connolly, 2015). While people from other cultures may not have any particular memories tied to the same food, they nevertheless can recognize the sentiment and empathize with the person posting about the nostalgic food experience. More generally, food is associated with and implied in all aspects of the human experience (Ibrahim, 2015). By publicly sharing everyday food images, people allow for a deep and intimate look into their private lives, juxtaposing the private and public spaces. In this private and public hybrid space, cultural exchange is enhanced (Ibrahim, 2015). It seems not surprising, then, that these authors emphasize that "food is more than just fuel for bodies" (see also Connolly, 2015; Ibrahim, 2015).

Aim

This review aims to provide an overview of the research related to the interaction between everyday food photography habits and healthy eating behavior, suggest potential opportunities for future research as well as practical application. In this review, we will look at the following three food photography habits:

1. *Viewing* digital food-content, e.g., viewing others' food photography on social media;
2. *Creating* content, i.e., users engaging themselves in food photography; and
3. *Sharing* such content with other people.

We operationally define eating behavior as food choice and intake (Eertmans et al., 2001). With healthy eating, we refer to choosing nutrient-dense food in portion sizes supportive of healthy body function and level of body fat.

Under these definitions, we are neither exhausting all possible aspects of digital interaction with food in general, nor food photography in particular. For example, we will not cover in detail the pleasure of viewing food photography for its own sake, i.e., independently of an eating context. We will also not cover aspects of the social media landscape *per se*, e.g., market dynamics or incentives. Interested readers are referred elsewhere (cf. Labrecque et al., 2013; e.g., Lewis, 2018). Finally, we will not cover digital technology generally as a source of distraction (Oldham-Cooper et al., 2011; see, e.g., Teo et al., 2018). Instead, our focus will be on the direct interaction between viewing, creating, and sharing digital food photography and actual eating behavior at the physiological and psychological levels. **Figure 1** provides a schematic overview of the three activities and their relationship with each other and the research themes covered in this work.

The review is structured into two main sections. In the first, "State of the Art," we review and discuss direct research relating *viewing*, *creating*, and *sharing* food photography and eating behavior. In the second, "Future Perspectives," we will connect analogous and related research and hypothesize about other interactions between food photography and eating behavior, yet to be studied directly. The section will also include practical take-away points to guide the use of food photography in our analog lives.

Theoretical Underpinning: Grounded Cognition and Mental Simulation

Before discussing how each aspect of food photography might influence us, it is worth pointing out the cognitive mechanisms underlying behavior. Grounded cognition theories assume that cognition is fundamentally grounded in situated action, bodily states, and (mental) simulation (Barsalou, 2008). Action is inherently goal-directed and situated in the environment, which we perceive primarily in terms of affordances and constraints in relation to the goal (Gibson, 1979). Cognitive processes are affected by internal and external bodily states, e.g., feelings of anger or a cold environment. Mental simulations are re-enactments of perceptions in their respective brain areas, e.g., imagery in the visual cortex. The three pillars of grounded cognition are tightly connected and interdependent.

The concept of *modal* representations of knowledge is central in cognition. This means that the *"brain areas representing*

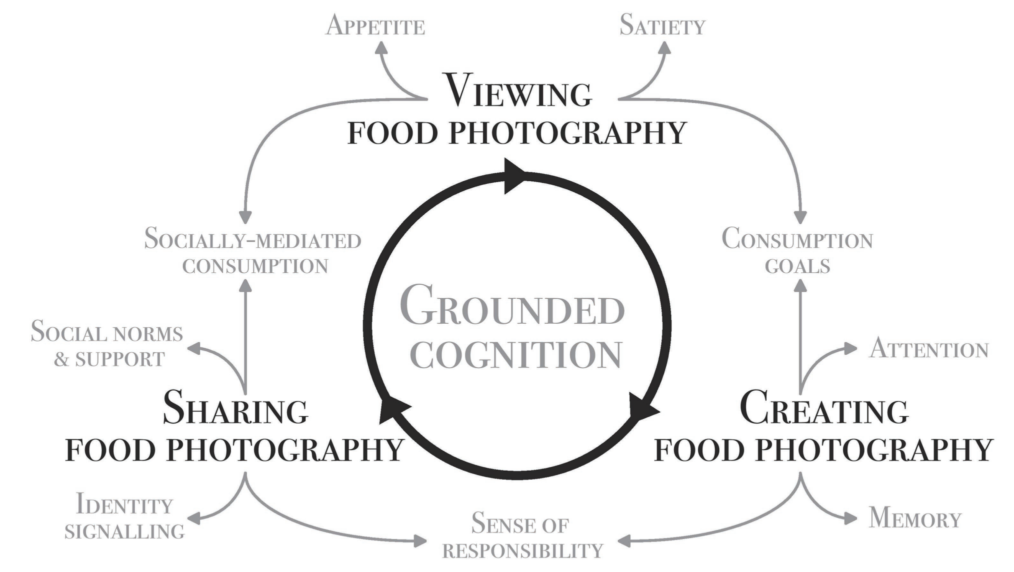

FIGURE 1 | Schematic representation of the digital food photography habits cycle and related influences.

knowledge for a particular category are those typically used to process its physical instances" (Simmons et al., 2005). Especially in this point grounded theories stand in opposition to classical theories of cognition, which claim that cognition works mainly on *amodal*, abstract symbols, with embodied and cross-modal effects only being peripheral or epiphenomenal (Barsalou, 2008). There appears to be no central "simulation area" in the brain; instead, multiple areas jointly produce these mental images. The activation of these brain areas can lead to subsequent physiological responses downstream, including desire to consume and satiation (for a review, see, e.g., Krishna and Schwarz, 2014; more recently, Papies et al., 2020). To quote Christian et al. (2016, p. 85): *"The pathway from simulation to consumption rests on the fact that mental imagery is facilitated by reactivation of the sensorimotor systems that support perception and action."* It might be worth pointing out that, while very much related, mental simulation and imagery are not the same. The former is an automatic and implicit process, while the latter is deliberate and conscious (Simmons et al., 2005). Either way, we see mental simulation and imagery as essential cognitive mechanisms in understanding the effect of viewing, creating, and sharing food photography.

Sociality is fundamental for humans, and we use a whole range of cognitive processes to successfully navigate the social fabric (see Barsalou, 2008). For example, based on others' visible cues and mental simulation, we infer their goals and affective states. The visual cues themselves activate so-called *mirror neurons*, which are an essential component in the inference process. Besides their role in empathy, mirror neurons are also implied in imitation-based activities, such as learning from others and social coordination. The fact that we have evolved dedicated brain structures to optimally pick-up on social cues illustrates their importance for regulating behavior.

STATE OF THE ART

Viewing Food Photography

The Biological Link Between Viewing Food Photography and Behavior

As alluded to in the previous section on grounded cognition theories, the modal representation of knowledge implies that knowledge of categories is represented in the same brain areas as those activated when engaging with the physical instances. This is also the case for food. Thinking about and seeing food depictions activates the same gustatory system as seeing real food (Simmons et al., 2005). The brain essentially infers taste as well as taste and consumption reward – including energy content (Toepel et al., 2009; van der Laan et al., 2011) – based on the visual food cues. Accordingly, hunger is modulated on at the neural level (van der Laan et al., 2011).

Evolution may have evolved the human brain to be highly responsive to visual food cues, with obvious survival benefits for pre-historic man. In fact, a dedicated neural network for eating has been identified (Chen et al., 2016) and recent evidence suggests that attention is biased toward food compared to non-food cues (see Spetter et al., 2020). This bias has been demonstrated both behaviorally (Higgs et al., 2012, 2015; Rutters et al., 2015; Kumar et al., 2016; Kaisari et al., 2019) and at the neurological level (Spetter et al., 2020). The cognitive basis for the effect is 2-fold. Firstly, while thinking of anything – i.e., holding representations in working memory – guides perceptual awareness toward similar environmental stimuli, this effect is more pronounced for food stimuli, especially when high in energy content (Toepel et al., 2009), due to their higher affective value (cf. generally Zeelenberg et al., 2006). Secondly, food representations are held more efficiently in working memory than those of non-food items. Therefore, more working memory will be available to process new environmental stimuli. In combination, these findings indicate that thinking about food further primes attention for food cues.

One general moderator of the visual attentional bias toward food is hunger. When hungry, individuals exert a higher bias toward food cues in general, irrespective of reported liking for the depicted food (Piech et al., 2010; Davidson et al., 2018). While satiation leads to some general attenuation of the bias, it is also highly sensory-specific, and correlates with post-consumption changes in individual food's pleasantness (cf. Rolls et al., 1981b; di Pellegrino et al., 2011). In fact, the satiation is sufficiently specific so that, for example, *ad-libitum* consumption of one type of sandwich only moderately decreases attentional bias for photographs of other types of sandwiches, and barely at all for photos of desserts (Davidson et al., 2018).

Individuals also differ in their proclivity to manifest biased food attention. For example, individuals scoring high in the trait restraint and low the trait disinhibition have a less of an attentional bias and also overall pay less attention to food cues (Higgs et al., 2015). A recent study showed that overweight and obese individuals engage in greater top-down attention modulation compared to normal weight individuals, which, in turn, was predictive of weight gain 1 year later (cf. Castellanos et al., 2009; Kaisari et al., 2019). A previous systematic review had similarly concluded that overweight and obese individuals show enhanced neural responses to food cues compared to lean individuals, particularly for energy-dense food (Pursey et al., 2014; cf. also Brunstrom et al., 2018).

The hormone ghrelin is a major mechanism linking visual food stimuli and eating behavior. In a classic paper, Wren et al. (2001) demonstrated in humans that exogenous ghrelin administration causes increases in both hunger and food intake. In the experiment, the blood-infused ghrelin led to a 28% increased energy intake at a subsequent buffet meal, compared with the saline control solution. In absolute terms, this increase amounted to an additional 300 kcal. Thus, ghrelin has become known as the "hunger hormone" (Hsu et al., 2016).

However, it might be more correct to refer to ghrelin as the "food anticipation hormone" (see Frecka and Mattes, 2008). For example, Frecka and Mattes (2008) showed that ghrelin blood concentrations are entrained to the habitual meal schedule and do not necessarily correlate with reported hunger levels. Researchers have implied the hormone in priming the gastro-intestinal system for food (Drazen et al., 2006). The connection between circulating ghrelin levels and food intake may, at least in part, be a learned response linking interoception and behavior (Hsu et al., 2016). More generally, ghrelin plays an important role in the regulation of food reward in the brain, *via* interaction with dopaminergic neurons (for a review, see Perello and Dickson, 2015). The food reward regulation affects both food-seeking behavior and motivation as well as the subsequent hedonic response.

Two experimental papers from the past decade have linked visual food cues, ghrelin, and the neurological control of eating behavior. First, Schüssler et al. (2012) showed in humans that viewing food images stimulates ghrelin secretion. This result suggests that the mere sight of food, even in image form, can cause physiologic food anticipation (contra Tooming, 2021). Second, van der Plasse et al. (2013) demonstrated in rats that visual food cues (a simple light signal Pavlovially associated with food availability) activated medio-hypothalamic brain regions, relevant in behavior regulation, and increased food anticipatory activity (i.e., laboratory animal's analog of food seeking behavior, see Mistlberger, 1994) similarly to exogenously administered ghrelin.

Viewing food photography induces physiological responses similar to seeing real food, yet how do the two stimuli compare? Researchers have not been in full agreement on this point. For instance, Romero et al. (2018) systematically investigated the difference of real and food images as cues to stimulate expected satiety and willingness-to-pay. The researchers concluded that real food and depictions elicit significantly different responses, based on the findings that participants expected real food to be statistically significantly more satiating (+0.55 on a 5-point satiety scale) and were willing to pay 6% more. However, despite the statistical significance, one may say that the absolute differences were relatively small. More to the latter point, a meta-analysis of a total of 3,300 study participants found equal outcome effect sizes in downstream eating behavior in response to viewing real food and food depictions (Boswell and Kober, 2016). Therefore, it seems reasonable to conclude that food photos elicit similar responses as seeing real food, both in kind and degree.

The Impact of Food Photography Content

Not all food photography are created equal. The degree to which food photos induce cravings depends on both *what* and *how* it is represented. For instance, researchers have studied the interaction between portion size and actual consumption with both real food and images. Rolls et al. (2002) established that the portion size (of actual food) influences overall food consumption in a meal. Madzharov and Block (2010) replicated the portion size effect by showing how the quantity of food printed on the packaging positively correlates with actual consumption. This would suggest that images that depict larger food quantities elicit stronger cravings. However, two other studies suggest that the effect of portion size is not so straightforward. In one study, by reducing the size of the serving plate while keeping the depicted food portion constant, participants rated the food more appetizing, were willing to pay more for it, yet served themselves *less* of the actual food (Petit et al., 2018). In another study, images of meals judged "too big" lead to lower activation in brain areas relevant in reward processing (Toepel et al., 2015). It seems, then, that the perception of portion sizes depends both on the depicted food quantity and the presentation, and that greater depicted portions lead to increased food intake only up to a point.

In the previous section, we have shown evidence for the fact that consumption of food can decrease the attentional bias toward visual cues of those same foods. Food photos also seem to induce such sensory-specific satiation. In an experiment by Larson et al. (2014), study participants that had viewed 60 salty images rated subsequently consumed peanuts as less appetizing, compared to participants who had viewed 60 sweet images or only 20 images of either taste. Similar work in the context of mental imagery suggests that this visually induced satiety should translate into actually decreased consumption (see Morewedge et al., 2010).

We have seen that the brain can automatically infer the energy-content of depicted foods. However, given that healthiness evaluations affect both food choice (Nikolova and Inman, 2015) and portion size (Suher et al., 2016), how do consumers determine the healthiness of depicted food? One common way is for consumers to simply categorize food as either "good" or "bad" (Rozin et al., 1996). A more subtle way is by how pretty the food looks. According to earlier research, food naturalness is heuristically linked to healthiness (Rozin, 2005). Following up on these results, Hagen (2020) conducted a series of experiments showing that consumers consider prettier images of the same food as more natural and, hence, more healthy, with an increased willing-to-pay. However, only images depicting food arranged according to classic esthetics, e.g., in symmetry and regular, induced the perception of naturalness. Also more generally, consumers seem to prefer symmetrically arranged of food depictions (Velasco et al., 2016).

Going beyond the physical food itself, food photographs can be manipulated with image filters. To study the effect of image filters on consumer engagement, measured in the form of views, likes, comments, and favorites, Flickr engineers analyzed of 4.6 million images of the platform (Bakhshi et al., 2019). On a general note, the engineers found that food photos had an approximately 30% higher engagement-likelihood, compared to non-food photos. Filter-edited food images were 16% more likely to be viewed, compared to raw images. It is important to remark that this was a correlational study and, while accounting for a multitude of variables, the authors emphasize that their analysis does not prove causality. To empirically study the impact of color on food image attractiveness, Paakki et al. (2019) asked consumers to rate the attractiveness of 10 different salads, five pale and five colorful. The color of each salad was measured with a colorimeter, and consumers ranked the photos of the salads according to attractiveness, and provided their reasoning as free text. The quantitative analysis showed that consumers preferred the colorful salads with high color contrast and saturation, as well as salads with the complementary colors red and green. Furthermore, text analysis suggested that the colorful salads signaled freshness and ingredient diversity. At least for fruit and vegetables, we may, therefore, conclude that higher contrast and deeper color saturation make for more attractive food photos.

In the introduction, we have alluded to the fact importance of sociality, both generally and in relation to food. It, therefore, does not seem overly surprising that depicted social cues also modulate the interaction between viewing food images and eating behavior. Indulging in unhealthy food typically causes a cognitive conflict between short-term indulgence and long-term health maintenance. This conflict reduces available cognitive resources and leads to reduced taste evaluations (Poor et al., 2013). Images of others eating (so-called "consummatory" images) unhealthy food serve as evidence for indulgence's social acceptability. This evidence resolves the cognitive conflict and increases taste evaluations (Poor et al., 2013). Interestingly, this need not even be images of others eating – self-reflections and statics self-portraits during eating also increase taste evaluation and consumption (Nakata and Kawai, 2017). Hence, images of unhealthy food cueing the consumption's social acceptability seem to promote unhealthy eating behavior more than depicting the food without any social cues.

The Impact of Photo Composition and Interaction Medium

The ease of mental simulations is a crucial factor for triggering downstream effects such as desire to eat. The photograph composition, as well as the interaction medium, make simulation easier if they mimic natural interaction with the food. For example, research by Shen et al. (2016) demonstrated that directly interacting with food images through touchscreens, rather than indirectly through a mouse or a touchpad, biases food choice toward indulgent food and away from healthy food. The touchscreen allows for a more direct and natural interaction with the food image. This triggers a "grabbing" reflex, subsequently increasing the desire for the hedonic, i.e., inherently pleasurable, product.

A photo compositional detail that influences the ease of mental simulation is the orientation of a dish. In one scenario studied by Elder and Krishna (2012), a plate of cake had a fork either on the left or the right side. As might be predicted, right-handed participants rated the image with the fork on the right side higher in terms of wanting and willingness-to-buy, and vice-versa for left-handed participants. Apart from orientation, the perspective of the image also seems to influence eating behavioral outcomes. Christian et al. (2016) found that imagining the consumption of indulgent food from a first-person perspective increased consumption and willingness-to-pay more than imagining it from a third-person perspective. The authors concluded that the ease of mental simulation makes the first-person perspective more affectively stimulating. In contrast, the simulation difficulty in the third-person perspective and the concomitant reduction in affect allows for more cognitive and deliberate decision making. These results were replicated in a neuroimaging study by Basso et al. (2018) in the context of food videos. The fMRI data suggest that a first-person perspective leads to higher activation in brain areas relevant for food pleasure and reward processing. In neither study did perspective influence outcomes of viewing healthy food.

Other aspects of perspective also seem to affect photo attractiveness and, presumably, the downstream behavioral response. In the context of developing real-time applications estimating food photo attractiveness, researchers from Japan have systematically assessed the effect of photography angle, scaling, and blurring of food photography. Albeit food photos were rated by only a small number of human raters,[2] and the findings certainly do not come as a surprise to professionals (see, e.g., Glyda, 2019), the researchers nevertheless document that the vertical photography angle (Takahashi et al., 2017) as well as *post-hoc* blurring and scaling (Hattori et al., 2018)

[2]In the case of Hattori et al. (2018), 20 computer science students in total.

impact the attractiveness of food photos. Furthermore, marketing of such assistive technology to consumers might soon make creating appetizing food photos trivial.

Creating Food Photography

Like any other behavior (cf. Gibson, 1979), eating is goal-directed. One of the implicit consumption goals is eating pleasure (cf. Poor et al., 2013). We suspect that the effects of photography on eating behavior depend on the congruence between the salient consumption goal and behavior (for a review on goal-priming, see Papies, 2016). Incongruence can lead to a cognitive conflict, which reduces the intensity of experienced pleasure (cf. Poor et al., 2013). Coary and Poor (2016) have shown that food photography can increase the taste evaluation of indulgent but not healthy food. The researchers provide evidence illustrating how photography both (1) directs attention to the food, i.e., increasing awareness of its properties, and (2) delays consumption, leading to an increased savoring of the indulgent experience. Healthy food is inherently less tasty than unhealthy food (Raghunathan et al., 2006), so healthy eating is incongruent with the consumption goal of pleasure. However, when Coary and Poor made descriptive healthy (vs. unhealthy) eating social norms salient, photographing healthy food before consumption lead to the same increase in taste evaluations seen previously for indulgent food. The awareness of the healthy eating social norm changed the consumption goal from indulgence to healthy eating, thus aligning goal and behavior. Photography becomes an amplifier for goal-dependent reward. One might ask, if being on a diet would shift the consumption goal toward healthy eating and enable photography's pleasure-enhancing effect *by default*? (cf. Papies and Hamstra, 2010).

In agreement with the findings by Coary and Poor, Diehl et al. (2016) show that photography, in general, increases the engagement in and enjoyment of experiences. The researchers approached customers at a highly frequented food market, asking them to participate in a questionnaire about their meal – either with or without instructing participants to take photographs of their meal. Customers that photographed their meal reported higher engagement and consequently increased meal enjoyment. The researchers also provide evidence for the claim that photography generally amplifies the inherent valence of experiences – positive experiences become more positive and negative experiences more negative. The *intention* to photograph directs attention toward valuable visual aspects of an experience – no need to actually photograph anything. Especially in the context of food, it might be worth noting that directing attention *toward* the visual aspects also means directing it *away* from other sensory aspects (cf. Barasch et al., 2017).

An important detail that Diehl et al. (2016) highlight is that photography only increases engagement and enjoyment of experiences when it does not interfere with the experience itself. In one of their studies, the researchers varied the interference level of photography. In the fully virtualized experimental setup, the low-interference group had to click a computer mouse to take a snapshot of a museum video. The medium-interference group had to drag and align a virtual camera onto the video, and the high-interference group additionally allowed participants to delete unsatisfactory snapshots. As predicted, the experimental groups differed in their level of enjoyment of the museum video tour, with the low-interference group enjoying the experience most. However, all of the experimental conditions were at least as enjoyable as the no-photography control condition. In the context of food photography sharing, this might mean that using the phone to take a photo of the dish adds to the meal experience, whereas navigating to the Instagram app, editing the image, and posting it detracts from the experience. Maybe, then, it would be better to wait until after the meal to share the experience.

Other researchers have recently looked to compare the effect of food photography and non-food photography on subsequent eating behavior (Yong et al., 2020). The researchers employed a within-participants design across two sessions separated by 1 week. In the first session, participants took photos before starting to eat, either of their food or of non-food objects, with the whole session lasting 12 min. The second session was an exact replication of the first, yet without any photography. The results showed no difference between the two photography conditions in any outcome measures, including ad-libitum food consumption, meal enjoyment, liking, wanting, or willingness-to-pay. Ad-libitum consumption in the first session was lower than in the second session. Due to the study design, it is impossible to say whether the fixed session order affected the results. Moreover, the lack of a comparable control group also raises the question, whether the similarity of the photography conditions is due to a general null finding or their actual equivalence. Furthermore, the study at hand took place in a laboratory setting, compared with the previous study's food market. In the former, baseline attention might have already been optimal, whereas, in the latter, the distracting environment made photography beneficial. The authors justify their study design referencing previous literature (i.e., Coary and Poor, 2016; Diehl et al., 2016), yet the lack of a proper control group or session randomization seem like a missed opportunity.

Although the above-mentioned literature has investigated food photography in terms of relevant end-points, such as food intake and meal enjoyment, research has yet to look at the activity mechanistically. Such studies in physiology, biometrics, and neurology may shed further light on the theoretical and practical interaction of food photography and eating behavior.

Sharing Food Photography

We have previously seen that social cues and norms can determine how viewing and creating food photography influences food intake and meal enjoyment. These results illustrate the social component of food. Therefore, it seems appropriate to investigate how interacting socially with and through food photography affects eating behavior. However, to our knowledge, the interaction of sharing food images and eating behavior has yet to be studied quantitatively. A potential explanation for the dearth of direct research on food photography sharing could be that researchers may consider observer effects more interesting based on the assumption that more people view food images than create and share them. In this section, we will, therefore, draw mostly on sociological research, as well as media reports, to outline what kind of food photography is shared, why it is shared, and how it might influence the sharer herself. In later parts of this review, we will expand on the topic by relating analogous scientific research to hypothesize about the impact of food photography sharing on eating behavior.

Social support is one reason to share food photography. People are known to use their Instagram profiles to track eating behavior, i.e., as food diaries (Connolly, 2015; Chung et al., 2017). People also use Instagram to supplement the recovery from eating disorders (Mirhashem, 2015; Benveniste, 2016). Using the platform as a food journal and recovery report, people can digitally receive emotional support from peers. However, Instagram supposedly invites and amplifies the natural tendency for social comparison and, as such, the maintenance of a favorable public presence can overtake the original intended purpose of supporting recovery.

The latter claim is further supported by sociological evidence. To uncover the motivations for food photo sharing, Atwal et al. (2019) conducted a diary- and focus group-study of French Fine Dining consumers. The researchers found that photos were intended for both private and public sharing. Motivations could be categorized as either experiential or symbolic. The experiential motivation revolved around enhancing the hedonic meal experience, altruism through sharing of information for others, and passion-collection. Symbolic motivations meant seeking social status, uniqueness, building self-esteem, or to present oneself socially favorably. These findings roughly correspond with earlier findings of Wang et al. (2017), who had investigated the motivations of traveler's food photography sharing.

In their (n)ethnographic study of online food photography sharing, Kozinets et al. (2016) found that the digital realm also affords the possibility of infinite food sharing and consumption. For some study participants, the practice was an explicit replacement (or compensation) for (the nowadays maybe rare) in-person commensality. The researchers also identified three levels of food-related social network participation: private, public, and professional. The overall distinction between these levels is, to paraphrase the researchers, that the private levels discipline, while the public ones exacerbate, food-related passions.

The content shared at the private level is at least as much social as it is about the food itself. For example, people themselves might be part of the photo (for public- and professional content this is not the case). Here, social norms also have a strong influence on behavior, at least in terms of sharing content. The researchers describe a mostly passion-repressive effect of these social norms. The question is how big this digitally-induced repressive effect is on actual eating behavior – will people change their behavior or simply omit "sinful" indulgences from being documented? As for now, we do not know.

As network participation becomes increasingly public and, ultimately, professional, content promotes "a concentrated state of pure consumption" (contra Tooming, 2021) and competes for audience attention. While content at the public level aims to shape and signal and image of the sharer herself, as a mechanism to build new relationships (cf. also Chen, 2017), professionals seek cultural influence and audience-engagement. The competition for attention drives a sort of "food porn extremism," resulting in transgressive content that appeals to the universal, primal, and visceral instincts of the audience (cf. also Matthen, 2015). This trend appears to stand in opposition to mainstream global obesity narratives promoting healthy eating and caloric austerity. Evidence for this notion of defiance could be seen in the paucity of "*broccoli or salad porn*" (Kozinets et al., 2016, p. 675). While not explicit in the aforementioned work, the implication in terms of the content creator's own eating behavior might be that in seeking for attention-catching transgressive novelty, she herself could fall prey to the bait.

There are further reasons to criticize the pervasive nature of food photography on digital platforms. The ubiquity of food photography is seen as a symptom – and by extension, amplifier – of societies and individuals' generally unhealthy relationship with food.[3] The obsession with photography supposedly devalues the multisensory experience – including flavors, atmosphere, and social aspects – in favor of a single-minded focus on the visual (Kingkade, 2013; Rawlinson, 2020).[4] This conceptualization seems to imply a zero-sum game – if vision is at the center of attention, and then all other senses must be at the periphery and, therefore, less important. Furthermore, the habit of sharing food photography proposedly changes what people eat, and changes even the primary motivation behind eating (see generally Turner, 2020; Turner and Gilmore, 2020). According to these authors, some people have come to choose food *solely* based on visual appeal and eat for social recognition instead of for taste and nourishment. In other words, the commentators lament precisely the fact that food "has moved beyond simply fuel" (Kingkade, 2013).

We will return to some of the above-mentioned themes in the next section to discuss future perspectives.

Interim Summary

So far, we have reviewed the literature on how different aspects of digital food photography, i.e., viewing, creating, and sharing, might influence our real-life eating practices (cf. **Figure 1**). Viewing food photos elicits similar responses to seeing real food (Boswell and Kober, 2016). Viewing a few food images can stimulate appetite (van der Laan et al., 2011), while viewing many images may induce satiety (Larson et al., 2014). These effects depend on the mental simulation of eating the depicted food. To this end, differences in image composition can make

[3]In her talk at the Canadian Obesity Summit 2013, Taylor also shows an arguably more extreme case of visual obsession with food: food tattoos.

[4]"We take pictures of things that are important to us, and for some people, the food itself becomes central and the rest – the venue, the company, et cetera -- is background" (Kingkade, 2013).

a substantial difference for the extend or ease of mental simulation (e.g., Elder and Krishna, 2012; Basso et al., 2018). Besides, images containing social cues to indulge influence food intake (cf. also Coary and Poor, 2016; Nakata and Kawai, 2017), as they can be used to, presumably unconsciously, justify such behavior.

The intention to photograph itself can increase the eater's attention on the food and amplify the pleasure of eating (Coary and Poor, 2016; Diehl et al., 2016; contra Yong et al., 2020). However, this effect seems to also depend on the consumption goal (Poor et al., 2013; Coary and Poor, 2016), for example, whether people, at least implicitly, eat for pleasure or for health. Only when the meal is congruent with the consumption goal does photography lead to increased enjoyment (Coary and Poor, 2016).

Finally, researchers have not yet studied the eating behavioral outcomes of food photography sharing, *per se*. Following anecdotal reports, the habit can be used in food diaries to improve eating behavior and aid recovery from eating disorders (Mirhashem, 2015; Benveniste, 2016). Sociological evidence suggests that consumers mainly share food photography for social reasons, while professionals seek attention for their work, thus proliferating the online space with highly appetizing food photos. To this end, food photography sharing has also been criticized for distorting the value placed on non-visual meal aspects (Kingkade, 2013) and changing the primary motivation for eating in the first place (Turner and Gilmore, 2020).

Next, we will draw upon scientific literature to outline several future research avenues related to the current trend of digital food photography (cf. **Table 1**). First, we examine the potential danger of viewing the endless variety of appealing food images offered on social media and how common usage patterns may lead to a net increase in appetite and, ultimately, food intake. Hereafter, we review the supporting evidence for encouraging photography at the table for increasing both food pleasure and improve long-term food intake regulation. Finally, we draw upon research from social eating to hypothesize how sharing food photography over social media may influence eating behavior. **Table 1** summarizes the evidence of demonstrated effects of digital food habits on eating behavior as reviewed in previous sections, and the predicted effects we will discuss in subsequent sections.

FUTURE PERSPECTIVES

Can Viewing Social Media Food Photography Lead to Overeating?

Some researchers have used the fact that viewing a high number of food images can induce sensory-specific satiety (as reviewed in previous sections) to suggest that food porn viewing may be a potentially health-promoting habit (e.g., Petit et al., 2016). Other researchers question this optimism (Missbach et al., 2014). First, these researchers replicated previous findings of mental imagery-induced sensory-specific satiety, whereby imagining eating gummy bears, compared to inserting coins into a laundry machine, decreased subsequent actual consumption of gummy bears. The authors went on to show that mental imagery-induced satiation does not occur when self-regulatory resources are depleted (e.g., when people are tired). The result of this study dramatically diminishes the practical utility of viewing food images to induce satiety, as it would be in precisely these situations of mental fatigue, and thereby impaired self-regulation (cf. Baumeister and Vohs, 2003), where external tools would be most beneficial.

Instagram and similar food-related social media sites are like buffets. Their image feeds are full of large varieties of indulgent foods, often depicting large portion sizes. The previous section on viewing food photography has established that type of food and the presented portion sizes are problematic, as they encourage overconsumption. Variety in a meal has a similar effect on food intake. Early research has established that within-meal food variety increases overall energy intake (Rolls et al., 1981a; see, e.g., McCrory et al., 2012 for a more recent review). This effect is closely related to sensory-specific satiety (see Remick et al., 2009). Moreover, the effect of variety also applies to mental imagery. Galak et al. (2009) instructed study participants to eat until satiated and subsequently recall the variety of past eating experiences. The recall "recovered" participants from satiation, thus, they would continue eating. While the effect of food *image* variety on food intake has yet to be studied, it seems natural to assume that the same overall effect would be seen, given the established connection of visual food cues and mental simulation. In combination, the effects of depicted food type, variety, and portion size suggest that food image platforms such as Instagram provide optimal appetite stimulation, which may sabotage any individual's best effort to control their food intake.

Overall, for individuals concerned about overeating, it seems justified to avoid food porn viewing, especially on social media on the smartphone.[5]

Should Food Photography Be Encouraged?

Food Photography to Enhance Agency

Agency is the sense of being in control of one's action, and is, therefore, an important motivator of goal-directed behavior (Bandura, 2010). Expenditure of effort is known to increase agency (Demanet et al., 2013). In a series of experiments, Hagen et al. (2017) have shown that low physical involvement when obtaining food decreases the sense of responsibility and concomitantly leads to less healthy food choices. The authors propose that the mechanism behind this result is due to self-serving (re)attribution – the psychological tendency to interpret behavior so that the most beneficial self-conception can be maintained (e.g., Heider, 1958). Thus, it is common for people to assume agency for their own positive behavior and reject agency, i.e., point at external factors, for negative behavior. Facts only loosely constrain such interpretations of personal responsibility. However, as these interpretations need to be

[5]Preliminary survey data of young Danish residents suggest that for 80% of respondents, the smartphone is the most frequently used device to view food photography (unpublished).

TABLE 1 | Published research of digital food habits, mediating mechanisms, and their (predicted) effects on eating behavior.

Food photography activity	Outcome (predicted)		Mechanism	References
Viewing	Food intake	↑	Visual stimulation of hunger	van der Laan et al., 2011; Pursey et al., 2014; Boswell and Kober, 2016
			Depicted portion size	Madzharov and Block, 2010; Toepel et al., 2015
			Depicted social cues	cf. also Poor et al., 2013; Nakata and Kawai, 2017
		(↑)	Depicted food variety	cf. Rolls et al., 1981a; Galak et al., 2009
			Mental simulation optimized image composition	cf. Christian et al., 2016; Basso et al., 2018
		↓	Image-induced sensory-specific satiety	Larson et al., 2014; but cf. Missbach et al., 2014
	Wanting	↑	Mental simulation optimized image composition	Elder and Krishna, 2012; cf. Christian et al., 2016; Basso et al., 2018
			Esthetic plating	cf. Velasco et al., 2016; Hagen, 2020
	Healthy food choice	↓	Grabbing reflex triggered on touchscreen devices	Shen et al., 2016
		(↓)	Depicted social cues	cf. Poor et al., 2013
		(↑)	Esthetic plating	Velasco et al., 2016; cf. Hagen, 2020
Creating	Meal enjoyment	↑	Increased attention	Coary and Poor, 2016; Diehl et al., 2016; contra Yong et al., 2020
		(↑)	Increased sense of personal responsibility	cf. Norton et al., 2012; Dohle et al., 2014
	Healthy food choice	(↓)	Increased sense of personal responsibility	cf. Hagen et al., 2017
	Portion size	(↓)	Increased sense of personal responsibility	contra Dohle et al., 2014; cf. Hagen et al., 2017
	Food intake	(↓)	Increased attention	cf. Robinson et al., 2013, 2014; contra Yong et al., 2020
			Increased food intake awareness	cf. Robinson et al., 2013
			Improved meal-time episodic memory	Higgs and Donohoe, 2011; cf. Robinson et al., 2013, 2014; Barasch et al., 2017
		(↑)	Increased sense of personal responsibility	cf. Dohle et al., 2014
Sharing	Food intake	(↓)	Digitally-mediated social comparison	cf. generally Herman, 2015; cf. Barasch et al., 2018
		(↑)	Digitally-mediated social sharing of responsibility	cf. generally Herman, 2017
	Healthy food choice	(↓)	Fulfillment of identity signaling needs	cf. Grewal et al., 2019
			Digitally-mediated social sharing of responsibility	cf. generally Herman, 2017
		(↑)	Digitally-mediated social comparison	cf. generally Herman, 2017; cf. Barasch et al., 2018
	Meal enjoyment	(↓)	Digitally-mediated social comparison	cf. generally Herman, 2017; cf. Barasch et al., 2018

Parentheses indicate effects that we predict based on related or analogous research.

socially believable, they hinge on the availability – or absence – of "reasonable" evidence. The studies of Hagen et al. (2017) show that comparatively minor physical actions are sufficient evidence to change the sense of agency and, consequently, behavior. For example, in a waiting room setting, having participants serve themselves unhealthy snacks from a big jar, compared with having pre-filled cups available, was sufficient to reduce sweets consumption dramatically. Follow-up investigations showed that choosing unhealthy food in low physical involvement conditions impacts positive self-regard less negatively than high physical involvement conditions. In contrast, when serving healthy food, there were no differences in amount consumed or feelings of positive self-regard between physical involvement conditions. We hypothesize that photographing food represents reasonable evidence of responsibility for the food choice and portion size, comparable to increasing physical involvement as reported by Hagen et al. (2017). As such, food photography could enhance the negative impact that unhealthy eating has on self-regard and, therefore, increase the likelihood of making healthier eating decisions long-term. The sense of agency also influences people's value perception. Norton et al. (2012) have shown that, mediated by an increased sense of agency, physical involvement increases the valuation of creations – the so-called "IKEA effect." Self-cooked food also tastes better, yet also leads to increased consumption (Dohle et al., 2014). These results are congruent with the digital photography-mediated increase in meal enjoyment reported by Diehl et al. (2016). By analogy, the congruence between these findings from the "physical" and the "digital" world suggests that food photography could lead to similarly increased healthy eating choices as seen in Hagen et al. (2017). In sum, we propose food photography as a promising method to increase people's sense of responsibility and, thereby, make healthier food choices.

A Photographic Food Diary to Promote Food Intake Memory

Food intake memory is inaccurate, with a self-serving bias toward underreporting (Lichtman et al., 1992; Schoeller, 1995; Seale and Rumpler, 1997; Hill and Davies, 2001). Food photography could be a more objective way to record eating behavior. The practice has been validated as a very accurate food intake measurement method in multiple settings and populations (for a review, see Martin et al., 2014). The Rapid Food Photography Method (RFPM) is a well-defined clinical methodology for measuring food intake under free-living conditions. Under 6 days of free-living conditions, the RFPM underestimated daily energy intake by an average of 150 calories, compared to the gold-standard method of Doubly Labeled Water (Martin et al., 2012). The method underestimated energy intake by 17 calories in a single buffet-style meal, compared with weighing the food. To provide some perspective, food labels in the European Union only need to be +/−20% accurate.[6] Participants of studies in free-living conditions scored the method highly in terms of practical viability. While the RFPM is more intricate than presented here, the point is that photography can provide accurate information of both food quality and quantity.

Carter et al. (2013) have shown that weight loss assistance apps on smartphones are superior in terms of adherence compared to implementations on websites on paper. Given the ubiquity of camera-quipped smartphones in the developed world (Pew Research Center, 2019), food photography thus shows the potential to be a practical and non-intrusive food intake management method.

Memory seems to be an important component in long-term food intake regulation. For example, amnesiacs may experience satiation, yet eat almost an entire second meal only a few minutes later (Higgs et al., 2008). In a systematic review on attentive eating, Robinson et al. (2013) showed that (1) reduced attention and visual cues during eating moderately affect immediate food intake, yet (2) reduced attention had a large effect on *later* food intake, and (3) episodic memory formation was linked to later food intake. In a follow-up experimental study, eating attentively led to a 30% reduction in later food intake in obese women (Robinson et al., 2014). However, contrary to the result of an earlier study (Higgs and Donohoe, 2011), the reduction in food intake was not mediated through improved memory. In the 2014 study, the authors noted that both the experimental and control groups had achieved high memory scores, presumably reaching a ceiling. In their review, the authors call to investigate practical methods that facilitate attentive eating, meal memory formation, and before-meal recall of prior consumption (Robinson et al., 2013).

A photographic food diary may be such a method! After all, photography increases engagement with and visual memory of experiences (Barasch et al., 2017). This effect is due to the shift in attention toward visual and away from other sensory experiences. As was the case for the findings by Diehl et al. (2016) reviewed previously, it is the intention of photographing that increases visual memory, and not necessarily the act of producing the photography itself. To further illustrate the point of photography's general effect on cognition, the memory of not-photographed objects was also improved. Here, we would like to reiterate that food photography needs to introduce as little distraction as possible *during the meal itself*. Not only does distraction impair the experience, but it also impairs memory formation (see Robinson et al., 2013) – quite the opposite of what we are trying to promote.

The photographic food diary would also be a convenient and effective format to facilitate recall. In her study on photography and memory, Henkel (2014) found that retrieval of museum tour memories was more effectively cued with photos than photographed object's names. Maybe meal companions should also be included among the food photos, as recall is improved when photos include people (Barasch et al., 2016). Following the findings by Robinson et al. (2013), photographs of recent meals should then be reviewed before a meal to recall prior consumption.

In sum, we suggest that the combination of taking food photos and reviewing them before subsequent meals could improve food choice and intake-regulation. These claims should be investigated to elucidate whether a photographic food diary in fact translates into long-term improvements in body weight management and eating behavior.

Manipulating Food Memory

It might make some sense to strategically manipulate previously taken food photos to enhance their eating behavioral effect upon review. One approach could be to influence how satiated one *ought* to be. According to the concept of *expected satiety*, satiety does not depend only on the actual nutritional content of food but also on how satiating it is believed or expected to be (Brunstrom et al., 2011). For example, in one study post-ingestive satiety of identical smoothies depended on whether the researchers told participants that the smoothie contained small or large amounts of fruit (Brunstrom et al., 2011). Based on the information given, the participants reflexively *imagined* how satiated they would be after the meal, affecting also their subsequent physiological response. While the effect studied by Brunstrom et al. (2011) was prospective, i.e., the information came before the sensation, under certain circumstances, it might be possible to trigger a similar effect in the reversed order (cf. Loftus and Pickrell, 1995). In the context of a photographic food diary, reviewing computationally enlarged images of the most recent meals might lead to compensation at subsequent eating occasions. This hypothesis is based on the assumption, that people would expect to be full more quickly, believing that previous meals were larger than they actually have been. AR applications that enlarge food sizes in real-time have already been proven to decrease consumption (Narumi et al., 2012), thus partly validating the concept.

Future research should aim to develop applications to make reviewing past meals convenient, while also measuring the effect that this practice has on long-term eating behavior.

Is Sharing Food Experiences Digitally Comparable to Social Eating?

As mentioned previously, there is a lack of directly focused research on the effect of sharing food photography with others on eating behavior. In the following sections, we draw on multiple research lines to speculate on potential avenues of research and application.

Food photography can increase the enjoyment of eating experiences, as described above. However, the purpose for taking photos can influence the effects on the experience itself. Barasch et al. (2018) showed how merely *intending* to take

[6]The *t*-20% accuracy is technically not completely correct, as accuracy is dependent on constituent and concentration range (European Commission, 2011); for the given argument, this oversimplification is sufficient.

photos for sharing can reduce the enjoyment of an experience compared to taking photos for personal use. Increased self-presentational concerns mediate this effect. The self-presentational concerns raise anxiety and shift the focus away from the experience and toward the self, subsequently reducing people's engagement with, and enjoyment of, the eating experience. For the same reason, audience size affects what is shared in the first place (Barasch and Berger, 2014). According to the Barasch and Berger (2014), audiences larger than one trigger self-presentational concerns, resulting in the sharing of less useful and more self-promotional content. In contrast, during one-to-one communication, people focus more on each other and share more useful information. These findings seem similar to those of Kozinets et al. (2016) levels of social network participation in a food context, discussed earlier. Therefore, we suspect that taking images intended for sharing might raise self-presentational concerns and thus reduce the subsequent meal enjoyment.

The abovementioned effects are analogous to the long-established phenomenon of socially facilitated eating, explicitly, eating with strangers. People eat less when eating with strangers – due to self-presentational concerns (Herman, 2015). The opposite is the case when eating in more acquainted settings. Eating with a friendly group of people is associated with significantly larger energy intake at meals. Specifically, the social context enables individuals to share responsibility and thereby rid themselves of individual responsibility. Some researchers have speculated that people arrange social gatherings precisely to engage in guilt-free indulgence (Herman, 2017). Young et al. (2009) found that this social eating effect depends on gender, both of that of the eater's themselves and their dining companions (see also Salvy et al., 2007). Specifically, women seem to reduce food intake when sharing a meal with men, while dining with other women increases it marginally. For men, the gender of meal companions seems inconsequential for food intake. Thus, it seems to matter who *you* are and with *whom* you share food with.

Sharing food images might have an unexpected catch. Marketing researchers have found that posting about an identity-signaling product decreases actual purchasing behavior (cf. generally Belk, 1988; Grewal et al., 2019). Essentially, posting about such a product fulfills the need to express identity. Food – and diet – are also expressions of identity (Yun and Silk, 2011; see Chuck et al., 2016). Therefore, we hypothesize that sharing, e.g., healthy food might fulfill the need to portray oneself as a healthy person and consequently decrease the need for actually eating healthily. However, the reverse might be equally true: sharing photos of one's indulgences might trigger the drive to make more healthy eating decisions. Digital confession, so to speak.

Based on the research presented above, it is unclear whether and how sharing food photography privately or on social media would affect eating behavior. The current scientific evidence seems to be ambivalent about the influences on healthy eating. Considering that many individuals are using social platforms to improve their eating habits (Mirhashem, 2015; see Benveniste, 2016), it is an area critical for future research.

CONCLUSION

Thus far, the steps within the cycle of food photography (see **Figure 1**) have been researched to varying degrees (cf. **Table 1**). Firstly, the subject of *viewing* food photography has accumulated the most direct research. On the one hand, viewing indulgent food images triggers mental simulations and thereby stimulates appetite (van der Laan et al., 2011; Boswell and Kober, 2016). On the other hand, viewing many food images could also induce sensory-specific satiety (Larson et al., 2014). However, we suggest that this approach is unlikely to be of practical benefit for two reasons. One, food variation in meals opposes the effect of sensory-specific satiety (Rolls et al., 1981a), and online image feeds tend to show a wide food variety. Two, the imagery-induced satiety effect depends on cognitive self-control resources (Missbach et al., 2014), which often are the limiting factor limiting self-control in the first place (cf. Baumeister and Vohs, 2003). Interestingly, viewing healthy food photos does not appear to have much of a beneficial effect (Poor et al., 2013; cf. Christian et al., 2016).

Secondly, *creating* photography has been subject to scientific investigation both generally and in the context of food. Research suggests that photography *per se*, irrespectively of the photographed object, increases (visual) attention (Barasch et al., 2017) and the overall enjoyment of experiences (Diehl et al., 2016). These general effects also seem to apply to food and increase meal enjoyment and taste evaluation (Coary and Poor, 2016; Diehl et al., 2016; contra Yong et al., 2020). However, the photography should interfere as little as possible with the eating experience (Diehl et al., 2016; cf. da Mata Gonçalves et al., 2019) – photo editing and uploading might best be delayed until after the meal. Further, we hypothesize that, by going through the effort of taking a photograph of the food, people will feel more responsible for their food choices, leading to greater satisfaction in the moment and healthier eating behavior over time (Norton et al., 2012; Dohle et al., 2014; cf. Hagen et al., 2017). The photography-induced increase in attention might improve memory (Barasch et al., 2017), which could be exploited to improve long-term bodyweight management (cf. Robinson et al., 2013). In this context, we see it as critical to review previous meals' photos before subsequent meals (Robinson et al., 2013; cf. Henkel, 2014).

Thirdly, the eating behavioral effect of *sharing* food photos has yet to be studied directly. We can only speculate how the sharing of food photography over social media may influence eating behavior. Existing research in commensality and, more broadly, social psychology suggest that food photography sharing could negatively influence food choice and eating pleasure (e.g., cf. Herman, 2017; Barasch et al., 2018). Future research should scrutinize the effects of food photography sharing.

In conclusion, food photography has become an integral part of many people's lives. Many questions remain about the influence of digital food photography on healthy eating behavior. However, it already seems clear that, if used wisely, photography can help us develop a healthier and more satisfying relationship with food.

AUTHOR CONTRIBUTIONS

TA, QJW, and DVB conceptualized the draft. TA wrote the initial draft and prepared the visualizations. QJW and DVB reviewed and edited the draft. All authors contributed to the article and approved the submitted version.

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Sonic Seasoning and Other Multisensory Influences on the Coffee Drinking Experience

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The coffee drinking experience undoubtedly depends greatly on the quality of the coffee bean and the method of preparation. However, beyond the product-intrinsic qualities of the beverage itself, there are also a host of other product-extrinsic factors that have been shown to influence the coffee-drinking experience. This review summarizes the influence of everything from the multisensory atmosphere through to the sound of coffee preparation, and from the typeface on the coffee packaging through the drinking vessel. Furthermore, the emerging science around sonic seasoning, whereby specific pieces of music or soundscapes, either pre-composed or bespoke, are used to bring out specific aspects in the taste (e.g., sweetness or bitterness) or aroma/flavor (nutty, dark chocolate, dried fruit notes, etc.) of a coffee beverage is also discussed in depth. Relevant related research with other complex drinks such as beer and wine are also mentioned where relevant.

Keywords: sonic seasoning, multisensory experience design, digital seasoning, coffee, experiential tasting

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INTRODUCTION

Coffee is one of the oldest of beverages, with the beans first cultivated in Ethiopia many millennia ago (Buffo and Cardelli-Freire, 2004). It is also one of the world's most popular beverages (Lim et al., 2019). By the opening years of the twenty first Century, it was estimated that somewhere in the region of one and a half billion cups of coffee were being consumed every day somewhere around the world (see Luttinger and Dicum, 2006, p. ix), or more than 400 billion cups annually (Illy, 2002). Coffee is considered to be the second biggest export product after oil for many developing countries. Over the years, a rich culture has evolved around the preparation and consumption of coffee (e.g., Robinson, 1893; Schultz and Yang, 1997; Pendergast, 2001; Weinberg and Bealer, 2001; Luttinger and Dicum, 2006; Kleidas and Jolliffe, 2010; Tucker, 2011). The beverage that so many of us enjoy today reflects a complex combination of the genetics of the coffee plant, the roast, grinding, and extraction of the beans (e.g., Sarrazin et al., 2000; Glöss et al., 2013).

Coffee is a very chemically complex beverage, with an estimated 850–1,200 volatile compounds (e.g., Grosch, 1998; Buffo and Cardelli-Freire, 2004; Fisk et al., 2012; Clarke, 2013; Faina, 2013; Yeretzian, 2017)[1], as compared to just 600–1,000 in a quality glass of wine (e.g., Rapp, 1990; Tao and Li, 2009), and around 137 natural volatiles in a glass of apple juice (Maarse, 1983). At the same time, however, it is also worth noting that only roughly 25–30 key volatile compounds actually contribute to the aroma/flavor of the final beverage (Buffo and Cardelli-Freire, 2004; Faina, 2013). In fact, according to Grosch, there may only be 13 really important volatiles contributing to the aroma/flavor (e.g., Grosch, 1998; Sarrazin et al., 2000).

[1]Though the majority of estimates tend to be toward the lower end of this range.

THE FLAVOR OF COFFEE: PRODUCT-INTRINSIC FACTORS

While it appears to many of us that we taste primarily with our tongue, all the senses are actually involved in the appreciation of the flavor of food and drink (see Spence, 2015d). In a sense, we really taste with our mind, since that is where the various sensory cues are first combined, along with the influence of mood and emotion (Spence, 2017a; see also Mitenbuler, 2015, p. 6). It is certainly true that the acidity-bitter-sweet nexus is crucial for those wanting to deliver a "well-balanced" cup of coffee (e.g., Seninde and Chambers, 2020; see also Costello, 2009).[2] However, matters are soon complicated by the fact that certain smells, like caramel (that one can sometimes find in the aroma of a cup of coffee), are associated with specific taste properties, such as sweetness (Blank and Mattes, 1990; Stevenson and Boakes, 2004; see also Labbe et al., 2006). It is really the volatiles resulting from the fermentation and, perhaps more importantly, the roasting (Yeretzian et al., 2012; Schenker and Rothgeb, 2017), and, thereafter, the grinding of the beans and the extraction of the coffee that turn out to be key to delivering that most desirable of aroma/flavor profiles that so many of us know and love (e.g., Semmelroch and Grosch, 1996; Grosch, 2001; Kerler and Poisson, 2011; Fisk et al., 2012; Charles et al., 2015). The majority of the coffee aroma is carried by the coffee oil that constitutes roughly 10% of the roasted coffee bean (Buffo and Cardelli-Freire, 2004).

A great deal of sensory analysis research has been conducted concerning the volatiles that are given off by different coffee plant cultivars (e.g., Arabica, Robusta) as a function of the specificity of the processing, including the fermentation (Schwan et al., 2012), and, perhaps most importantly, the roasting profile that they undergo (e.g., Calviño et al., 1996; Geel et al., 2005; Bhumiratana et al., 2011; Yeretzian et al., 2012; Caporaso et al., 2018). The coffee grown in different parts of the world tends to be associated with different taste/aroma properties (e.g., Costa Freitas and Mosca, 1999; Pawliszyn et al., 2008). Brazilian coffee, for example, tends to be sweeter than the coffees from Africa, which are often more acidic. The aroma of *Coffea canephora* (Robusta) tends to have a harsher earthier note due to the higher concentration of phenolic compounds such as guaiacol and vinylguiacol (Faina, 2013).

While the coffee aroma is made up of a complex mix of volatile compounds, the sourness, bitterness, and astringency result from the presence of a variety of non-volatile compounds (Vitzhum, 1999). As Stuckey (2012, p. 197) notes in her book, coffee is one of the world's most widely consumed bitter foods (see also McLagen, 2015). However, it is important to note that the caffeine is responsible for only about 10% of the bitterness that one tastes in a cup of coffee (this is why decaffeinated coffee tastes pretty much as bitter as the caffeinated variety). The majority of the bitterness in coffee is actually derived from the phenolic acids that are generated by the roasting process (see Stuckey, 2012, p. 197). One of the most salient ways in which coffee varies is in terms of its strength or bitterness (Dijksterhuis, 1998; Köster, 2003), with the degree of roasting described as "light," "medium," or "dark" (Buffo and Cardelli-Freire, 2004). Over the last decade or so, commentators have noted a general shift toward a preference for a stronger coffee in the west (Lambert, 2009).

The nutty, chocolately, fruity, cereal, and floral aromas that roasting and blending the right combination of beans can help to deliver are all enjoyed (or rather detected) primarily by the olfactory receptors in the nose (Spence, 2015a). In fact, coffee is one of the few drinks that is mentioned as sometimes being even more pleasurable orthonasally as we sniff and inhale the aroma,[3] than when we get a retronasal burst of flavourful volatiles pulsed out from the back of the nose (Rozin, 1982; cf. Ge, 2012). "Oral referral" is the name given to the fact that we all tend to mislocalize food aromas that are detected by the olfactory receptors in the nose to the mouth, and hence experience them as tastes (see Spence, 2016; see also Heath, 1988).

Researchers working at NIZO in New Zealand have argued that our mouth makes a different sound when we rub our tongue against the soft palate on the roof of the mouth after having tasted black coffee vs. after drinking coffee with a little cream (van Aken, 2013a,b; see also Nicola, 2013). The sounds that are associated with the consumption of coffee—think here only of the sound of slurping (Youssef et al., 2017; see also Seo and Hummel, 2011)—this something that is a distinctive element of professional coffee cupping (Schoenholt, 1995), is also an important part of the tasting experience (or at least it can be). Even appreciative food sounds (e.g., "Aaaaagh") have been suggested to influence people's judgments of the healthfulness of a beverage (Arroyo and Arboleda, 2021; see also Winter et al., 2019). In contrast to many other beverages, though, the visual appearance of a freshly-brewed filter coffee tends to be rather less informative than, say, the subtle gradations of shadings that one finds in a glass of wine (see Little et al., 1959; Spence, 2010a,b; Dmowski and Dabrowska, 2014).[4] Nevertheless, the coffee-drinking experience is one that can most definitely engage all of the senses, as we will see below (see Spence, 2014c).

PRODUCT-EXTRINSIC INFLUENCES ON THE PERCEPTION OF COFFEE BEVERAGES

A growing body of empirical research now shows that many aspects of the environment influence the coffee-drinking experience in a more-or-less subtle manner (see Spence, 2015b; Samoggia and Riedel, 2018): Everything from the cup to the background music (e.g., North and Croeser, 2006; Gater, 2010) to the softness of the chair that you happen to be sitting on (de Luca and Pegan, 2014; see also Pramudya et al., 2020), and from the brightness of the ambient lighting (e.g., Gal

[2] Salty and umami are not such dominant taste qualities of ground coffee, though the "smoked ham" note can be a distinctive feature in some instant coffees (Sarrazin et al., 2000).

[3] Indeed, cross-cultural studies often highlight the smell of coffee as being one of the most pleasant of smells (e.g., Knowles, 1963; Ayabe-Kanamura et al., 1998).

[4] Though, as noted by Spence and Carvalho (2020), the visual appearance of the crema appears to be an especially salient sensory cue in the marketing of espresso coffees.

et al., 2007) through to the sound of coffee preparation (see Knöferle, 2012)—not to mention the background smell of the toasted cheese sandwiches as Starbucks found to their cost a few years ago (see Nassauer, 2014). The majority of the research on product-extrinsic influences on the perception of coffee has been conducted amongst those who like coffee. It must therefore remain an open question for future research as to whether or not those who do not like this bitter-tasting drink would be influenced in a similar manner by such product-extrinsic factors.

Consider the Coffee Cup

The cup, or receptacle, that you drink your coffee from has more of a role than you might think: Everything from its size (Van Doorn et al., 2017) through to its shape (Carvalho and Spence, 2018), and from its color (Guéguen and Jacob, 2012; Van Doorn et al., 2014; Carvalho and Spence, 2019; Hansen, 2019; see also Favre and November, 1979 and Labbe et al., 2021) through to its texture (Carvalho et al., 2020) and even its material properties (Carvalho and Spence, 2021). Drinking coffee from a heavier cup is likely to intensify the aroma and perceived quality of whatever you happen to be smelling/drinking (cf. Gatti et al., 2014; Kampfer et al., 2017). The art on top of a latté has also been shown to influence how much people enjoy and, more importantly, are willing to pay for, their coffee too (see Van Doorn et al., 2015).

People sometimes say that hot beverages taste better from their own favorite mug rather than from someone else's too. The limited scientific evidence on this particular score would certainly appear to provide at least tentative support for the claim (Spence, 2017a). It has even been suggested that the quality of the coffee paraphernalia (e.g., the sugar dispenser) can make a difference to judgments of the quality of coffee, though robust data supporting this claim is yet to be forthcoming (Ariely, 2008).

The Context of Coffee Consumption

Researchers have known for years now that the atmosphere and environments in which we eat and drink can exert a significant influence over the coffee-drinking experience (e.g., Sester et al., 2013; see Spence and Carvalho, 2020, for a review). Coffee is, of course, not unique in this regard (Kotler, 1974; Bell et al., 1994; see also Keller and Spence, 2017), though, as one of the world's most popular beverages, it has certainly attracted more than its fair share of attention from the research scientists (e.g., Petit and Sieffermann, 2007; Maguire and Hu, 2013; Richelieu and Korai, 2014; Wu, 2017). These days, researchers often experiment with virtual and augmented reality (VR and AR, respectively) environments in order to help study the impact of the atmosphere, in one study comparing people's ratings of various different coffee beverages in the virtual coffee shop—complete with the appropriate visuals, sounds, and even the smell of freshly-baked cinnamon rolls—vs. a standard sensory testing lab in one study (Bangcuyo et al., 2015; see also Wang et al., 2020). The evidence clearly shows that the context, no matter whether real or virtual, really can make a difference to the tasting experience. Bangcuyo et al.'s study, for example, demonstrating that people's discriminative abilities and preferences amongst a range of different coffees could be better predicted by having them evaluate the beverages in the context of a virtual coffee shop, rather than it the traditional sensory testing laboratory.[5] Other researchers, meanwhile, have tried to evoke a specific drinking situation by having their participants read a description before tasting, and rating, coffee (e.g., Kim et al., 2016; Spinelli et al., 2017).

Sensploration: Welcome to the Coffee Sensorium

This growing understanding of the many product-extrinsic factors that have been shown to influence the multisensory tasting experience have led to an explosion of multisensory testing events where the various environmental cues are specially designed to match and/or to enhance a given taste quality (e.g., Velasco et al., 2013b; Spence et al., 2014a; Wang and Spence, 2015a). What is more, many consumers are becoming increasingly intrigued by the growing wave of interest in "Sensploration" (see Aroche, 2015; Spence, 2019b), this, the name given to the growing interest in exploring the surprising, almost synaesthetic, connections between our senses (see Spence, 2012). The 2015 *Tate Sensorium* exhibition provided one intriguing and extremely popular example of this, when a series of paintings were accompanied by scents, ultra-haptics, and even a gritty, smoky chocolate to taste (see Davis, 2015; Pursey and Lomas, 2018; Spence, 2020d). However, a number of the coffee exhibitions that have been put on in museums in the last few years have also become increasingly multisensory and immersive, As, for example, in the case of the Cosmos Coffee exhibition at the Deutsches Museum in Germany (https://www.deutsches-museum.de/en/exhibitions/special-exhibitions/archive/2019/cosmos-coffee/).

Visual Design Influences on the Perception of Coffee

In one striking recent study, 120 consumers in a coffeehouse in a Dutch university campus rated a coffee as tasting stronger and liked what they were drinking more when exposed to an ad displaying vertically- rather than horizontally-oriented visual cues during a coffee sample test (Van Rompay et al., 2019). The participants in this particular study were told that the new coffee blend that they were rating was linked to a poster shown on the wall (though, in fact, it was actually the coffeehouse's regular blend that they were tasting). When the ad incorporated vertical lines, participants rated the taste intensity of the coffee significantly higher relative to those participants who viewed a poster displaying horizontal elements instead. Mean ratings (on a 7-point scale) were 4.68 vs. 3.88 for taste intensity and 5.41 vs. 4.67 for the taste liking, as a function of the orientation of the background stripes/lines on the coffee ad that they saw.

Even the typeface of the text on coffee packaging has been shown to influence people's perception of specialty coffee,

[5]Much of the sensory panel work is done under red lighting in order to mask the visual appearance of the products under consideration (cf. Oberfeld et al., 2009; Spence et al., 2014a). Is it any wonder, one might ask, that so many new food and beverage products fail soon after launch when the environments in which they are tasted are so different from the context in which they are likely to be consumed?

with angular typeface enhancing expectations, and thereafter experienced, acidity in a cup of coffee amongst 146 regular consumers in one recent Brazilian study (de Sousa et al., 2020). The latter study, note, building on a growing body of empirical research showing that shape properties are matched to both tastes and aromas (e.g., Seo et al., 2010; Deroy et al., 2013; Hanson-Vaux et al., 2013; Velasco et al., 2018a). Furthermore, staring at angular (rather than rounded) shapes (Gal et al., 2007; Huisman et al., 2016) or typeface (Velasco et al., 2018b) has been shown to accentuate the acidity (rather than sweetness) in food and drink more generally (though see also Rolschau et al., 2020).

As yet, though, it is unclear the extent to which such shape matches to taste/flavor are based on the hedonics or valence (i.e., matching pleasant shapes with pleasant tastes with round and sweet both being liked, whereas angular and bitter are typically not; Salgado-Montejo et al., 2015) vs. on some kind of spatiotemporal translation of the taste experience that people have (e.g., with sour tastes tending to come and go rapidly, while sweet tastes tend to linger on the palate, coming and going much more gradually; see Deroy and Valentin, 2011; Obrist et al., 2014). Of course, both explanations may play a role in explaining why people match shapes to tastes/flavors in quite the way they do.

Auditory Influences on the Coffee-Drinking Experience

Background noise can exert a dramatic impact over our tasting abilities (Woods et al., 2011; Spence, 2014a, 2019a; Yan and Dando, 2015), masking our ability to perceive certain tastes (such as sweet and salt) while, at the same time, enhancing our ability to taste others (e.g., umami; see Spence et al., 2014b). On the downside, however, loud background noise (noise, note, defined as sound that is unpleasant) can interfere with our tasting abilities (e.g., Bravo-Moncayo et al., 2020; see also Alamir et al., 2020, Rahne et al., 2018, Seo et al., 2011, 2012, Stafford et al., 2012, 2013, Trautmann et al., 2017, and Velasco et al., 2014). In a recent study by Bravo-Moncayo et al. (2020), for example, listening to loud background music reduced a range of desirable attributes in a sample of coffee, being especially noticeable for ratings of bitterness and aroma intensity, as well as resulting in a lower willingness to pay. A total of 384 participants tasted and rated the same black coffee (a medium roast green Arabica from Ecuador) while listening to louder or quieter background noise [85 vs. 20 dB(A), respectively]. Given such results, is it any wonder that professional tasters often ask for silence when they taste (e.g., see Peynaud, 1987; see also Crocker, 1950)? At the same time, however, it is important to stress that the latest research also shows that listening to the appropriate music, rather than noise, can help to enhance the multisensory tasting experience (see Spence et al., 2019a, for a recent review of the evidence supporting this claim).

Background music has also been shown to exert a not inconsiderable effect over the multisensory tasting experience. This is an area that has come to be known as "sonic seasoning" (see Spence, 2017b). There has, in fact, been a huge explosion of interest in the crossmodal influence of atmospheric soundscapes and music on multisensory taste/flavor perception over the last decade or so (see Spence et al., 2019a). Indeed, the world-famous chef, Heston Blumenthal (of *The Fat Duck* fame, https://thefatduck.co.uk/) has described sound as the *"forgotten flavor sense"* (see Spence et al., 2011). Furthermore, when interviewed on the BBC's Radio 4, Blumenthal said that: *"I would consider sound as an ingredient available to the chef."* Other forward-thinking chefs, meanwhile, have even gone so far as to include a musical recommendation for each of the recipes in their cookbooks (e.g., see Pelaccio, 2012). Relevant here, it has been suggested that the emotion evoked by listening to music can influence how we end-up seasoning a dish or making a drink, and hence even perhaps also how strong a coffee we go for (see Spence and Piqueras-Fiszman, 2014; Spence, 2015c). Researchers have demonstrated that listening to specially chosen prerecorded pieces of classical music (chosen, in this case, because they could easily be associated with either a sweet, or sour taste) biased the sweet-sour balance when participants were tasked with making a well-balanced drink given a range of sweet and sour ingredients to blend together (Kontukoski et al., 2015).

Here it also worth bearing in mind the cultural aspects/differences in coffee drinking practices. That is, people drink coffee in many different ways around the world. Hence, even if the music may be the same, its impact on the multisensory coffee tasting experience might be expected to differ. As such, it is worth stressing that the majority of the research that has been reviewed here has been conducted in Western consumers drinking conventional filter or espresso coffees.

Musical Influences on Our Food and Beverage Choices/Preferences

The music that is playing when people decide which coffee to choose has been shown to influence their decisions too. In fact, a growing body of empirical research suggests that playing (e.g., ethnic) music can bias our food and drink choices (e.g., North et al., 1997, 1999; Feinstein et al., 2002; Muniz et al., 2017; Zellner et al., 2017; see also de Paula et al., 2020),[6] and possibly even our perception of the authenticity/ethnicity of the dish too (Yeoh and North, 2010). Background music has also been shown to bias people's covert visual attention and eye movements (e.g., Padulo et al., 2018; Peng-Li et al., 2020). There is also a literature emerging on the impact of variations in the physical parameters of sounds and music (e.g., high- or low-pitched instrumental sounds or voices) on consumer choice (see Lowe et al., 2018; Biswas et al., 2019). There are, then, likely a number of ways in which what we hear influences both what we taste and what we think about the experience (see Spence et al., 2019b, for a review of the emerging body of literature).[7] However, before we take a closer look at the emerging literature on sonic seasoning, it is worth noting that those sounds that are related to the preparation

[6]Music, of course, being but one element of the multisensory atmosphere influencing our coffee choice behavior (e.g., Bawa et al., 1989).

[7]Here, it is also worth noting that the tempo of the music is also an important factor modulating the speed of consumption (e.g., Mathiesen et al., 2020), though a detailed discussion of the literature in this area falls outside the scope of the present review.

of the coffee itself also help set our coffee-related expectations and hence experiences.

The Sounds of Coffee Preparation

There are, in fact, a number of different ways in which the sonic backdrop can influence our tasting experiences (including noises, atmospheric sounds, and music): The sounds of preparation, think only of the sounds of the coffee machine grinding, dripping, steaming, etc. are undoubtedly important: These sounds, no matter whether we pay attention to them or not, can help set our sensory expectations regarding the drink that we are about to consume (see Knöferle, 2012). Here, it is important to note that very often we taste what we predict, or expect that we are going to taste (see Deliza and MacFie, 1997; Piqueras-Fiszman and Spence, 2015, for reviews). It turns out that it is possible to hear the temperature of a beverage such as the coffee as it is poured into a cup (Velasco et al., 2013a,c), with changes in the temperature of a liquid changing the viscosity which, in turn, changes the pitch of the sound (see Parthasarathy and Chhapgar, 1955). That is, the majority of people can discriminate the sound of hot from cold water when poured at a level that is significantly above chance. Given that the temperature at which beverage, such as coffee, is served, influences the release of aromatic flavor volatiles from the surface of the drink (Steen et al., 2017), the sound of temperature likely helps to subtly set people's aromatic flavor expectations too. The various informative sounds associated with the preparation of coffee can help to set people's (often unconscious) expectations, just like the *"sizzle that sells the steak."* This, the famous 1930s strapline from legendary North American marketer Elmer Wheeler (Wheeler, 1938)[8].

Atmospheric Soundscapes

Jo Burzynska, a professional New Zealand wine judge and sound designer has developed some intriguing soundscapes recorded in the vineyards to be heard while tasting the wine made from the grapes that were harvested in the place that drinkers are listening to Burzynska (2012, 2018). Listening to such soundscapes helps to draw one's attention to the natural origins of the product, and perhaps also emphasizes notions of terroir (see also Brennan, 2020; Unusual Ingredient, https://unusualingredients.co/). Burzynska's work can be seen as building on prior work showing that the sound of the sea can enhance the taste of seafood (Spence et al., 2011; see also Marinetti, 1932/2014). Here, then, one could perhaps think about connecting the coffee drinker to the nature sounds of the coffee plantation where the coffee beans (or rather coffee cherries) fruited. At the same time, however, it is worth stressing that the aromas that so many of us enjoy in a cup of freshly-brewed coffee are perhaps more dependent for their delicious flavor on the processing (including the fermentation, roasting, and thereafter the grinding and extraction) than in the case of wine, hence meaning that the connection with the coffee plantation is a little weaker than in the case of the fruits of the vine for wine. That being said, there is now plenty of evidence to suggest that environmental sounds do indeed influence the tasting experience (e.g., in the case of gelati; Lin et al., 2019; Xu et al., 2019a,b).

Sensation Transference From the Background Music

The music we listen to affect our perception of everything from the sexiness of another's touch (even if that caress happens to be delivered by a robot; see Fritz et al., 2017) through to the softness of the material that we happen to be evaluating (Imschloss and Kuenhl, 2019). Even our rating of the attractiveness of pictures of other people (May and Hamilton, 1980) and paintings can be modified by the background music (see Spence, 2020c, for a review). There is, in other words, extensive evidence of "sensation transference" (see Cheskin, 1972): This is the name given to what happens when what we feel about one stimulus is automatically carried over to what we think about a simultaneously-experienced but independent stimulus (see also Lowe and Haws, 2017). This is presumably one of the mechanisms by which "sonic seasoning" operates in the case of multisensory coffee tasting.

SONIC SEASONING

There is now a large and growing body of peer-reviewed empirical research matching sound qualities to specific taste qualities (e.g., see Knöferle and Spence, 2012; Knöferle et al., 2015; and for more recent sonic seasoning research, see only: Mesz et al., 2011, 2012; Guetta and Loui, 2017; Watson and Gunter, 2017; Höchenberger and Ohla, 2019). A summary of the musical properties associated with each of the basic tastes as reported by Knöferle et al. (2015) is shown in **Figure 1**. Meanwhile, Spence et al. (2019b, Table 1) provide a detailed review of sonic seasoning studies that have been published to date.

There has, in fact, been an explosion of research on sonic seasoning over the last decade (Spence, 2017b). Contemporary interest in this area builds on the early research demonstrating the "pitch of harmony" for many food flavors (e.g., Holt-Hansen, 1968, 1976; Rudmin and Cappelli, 1983; see also Reinoso Carvalho et al., 2016c). Crucially, recent research has successfully managed to replicate Holt-Hansen's early suggestion that simply by matching the tone to the taste (or flavor) one can actually enhance the subjective enjoyment of the tasting experience (Reinoso Carvalho et al., 2015a). Much of this research has been conducted with bittersweet foods such as chocolate (e.g., Reinoso Carvalho et al., 2015b) and beer (e.g., Reinoso Carvalho et al., 2016a,b). There is therefore every reason to believe that similar crossmodal effect would also be demonstrated with coffee as well. At the same time, changing what people hear has also been shown to influence both sensory discriminative and hedonic response to gelati (Kantono et al., 2016).

Research from a wide range of consumers shows the musical parameters that are matched with specific tastes (Knöferle and Spence, 2012; Knöferle et al., 2015; see also Ngo et al., 2011 and Simner et al., 2010, on the vocal parameters matched with

[8]There are a number of examples, now, of where distinctive liquid pouring sounds have been emphasized in adverts (McMains, 2015). See also Anon. (2012), Garber (2012), Knoeferle and Spence (2021), and Spence (2014b), on the advertising potential of sonic cues.

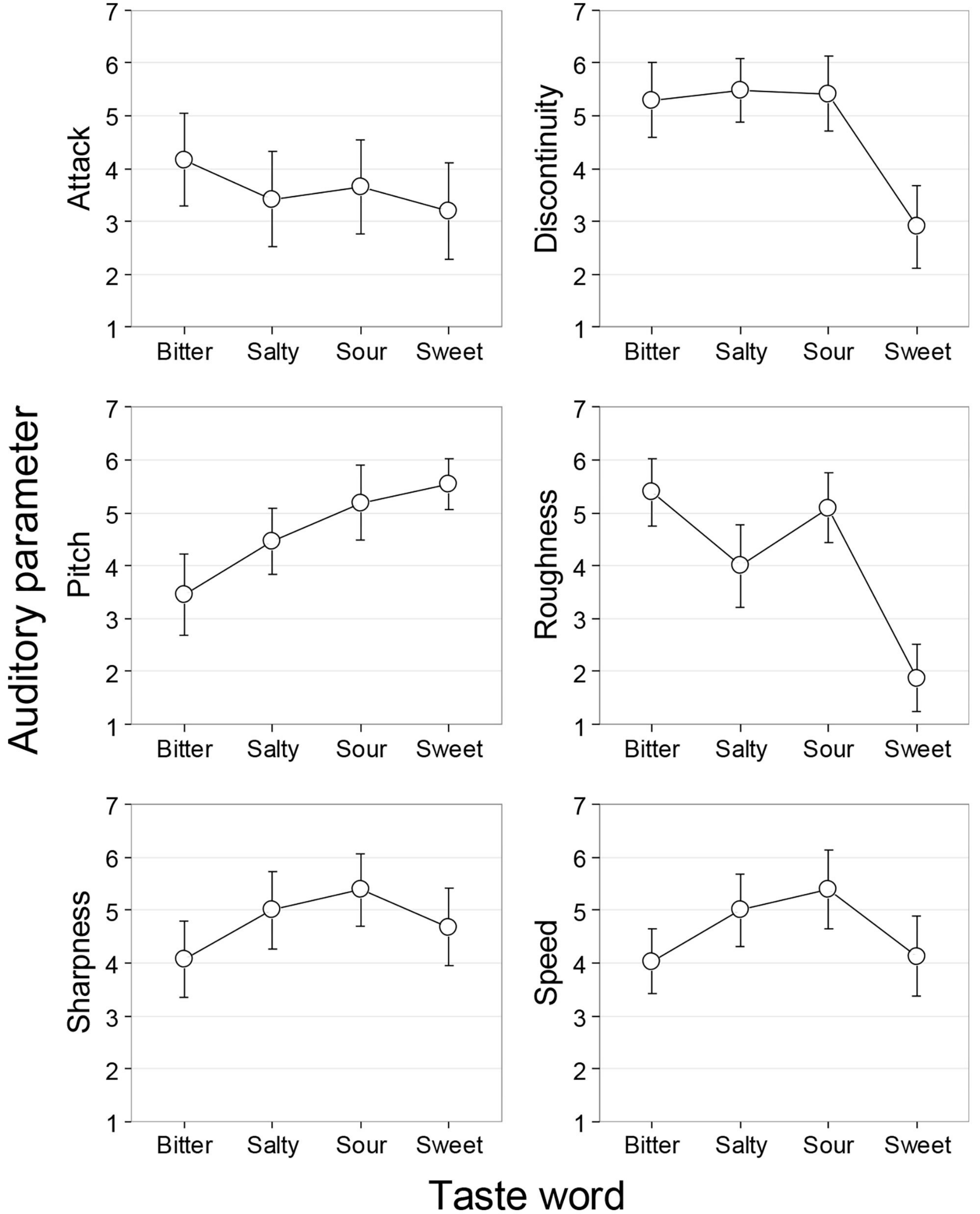

FIGURE 1 | Participants' selections for (psycho-)acoustic parameters in response to basic taste words in Knöferle et al. (2015, Experiment 1). Error bars indicate 95% within-subjects confidence intervals (Morey, 2008).

each of the four basic tastes), temperatures (Wang and Spence, 2017a), textures (Reinoso Carvalho et al., 2017), trigeminal attributes (such as spicy, Wang et al., 2017), and olfactory notes (e.g., Crisinel and Spence, 2010, 2012a). Low-pitched music has also been shown to enhance other beverage qualities, such as the body of a red wine (Burzynska et al., 2019). There now exists a reasonably well-worked out musical menu of the sonic characteristics that help bring out the acidity, bitterness, and sweetness in a multisensory tasting experience. Furthermore, given all the sonic seasoning tracks that have been generated to date, it has been possible to compare different compositions in order to then extract the distinctive sonic features of the tastiest of musical tracks (Wang et al., 2015). This kind of analysis has, for instance, revealed that the lower the pitch, the more bitter the sound.

In one of the earliest sonic seasoning studies, Crisinel et al. (2012) demonstrated that a bittersweet cinder toffee could be sonically seasoned to taste either a little sweeter or more bitter. Which sonic manipulation is most appropriate might, then, depend on an individual taster's preferences. Meanwhile, in one marketing-led intervention, the Xin café in Beijing used augmented glassware to play sweet music and so reduce the sugar content in the hot beverages they served to their customers (Blecken, 2017). Note here that the research suggests that the sweetest tracks tend to be higher in pitch and consonant (Wang et al., 2015). The sound of a tinkling piano has also been associated with sweetness in several studies (e.g., see Crisinel and Spence, 2012a).

Septimus Piesse (1891), the British-born French perfumer, published his famous scent scale in the latter half of the nineteenth Century, explicitly matching various olfactory notes with specific musical notes. Meanwhile, contemporary interest in the sound of odor has highlighted the musical translation for the fruity, earthy, and nutty notes that one can find in a specialty coffee (e.g., Belkin et al., 1997; Crisinel and Spence, 2010, 2012a). Indeed, given that 75–95% on what we think we taste, we actually smell (Spence, 2015a, 2016), matching the sonic seasoning to what we smell (whether by the orthonasal or retronasal route) is likely going to be especially important. The typical aromas that the consumer may expect to experience in a cup of freshly-brewed specialty coffee include "nutty," "almond," "brown spice," "floral," and "jasmine" (see, for example, the coffee lexicon developed by World Coffee Research: https://worldcoffeeresearch.org/work/sensory-lexicon/; Chambers et al., 2016; Croijmans and Majid, 2016, on the language used by the coffee experts).[9]

There is growing interest in sonically signaling olfactory properties (be it of a drink or other fragranced product; see Deroy et al., 2013, cf. Mahdavi et al., 2020). It has been suggested that such crossmodal influences may build on the various direct connections that have been reported between the nose and the ear (e.g., see Wesson and Wilson, 2010, 2011; Zhou et al., 2019). At the same time, however, there may be more indirect routes to sonic seasoning given that, as has been mentioned already, different olfactory notes can be associated with taste properties such as sweetness (see Blank and Mattes, 1990; Stevenson and Boakes, 2004). So, for example, the aromas of caramel and vanilla are both associated with sweetness (cf. Bronner et al., 2012). Bronner et al. (2012) developed music specifically for the flavor of vanilla and citrus. However, given that these tastes are strongly linked with sweetness and acidity, it remains rather unclear whether the music was actually primarily being matched to the dominant taste that we associate it with.

Attending to the Multiple Elements in a Multisensory Tasting Experience

Another of the ways in which sonic seasoning works, especially for a "complex" tasting experience, is to help draw a taster's attention to something in their tasting experience that they might otherwise overlook (see Spence, 2019c, for a review). Here, it is also worth noting that a carefully-orchestrated piece of music can help to structure a taster's temporally-evolving taste experience (e.g., see Crisinel et al., 2013).[10] This was demonstrated in one innovative project were a separate instrumental track was associated with each of the dominant olfactory notes in a cognac (e.g., candied orange, *crème brûlée*, coffee, violet flower, etc.). Initially, people were encouraged to sniff each distinct aroma while listening to the matching instrument. Thereafter, they were supposed to taste the drink while listening to a musical composition that incorporated elements from each of the individual tracks. The idea was that the temporal structure of the music (with different instruments tied to different aroma notes) would enable the consumer to better pick out the various distinctive elements in their tasting experience. A similar approach was adopted more recently by chef Jozef Youssef (of Kitchen Theory) and sound designer Steve Keller in a project for Chivas whisky (The Sound of Chivas Ultis, 2017). The *Godiva: A symphony of taste* project from 2018 provides yet another example of how compositions can be created specifically to match the temporally evolving taste/flavor profile of a complex food such as chocolate.[11]

Stylistic Musical Influences on the Tasting Experience

There are semantic qualities and associations that we may have with particular styles of music. There is, for example, a wide body of research on the association between classical music and quality (e.g., Spence et al., 2013; Wang and Spence, 2015b; see also Zolfagharifard, 2013). In fact, across a range of situations, people have been shown to spend more and to rate taste experiences as higher class (or better quality) when in the presence of classical music, e.g., rather than pop music (see Spence, 2017a, for a review; see also De Luca et al., 2019).[12] The semantic associations

[9] *LeNez by Jean LeNoir Provides a Selection of Kits Highlighting Specific Coffee Aromas.* Available online at: https://www.lenez.com/en/kits/coffee?gclid=EAIaIQobChMI2MbirsGd7QIVRbTtCh3m2Ai0EAMYASAAEgLQafD_BwE.

[10] Here it is also worth noting the similarity in blending different coffees to deliver a harmonized taste and the process involved in harmonizing musical compositions (see King, 2014a,b).

[11] See https://www.youtube.com/watch?v=wvH_fYCoPzs; https://www.youtube.com/watch?v=rph6oyIEJ9o.

[12] Traditionally, there was a whole area of music designed specifically to be listened to at mealtimes. This is what is known as *Tafel music* (i.e., table music; Reimer,

with different styles of music may, then, be expected to prime certain qualities or attributes that are expressed in the taste of whatever it is that we happen to be tasting, be that a cup of coffee or something else. By systematically pairing music with taste/flavor it is possible to enhance the multisensory tasting experience, as many companies and brands have now started to do (e.g., Victor, 2014; McCarthy, 2015; Sanderson, 2015).

In one unpublished study, Gater (2010) investigated the impact of listening to different musical genres on people's perception of the sensory properties of a commercial coffee sample over a period of 10-min. The participants either tasted in silence, or else while listening to jazz, classical, or rock music genres. The musical selections all had equivalent tempi (≥90 BPM) and volume (70 dB). The seven participants who took part in this study (this sample size, unfortunately likely too small to obtain reliable significance) rated the same standardized coffee beverage on four key characteristics (aroma, flavor, bitterness, and astringency) every minute using a Qualitative Descriptive Analysis (QDA) methodology. Despite the very small sample size, Gater was nevertheless still able to observe some intriguing trends suggesting that exposure to the background music increased the time needed to detect a significant change in the aroma of the coffee. Gater's results also suggested that the association between jazz music and a café-type atmosphere resulted in participants rating the coffee's flavor, bitterness, and astringency as somewhat less intense than in the other conditions (see also Fiegel et al., 2014; Ziv, 2018; De Luca et al., 2019, on the positive effect of background music on the enjoyment of food). There is some evidence of there being a preference for listening to live rather than pre-recorded music while drinking coffee, at least amongst coffee drinkers in South Africa (North and Croeser, 2006; see also Wang and Spence, 2015b). Elsewhere, Brown (2012) has also suggested specific musical matches for different beers, and co-creation of music for coffee shops has also been suggested as a successful strategy (Jeon et al., 2016; see also Unnava et al., 2018, on the more social aspects of caffeine consumption).

Sonic Sensation Transference: Musical Affect/Emotion

It has long been known that listening to music provides an effective means of communicating affect, and possibly also basic emotions (e.g., Konečni, 2008; Reybrouck and Eerola, 2017; though see Cespedes-Guevara and Eerola, 2018). The musical manipulation of our emotional state, then, provides another means by which what we hear can influence what we taste, and how much we enjoy the experience (though there may be some cultural differences to be aware of Athanasopoulos et al., 2021). For instance, illustrating the impact of induced emotion on taste, Noel and Dando (2015) conducted a study in which people had to rate a sweet-sour drink at the end of an ice hockey game. Those who were supporting the winning team rated the drink as tasting sweeter than those whose team lost. Similarly, Wang and Spence (2018) demonstrated that simply looking at pictures showing positive or negative emotions, biased people's taste perception. Looking at a happy smiling child accentuated the sweetness in an unfamiliar sweet-sour blend, while looking at a crying child had the opposite effect (see also Desira et al., 2020; Liang et al., 2020). Oftentimes, especially when selecting those crossmodal correspondences involving musical stimuli, emotion seems to mediate the mapping, be it between music and paintings, music and color patches, and hence presumably also between music and coffee (see Wang and Spence, 2017c; Spence, 2020c).

Hedonic/emotional sensation transference effects from music to taste have also been demonstrated (e.g., Reinoso-Carvalho et al., 2019, 2020a). Indeed, some of the most exciting recent research has shown that sonic seasoning and sonic sensation transference can be combined and thus be triggered concurrently (see Reinoso-Carvalho et al., 2020b). In the latter study, for instance, Reinoso-Carvalho et al. chose one pair of musical tracks designed to induce emotion, and another pair of tracks that had been demonstrated to give rise to sonic seasoning. In a large-scale between-participants study, each participant listened to one of the four tracks and tasted a piece of chocolate. The results provideded strong support for the crossmodal effect of music on taste ratings, though the emotional influences were numerically larger than those reported for the sonic seasoning tracks in this case. Ultimately, therefore, one of the aims of sonic seasoning research is to pick, or select, music combining elements of "sonic seasoning" to enhance the desirable taste qualities, and positive "emotional sonic sensation transfer" to enhance the overall multisensory experience.[13]

What is also worth noting here, sonic seasoning, and sonic sensation transference, have now been demonstrated in a wide variety of populations, from the US to the UK, and from Korea to India, and Japan (e.g., see Knöferle et al., 2015; Reinoso-Carvalho et al., 2020a,b). Such findings therefore hint at the possibly universal underpinnings of sonic seasoning and sonic sensation transfer. That said, it should also be remembered that cultural practices around coffee do differ, and hence the influence/impact of music might also be expected to vary—though, this has not been studied much to date.

Who Needs Sonic Seasoning?

At this point, it is perhaps worth addressing those naysayers who are critical of the entire sonic seasoning approach. There are those, primarily in the upper echelons of wine appreciation it has to be said, who are minded to say something of the sort, why bother changing the music to improve the taste of the drink, when you can simply pick a different wine that is more to your taste.[14] It would seem legitimate to ask whether the

1972; Littler, 1989), and was born in the early seventeenth Century in central Europe. In terms of music linked to coffee, one might also consider JS Bach's Café Cantata (BWV 211; https://parkersymphony.org/coffee-and-classical-music).

[13]Importantly, given the current replication crisis running through the psychological sciences (especially, it has to be said, social psychology), it is worth stressing that the latter results were based on Bayesian statistics (which many statisticians consider to provide a more robust approach than traditional null hypothesis testing. The sample size (>1,600 participants), was also far greater than in the majority of studies of sonic seasoning that have been published to date (cf. Watson and Gunter, 2017; Höchenberger and Ohla, 2019), thus helping increase the power of this study.

[14]One might wonder here whether the study of effect sizes might help to provide a more objective means of assessing the magnitude of the effect of changing the coffee/wine vs. changing the musical accompaniment.

same could also be said when it comes to sonically seasoning one's coffee. Other commentators, meanwhile, worry that a well-balanced wine, or presumably coffee, are more likely to be knocked out of balance if music is played that is overly sweet, bitter, or acidic, say (see Crawshaw, 2012). Then again, there have even been some who, perhaps understandably, have doubted whether what we hear has any impact on what we taste at all. Just take the following, from journalist Alice Jones, writing in *The Independent* newspaper, when she expressed doubt that the claim that *"wine tastes better with music"* would *"stand up to scientific scrutiny."* (Jones, 2012, p. 51). The critics tend to be especially doubtful that such crossmodal effects would be evidenced in expert tasters (like themselves)—though, once again, the evidence suggests that they are wrong on this score too (e.g., see Beckett, 2017; Wang and Spence, 2017b; see also Spence and Wang, 2015a,b,c).

As a sign of the times here though it is worth noting that the growing interest in sonically-seasoning one's coffee beverage has already started to appear at a number of professional barista competitions in recent years (see **Figure 2**). It all goes to show that the science of enjoying a great cup of coffee isn't only about the liquid in the cup (hugely important though that undoubtedly is), but ultimately involves the optimization of the total experience (Illy and Illy, 2015; Vanharanta et al., 2015), and that undoubtedly includes any music that might happen to be playing in the background. The incorporation of a sonic element can also be seen as hinting at the growing acceptance of the influence that sonic factors have over the multisensory tasting experience.

Ultimately, it is important to note that there is always a sonic backdrop to our coffee tasting experiences. It might be background noise suppressing the tasting experience or else a silence that can itself be uncomfortable/oppressive. Hence, one cannot simply ignore the auditory environment and pretend that it doesn't exist or matter when tasting coffee (see Spence, 2017a). The real question, therefore, is which sounds/musical selections work best to deliver the outcome that the coffee-drinker wants. While some might choose to complement their coffee with matching music, others might prefer more of a contrast (a kind of crossmodal counterpoint if you will). Get the sonic seasoning right, however, and the combination of tastes and tunes can be truly transformative. That, at least, has been the experience of some experienced wine tasters. Just take the following from the late James John (MW—Master of Wine), Director of the Bath Wine School (which is now the Bristol Wine School), as a representative example, when he writes of the combination of Mozart's Laudate Dominum, and Chardonnay: *"[...] Just as the sonant complexity is doubled, the gustatory effects of ripe fruit on toasted vanilla explode on the palate and the appreciation of both is taken to an entirely new level"* (quoted in Sachse-Weinert, 2012, see also Sachse-Weinert, 2014).[15]

[15]And when thinking of the musical match for latte, one might take the following analogy from Luciano Franchi, MD of several London coffee shops when he suggests that *"Latte is to coffee what Stock, Aitken and Waterman is to music"* (Lambert, 2009, p. 3).

As a taste of things to come, one need only take the example of the speciality coffee shop that opened up recently in Korea where every seat at the counter comes with a pair of headphones so that the music that each customer listens to can be matched to the coffee that they have ordered (see Spence, 2020a) (see **Figure 3**).

Finding the Optimal Musical Match Given One's Personal Taste in Coffee

Knowing what we now do about the fascinating world of "sonic seasoning" (Spence, 2017a; Spence et al., 2019a), it can be argued that it makes sense to match the music to the coffee, rather than leaving this opportunity to pair our experience (sensory pleasures) up to chance. This is especially true given that we all live in our own worlds of taste (Bartoshuk, 1980). According to Chaham Yeretzian, one of the foremost coffee chemists out there: *"Every coffee drinker is different. What a coffee really tastes like depends on the form of the oral cavity and where the coffee first touches the tongue."* (quoted in Scholl, 2012, p. 30)[16]. In the same article, Yeretzian also states that: *"Different people experience differently too"* (quoted in Scholl, 2012, p. 29).

Some of us prefer a slightly sweeter or more acidic finish in our coffee beverages. As such, sonic seasoning can be framed as allowing any one of us to take a great-tasting coffee and season it to our own particular preferences without the need to add sugar or change what we are drinking (Gal et al., 2007; cf. Blecken, 2017). Several individual differences in the worlds of taste that we inhabit are worth mentioning in the context of coffee. These include the fact that there are supertasters (roughly a third of the population) who find coffee more bitter than others—the so-called medium and non-tasters (e.g., Stuckey, 2012, p. 197–198; Masi et al., 2015). There are also sweet-likers and those who are neutral about sweetness in the population (e.g., Bartoshuk, 1991; Looy et al., 1992; Keskitalo et al., 2007; Yeomans et al., 2007; Frayling et al., 2018). At the same time, however, our preference for sweetness in coffee may also be determined, at least in part, by how long we have been drinking it for. Note here only how many people initially start drinking coffee by sweetening it to help mask the bitterness (e.g., Zellner et al., 1983). Once they acquire a liking for the taste of this distinctive bitter beverage, they may then reduce the amount of sugar, or sweetener added.

On top of these genetic differences in gustatory perception, there are also relevant individual differences and selective anosmias that affect smell too (e.g., see Reed and Knaapila, 2010). Such individual differences may also influence people's rating of the best sonic/musical match for a given taste (see Crisinel and Spence, 2012b). Supertasters have, for instance, been shown to match the tastes for which they are especially sensitive to a louder sound than non-tasters (cf. Bartoshuk, 2000).

[16]Though note that we should perhaps be skeptical of the claim that different tastes are detected on different parts of the tongue (i.e., sweetness on the tip of the tongue, acidity on the sides, and bitterness at the back). This outdated notion, in fact based on a mistranslation of an early German text (Hänig, 1901), also appears in promotional materials from Nespresso. While it might be true that subjectively we experience different tastes differently on different parts of the tongue, the taste buds are all sensitive to exactly the same range of basic tastes. That said, there may be more to say on this topic (Feeney and Hayes, 2014).

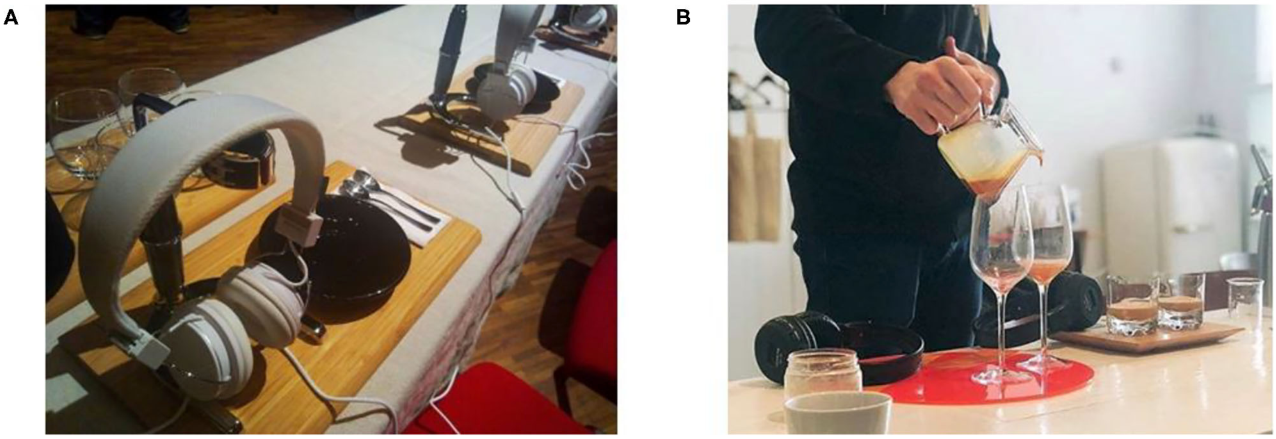

FIGURE 2 | Multisensory experience designs during barista championships. **(A)** Rasmus Helgebostad's sonically-enhanced coffee drink served as part of his entry in the 2011 Norwegian barista championships; **(B)** Matt Winton's multisensory experience of the same signature coffee drink being served in two different setups (including distinct soundtracks) in the 2018 World Barista Championship. This figure reprinted from Spence (2020a, Figure 2).

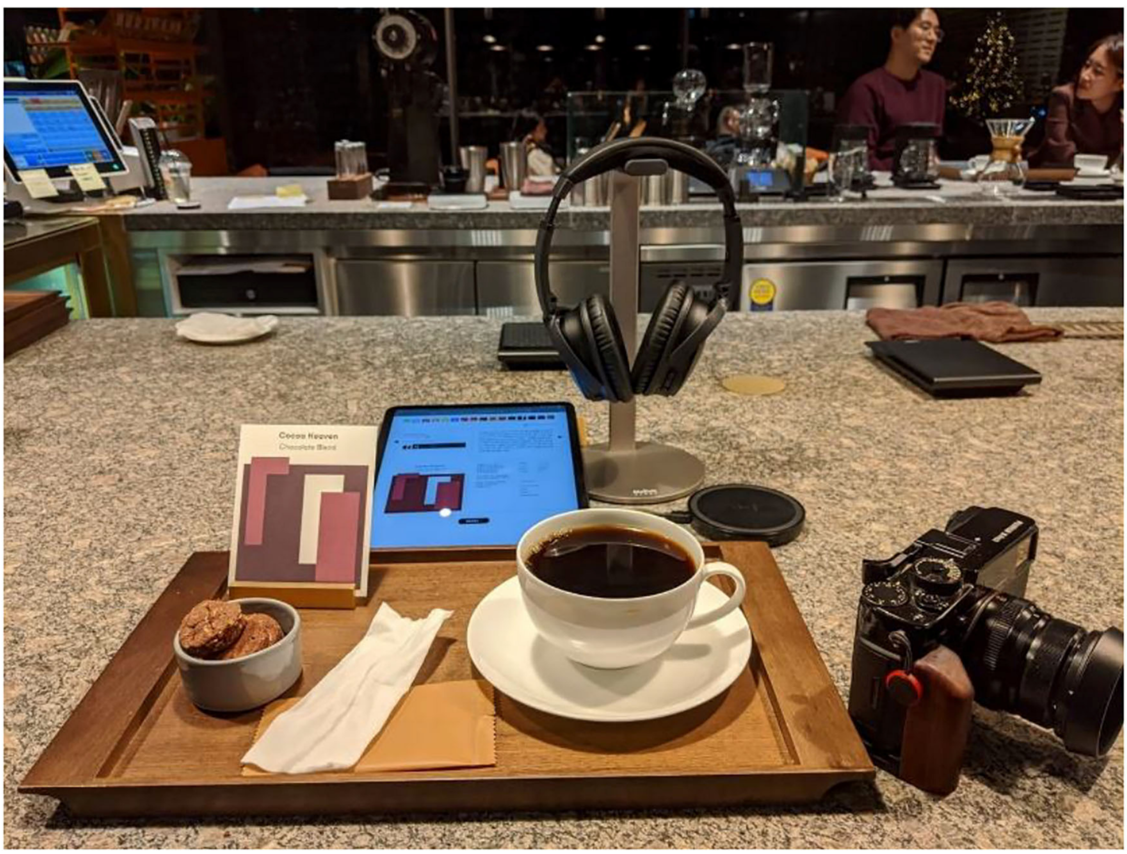

FIGURE 3 | Korean coffee-shop where music is paired with the choice of coffee designed to match the customer's taste preferences. This figure reprinted from Spence (2020a, Figure 1).

There is growing commercial awareness of the marketing potential associated with matching-up one's product offering with the more widespread genetic differences in taste/olfaction (in the world of wine, see Blank, 2008; and in the case of beers, see Wu, 2016). There are well-documented individual differences in people's coffee preferences (e.g., Rozin and Cines, 1982; Cristovam et al., 2000). Beyond these genetic differences in the worlds of taste and smell that each and every one of us inhabits, there are also noticeable individual differences in the preferred serving temperature (Borchgrevink et al., 1999), and, as mentioned earlier, this too will likely affect release of volatile aromas from the surface of the coffee beverage.

It is now becoming increasingly common to compose music specifically to match the taste/flavor of a specific food or beverage product, such as, for example, coffee (see Spence, 2013), or any other drink for that matter (e.g., see Howarth, 2014; Birkner, 2016; Spence, 2019b). However, the problem with such bespoke musical compositions is that they are often not widely available (as in the music available on *Spotify*, say), nor are they necessarily optimized for that feel-good uplifting factor that one associates with so many of the songs one likes to listen to (e.g., Welsh, 2015; Boult, 2016). At the same time, however, one of the key challenges when picking off-the-shelf music is that there can be changes of mode—e.g., from major to minor chord [see Queen's "Bohemian Rhapsody" or in Mozart's Piano Sonata No. 12 in F Major (K332), both examples from Crawshaw (2012); see Spence and Wang (2015a,b,c)]. Indeed, deliberately changing between different pieces of music while people are tasting a drink has been shown to alter the tasting experience dynamically (cf. Wang Q. J. et al., 2019). The evidence clearly shows that even though people know that they may be tasting the same drink, as soon as the music changes, the taste/flavor experience can sometimes change too. Hence, when selecting pre-composed music to sonically season one's coffee drinking experience, one needs to make sure to choose those tracks that are fairly consistent in terms of their mode/instrumentation from start to finish.

UTILITARIAN AND HEDONIC COFFEE CONSUMPTION

People consume coffee for a range of reasons, both hedonic and utilitarian. For example, people sometimes drink in order to help them to stay alert in the morning or give us an uplifting boost during the day (this is the utilitarian cup of coffee). However, at other times the focus is more on enjoying the experience (this is the hedonic cup of coffee). The two key utilitarian aims of drinking coffee are helping people to wake up in the morning, and thereafter giving themselves an uplifting mood boost later in the day. Crucially, specific musical recommendations exist to help the coffee drinker to achieve these goals. What is more, specific emotions can also be triggered when people drink coffee (see Labbe et al., 2015 see also Kanjanakorn and Lee, 2017).

It is worth noting that there has been interest (e.g., with the Marlow vending machine) that was a feature of many public spaces 5 years ago or so, in digitally representing the background noises of the coffee shop, whenever a customer purchased a cup of instant coffee from the machine (Houghton, 2014). I know of other coffee vending machine manufacturers who have been interested in the question of whether having their machines play a particular piece or style of music could be used to bias consumers toward choosing one drink over another. In some of our own research in this space, we actually worked with Starbucks some years ago here in the UK on the design of a downloadable audio track that consumers could listen to at home while drinking the then-new Starbucks Via coffee drink (see Spence, 2017b). The track was designed to contain low notes consistent with the bitter taste of coffee. Unfortunately, however, in this marketing-led intervention, there was no opportunity to determine whether listening to this specially-composed track while tasting coffee had an influence on people's ratings. Meanwhile, Keurig coffee is about to release K-Supreme® Playlists—a set of five Spotify playlists designed to match the distinctive flavor profiles of its coffees (DiPalma, 2021). This, then, hinting at the growing interest in matching music to the coffee tasting experience. The recent launch of various wine apps that allow the consumer to scan a wine bottle label and automatically recommend a putatively matching sound (e.g., see the Wine Listening app; http://winelistening.com/). Meanwhile, Spotify teamed up with the alcohol delivery service Jimmy Brings in 2018 to create the "Songmelier Edition," pairing a range of wines with the perfect music (Khale, 2018) is also an intriguing development, and may be extended to the world of coffee before too long. There is also emerging interest from the world of HCI in the design of engaging playful gustosonic experiences (Wang Y. et al., 2019).

While this kind of pairing has thus far been established primarily on the basis of empirical studies in which people are given (or asked to imagine in the case of very familiar foods) a range of tastes, aromas, and/or flavors and asked to pitch the best-matching sound from a range of alternatives varying on parameters such as pitch, timbre, roughness, tempo, loudness etc. The results of many such studies have now provided musical menus of sonic features matched to different taste/flavor properties that are then incorporated into the design of new music/soundscapes or else the selection of pre-existing pieces of music with the appropriate properties (see Spence et al., 2019a). However, looking to the future, it is intriguing to consider whether big data analysis and machine-learning approaches might be able to establish connections between music and taste (cf. Caliskan et al., 2017; Chartier and Kitano, 2019). At the same time, analysis of those tracks that have been created to convey specific tastes, and analyzing the sound parameters of the most effective exemplars has also proved to be a fruitful approach (see Wang et al., 2015).

Looking to the future, further research is needed to determine the best musical matches for the various distinctive aromas that are found in coffee (e.g., nutty, dried red fruits, chocolate, grapefruit, hazelnut, etc.)—that is, to go beyond the musical matching of taste properties. Furthermore, it is also unclear whether sonic seasoning may work better when the sounds are presented over headphones, and thus localized intracranially (i.e., in the same place as tastes and flavors), rather than from external loudspeakers. It is also unclear whether sonic seasoning effects are more pronounced when the connection between the music and tasting experiences are made more explicit. Finally, given the fact that complex flavor experiences tend to evolve temporally, then creating music and soundscapes that evolve with the flavors on the palate will likely enhance the beneficial effects of sonic seasoning still further.

CONCLUSIONS

Ultimately, the coffee-drinking experience is both complex (Illy, 2002; Spence and Wang, 2018, for a review) and multisensory (Yeretzian et al., 2010; see Spence and Carvalho 2020, for a review). What we taste in a cup of coffee is determined not only by what is in the drinking vessel (i.e., the liquid itself), but also by the sensory properties of the cup from which we happen to be drinking (see Spence and Carvalho, 2019, for a review), not to mention the multisensory attributes of the environment in which we choose to drink (see Bangcuyo et al., 2015; Spence and Carvalho, 2020, for a recent review). In fact, pretty much every aspect of the environment, be it the lighting (Gal et al., 2007), the visual design (Favre and November, 1979; Ly, 2011; Qian, 2014; Van Rompay et al., 2019; de Sousa et al., 2020), the color scheme (Qian, 2014; Spence and Carvalho, 2019), the background music (e.g., Rahner, 2006; Gater, 2010), or any background noise exert a modulatory influence (e.g., Bravo-Moncayo et al., 2020; see Spence, 2014a, for a review). It is all part of the multisensory tasting experience, broadly-defined (Kotler, 1974; Spence, 2017a), as certain famous coffee chains have known for decades (e.g., Pine and Gilmore, 1998, 1999; Carbone, 2004; and see Spence and Carvalho, 2020, for a recent review).

The multisensory aspects of the coffee-drinking experience are, of course, also influenced by branding (e.g., Martin, 1990), typeface, and packaging design (e.g., Henry, 2009; Harith et al., 2014; Sousa et al., 2020), not to mention the sensory-descriptive language (Fenko et al., 2018), and any other information that may be provided about the coffee (e.g., eco-labeling; see Scholl, 2012; Sörqvist et al., 2013; Van Loo et al., 2015; cf. de Pelsmacker et al., 2005). All that before one gets to the influence of celebrity endorsement (Muston, 2012).

During the current Covid-19 pandemic, as more of us are drinking our coffee at home than ever before, it makes more sense than ever to optimize the multisensory atmosphere in our own homes to help get the most out of each and every cup (see Spence, 2020b, 2021). And while, as we have seen, every aspect of the environment is undoubtedly important (see Spence and Carvalho, 2020, for a review), perhaps the simplest element of the atmosphere to change and optimize is the music we listen to while enjoying a cup of coffee (Spence, 2017a). Notice here how sonically-seasoning one's coffee-drinking experience at home to help maximize the desired effect/experience also fits right in with the growing interest that has emerged in optimizing and/or personalizing the multisensory environment in order to deliver the kind of tasting experience that you, the coffee consumer, wishes to have (Spence and Carvalho, 2020; see also Hall, 2012; Walton, 2012).

AUTHOR CONTRIBUTIONS

CS wrote all parts of this review.

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Taste in Motion: The Effect of Projection Mapping of a Boiling Effect on Food Expectation, Food Perception, and Purchasing Behavior

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The appearance of food affects its taste. Many studies have examined how to improve the taste of foods by manipulating their appearance. Most of those studies have focused on static appearances, such as color and texture; however, the impact of the dynamic appearance has not been explored. In this study, the perceptions (sweetness, sourness, saltiness, spiciness, temperature, deliciousness) and value judgments (the price of food, appetite) perceived from food before and after tasting with a projection-based dynamic boiling texture were investigated. The results revealed that the dynamic texture influences expectations for saltiness, spiciness, temperature, deliciousness, price, and appetite before eating the meal and perceived saltiness, spiciness, and appetite when eating. In addition, its influence on the consumers' behavior was also investigated through an empirical user study in a restaurant. The results indicated that the consumers had a greater tendency to order the meal when they saw it with the projection-based boiling effect. From these, this study demonstrates the effect of projection mapping of a boiling effect on food expectation, perception and consumer behavior.

Keywords: human-food interaction, food, dynamic texture, food perception, food evaluation, projection mapping

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INTRODUCTION

The appearance of food, such as color (Zampini et al., 2007) and shape (Velasco et al., 2015), is a factor that has a great influence on the culinary experience. In addition, a meal's appearance changes the consumers' behavior (Alfnes et al., 2006; Aslam 2006; Clement 2007; Kuvykaite et al., 2009) and the evaluation of the quality (Hagtvedt and Patrick 2008; Van Rompay et al., 2012; Labrecque and Milne 2012). As such, a significant amount of research has been focused on the appearance of food for marketing purposes. Although there has been research conducted on the effect of appearance of food on perception of food and the culinary experience, inquiries into engineering techniques to apply this knowledge is a new area of research – Human-Food Interaction.

Previous Human-Food Interaction research aimed at changing the eating experience by manipulating the appearance of food. Most of those studies has focused on the effect of static appearances such as color, shape, texture, and size on food perception and the culinary experience (Narumi et al., 2011; Narumi et al., 2012; Nishizawa et al., 2016; Fujimoto, 2018; Nakano et al., 2019). Meanwhile, the dynamic appearance of food also plays an important role when dining (Gvili et al., 2015). Occasionally, food is served in motion, changing its appearance from moment to moment. The motion of the food is defined here as the movement the food has when it is served. The motion of the food can be a critical clue to understanding its freshness (Kruger et al., 2004; Pham and Avnet, 2009; Chang and Pham, 2013). Living animals move; Healthy animals move more than diseased animals; A freshly cooked pot emits steam remove and bubbles; A freshly opened bottle of champagne is filled with bubbles. Dynamic textures of a meal including the boiling of hot liquids, the rising of steam, melting ice, and shimmering motions contribute to the estimation of food quality. These motions also bring a sizzling feeling to the food. For instance, if a hot pot seems to be boiling, it may stimulate hunger and increase one's expectations for the dish.

However, these dynamic textures can disappear when you stop heating the pot. Currently, the development of digital technologies enables us to add these dynamic textures to lukewarm dishes to make them appear very hot. The purpose of this study is to demonstrate the unknown effects of adding dynamic textures to food with the aid of digital technologies. In particular, this study focuses on the effect of dynamic boiling textures. This approach also contributes to control experimental conditions other than the dynamic boiling texture. Therefore, it enables us to investigate the effect of dynamic boiling textures without being affected by other stimuli such as actual temperature.

To investigate the effect of adding dynamic textures to meals, this study developed a system to project the motions onto dishes and the research was focused on the boiling motion. Our experiment investigates whether projecting a boiling-motion texture enhances the perceptions (sweetness, sourness, saltiness, spiciness, temperature, deliciousness) and value judgments (the price of food, appetite) perceived from food. In particular, by comparing the perceptions and value judgments expected before eating the food with those felt after eating, we examine how changes in perception and value judgments occur. Moreover, an empirical user study was performed in a restaurant where a food item was displayed at the entrance and had a boiling motion. This was done to determine if the boiling motion influences the purchase behavior (the ordering rate of the dish).

This research makes the following contributions. First, it contributes to the field of investigating the relationship between material perception via vision and perception of food/eating behavior. Although research on the relationship between the static texture and food has been widely carried out (Morrot et al., 2001; Zampini et al., 2007; Wada et al., 2010; Velasco et al., 2015; Chung and Fong 2018; Paakki et al., 2019), the relationship between dynamic textures and the dining experience has been rarely investigated. In addition, this technique is also useful for multisensory food marketing. For example, there are many restaurants where food model displays are placed at the front of their shops. These food model displays present information to customers about the cuisine, and they are used to attract customers in Japan. By applying the proposed technique to food displays, it is hypothesized that this technique would attract more customers. It is also possible to draw attention from consumers by providing dishes with a dynamic texture as a new culinary experience.

CONCEPTUAL BACKGROUND

Appearance of Food and Culinary Experience

This study investigates the culinary experience when combined with dynamic textures. Before introducing the concept of the dining experience with new technologies, this section presents the relationship between the appearance of food and the dining experience. Because the appearance of food is related to the perceived taste as well as the preference and purchasing behavior, many studies have been performed to clarify this relationship. For example, the color of food is reported to influence the consumers' evaluation of the taste and flavor (Morrot et al., 2001; Zampini et al., 2007; Wada et al., 2010; Paakki et al., 2019). One study investigated the effect of the color of a drink and the predicted flavor. This study revealed that the participants who drank the improperly colored beverage significantly failed to discriminate the flavor even though they were told that the drink color is useless to discriminate its flavor (Zampini et al., 2007). In addition, the influence of color is not limited to public consumers. Even trained panelists have described white wine that was colored red with an odorless dye as red wine (Morrot et al., 2001). Previous studies have reported that luminance and saturation are also important for food. The distribution of luminance is one of the indicators that represents the freshness of cabbage (Wada et al., 2010). In addition, colorful and high-contrast salad portions are reported to be associated with freshness and visual attractiveness (Paakki et al., 2019).

The shape of food can also have an influence on the eating experience. Velasco et al. (2015) investigated the correspondence between the shape and taste. Velasco et al. reported a tendency to associate sweetness with rounded shapes and sourness with angular shapes. As for children, transforming fruits and vegetables into snack like shapes, such as popsicles or pancakes, increases their consumption and appetite for these food products (Chung and Fong, 2018).

Both the appearance of food and its presentation are important factors that can influence the diners' reaction. For example, if the food arrangement is more attractive, the diners will have a more favorable evaluation in terms of liking the dish and they will be willing to pay more (Zellner et al., 2010; Zellner et al., 2011; Zellner et al., 2014; Michel et al., 2014; Michel et al., 2015). Multisensory cues from cutlery also influences the eating experience. For instance, yoghurt is perceived denser and more expensive when it is tasted from a heavier spoon in comparison to a lighter spoon (Harrar and Spence, 2013).

The appearance of food not only affects the consumption of food, but it also changes the purchasing behavior of consumers. For example, Loebnitz and Grunert (2015) examined the effect of food shape abnormality for two kinds of vegetables and two kinds of fruits in terms of purchasing intentions. This shows that the purchasing intention is lower for food with an abnormal shape than for food with a normal shape. Another study investigated the affective impression of the packaging of chocolate bars and the snack itself to create a coherent design in terms of Kansei Engineering (Schütte, 2013).

In this study, we deal with dynamic textures in food appearance. When we think of texture in food, we tend to think of mouthfeel. In this paper, we use the term dynamic texture as a visual feature that conveys motion, rather than mouthfeel. Doretto et al. (2003) defined that dynamic textures are sequences of images of moving scenes that exhibit certain stationarity properties in time; these include sea-waves, smoke, foliage, whirlwind etc. These visual characteristics are especially evident in freshly prepared foods. That’s why these visual features affect the judgment of food freshness. These effects are often used in advertising. Gvili et al. (2015) investigated whether the often-used depiction of foods in motion both on packaging and in marketing campaigns helps improve consumer judgments of food products and showed that depictions of food with implied motion led to enhanced evaluations of both freshness and appeal. A number of studies have shown that the perception of food freshness can lead to strong sensory features and feelings of attractiveness from food (Steenkamp and van Trijp, 1996; Cardello and Schutz 2003). Therefore, we hypothesized that adding dynamic texture to food by projection mapping would improve the sensory perception of food (especially the smell, heat, and intensity of flavor that are strongly felt in freshly cooked food), the palatability of food, and the value judgment of food.

Manipulation of the Appearance of Food with Digital Technologies for Improving Taste

The research described in the previous section manipulates the appearance of the food by modifying the food itself. However, this method may damage the taste and texture/mouthfeel of food. It is not practical since it requires great care. In the meantime, methods that use digital technology are being used to manipulate the space around food or appearance of food. This can be achieved by applying a head-mounted display (HMD) or a projection mapping technique. By taking advantage of these technologies, ample research has been conducted to investigate the effects of changes in the appearance and environment of food without modifying the food itself. For example, Narumi et al. (2011) devised a system so that a plain cookie had a variety of flavors such as chocolate or strawberry. This was achieved by displaying corresponding images that were superimposed onto the cookie. This was achieved using an HMD and simultaneously presenting the fragrance materials. In addition, Nakano et al. (2019) constructed a system that replaces the appearance of food displayed using an HMD. This was performed by superimposing different food images of food in real time in response to the changes in the shape of the food item.

In these studies, the appearance of food is manipulated by superimposing the images on the food displayed using an HMD; however, it is not realistic to have dinner with an HMD. Projection mapping is an attractive technology as it can enhance the meal experience without a user wearing any equipment. For example, Nishizawa et al. (2016) constructed a projector-camera system that is capable of changing the appearance of food and tableware in real time, which demonstrates that enhancing the saturation of castella causes the enhanced perceived sweetness. In addition, they also revealed that enhancing the hue of potato chips leads to changes in the flavor. Fujimoto (2018) also makes it possible to improve the taste under normal lighting by projecting images on food products. This produces modifications through chroma, highlighting, and partial colors.

Some of food appearances can be controlled by making various ‘actual’ food. For example, the color of food was controlled by actually dying food in previous research (Morrot et al., 2001; Zampini et al., 2007; Paakki et al., 2019). Meanwhile, digital technology including augmented reality and projection mapping allows manipulation of appearance without actual food processing. This helps to more rigorously investigate the effects of appearance that have been tested using the traditional approach using food processing. Moreover, it is also expected to help to verify effects that have been impossible to verify due to the difficulty of controlling factors with food processing. For example, Narumi et al. (2012) conducted a study on the manipulation of food intake by producing an illusion of portion size. This was achieved by rescaling the size of the food relative to the size of a hand or tableware displayed via an HMD with augmented reality. In this case, the effect of “perceived” food volume on satiety was purely investigated by changing the apparent size of food without changing its “actual” volume. A projection mapping technique also controls only the difference in the apparent amount when eating the same thing. Sakurai et al. (2013) also reported a study on controlling the feeling of fullness by dynamically changing the size of the plate. Without digital technology, it would be difficult to validate that dynamically changing the size of the projected eating utensils in response to the reduction in food consumption would lead to effective changes in food intake.

The motion of the food is a particularly difficult factor to control and has been difficult to verify with the traditional approach. However, these digital technologies make it possible to control the motion of the food. Although studies on investigating the relationship between the motion of the food and food perception are conducted, the concern has been limited to its acceptability (Spence, 2018). For example, some studies have focused on the crossmodal correspondences between taste and movement in animation (Huisman et al., 2016). Huisman et al. investigated associations between basic tastes and visualizations that differed in color, shape and animation speed, and revealed that associations between sweetness and red rounded shapes, and sourness and green angular shapes with a fast animation speed. They also have a lab study where the visualizations were projected around a cup of yogurt that participants tasted confirmed these associations, and specific combinations of visualizations and animation types were found to influence taste perceptions. This study shows that it is possible to influence taste by providing visual stimuli that are not directly related to the food. In contrast, our research aims to investigate the changes in sensory perception, preferences of foods, and purchasing behavior that are accentuated by

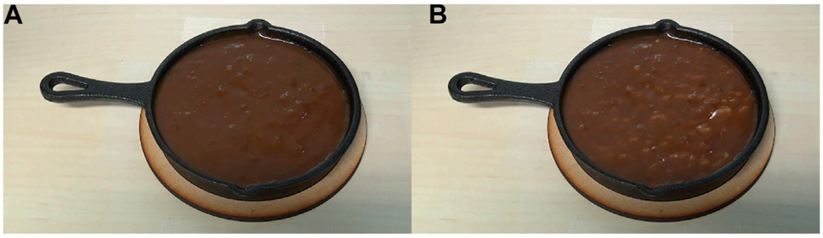

FIGURE 1 | (A) Curry with the single color projected and **(B)** with the boiling effect projected.

heating by projecting the movements that foods are expected to have when they are heated.

EXPERIMENT

There are two methods to add dynamic textures to food; superimposing textures using an HMD and projecting textures onto the target food using a projector. To make the dining experience more realistic and to reduce the user's effort, this study adopted projection mapping. Among the dynamic textures found in dishes, the boiling motion was selected for this study. This is because boiling is applicable to various foods such as gratin, curry, and hot pot meals. Among these foods, this study selected Japanese curry as the projection target because it is a very popular food that most Japanese like.

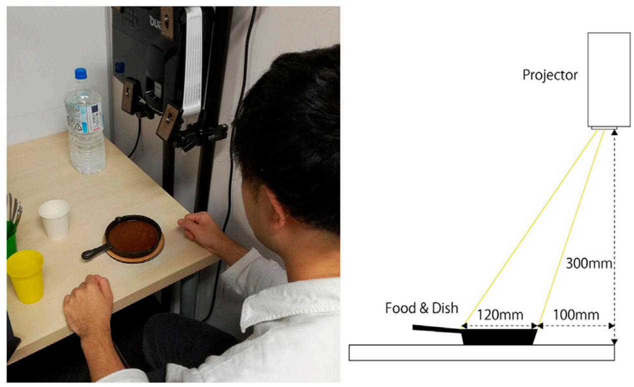

FIGURE 2 | Experimental setup.

Method

Conditions, Apparatus, and Food Stimuli

Two types of images were projected in this study (projection conditions): one expressed a static single-color image (**Figure 1A**) and the other showed a dynamic boiling motion (**Figure 1B**). The movies of them can be found online (curry with a static single-color image projection[1] and curry with a dynamic boiling motion projection[2]). Previous studies have reported that the luminance (Wada et al., 2010) and saturation (Nishizawa et al., 2016) of food affect the food perception. Therefore, in this experiment, to investigate only the effect of dynamic texture by eliminating as much as possible the effect of changes in luminance and saturation due to projection on the food perception, we decided to use a static single-color image projection as the control condition, in which an image with a color equal to the average luminance of the projected dynamic boiling motion is always projected. This is the reason why we used the static single-color image projection as the control condition in this experiment, instead of the no-projection condition. However, as a result, there is no significant change in appearance between no-projection and the static single-color image projection.

The dynamic texture projected were created by reference to the deformation lamps (Kawabe et al., 2016), which is a technique that adds a variety of illusory motion by projecting only dynamic luminance information onto 2D/3D objects. The detailed procedure to create the motion images were as follows. First, we recorded a boiling motion of curry using a video camera. An image before heating and images during heating in the recorded video were converted to gray scales and the difference was taken. The images created through this process had their dynamic luminance information extracted from the boiling motion. These were projected onto the actual food to give the observer that boiling was occurring. For realizing natural appearance of the curry with the boiling motion, multiple image processing methods were applied as follows: A gamma correction (γ = 1.3) and a linear color correction (minimum brightness 0, maximum brightness 192) were conducted and a color (R = 82, G = 65, B = 41) was applied to the gray scale images. Mask processing was also performed so the effects were only applied to the curry area. The single-color image used a color obtained by averaging all the luminance values in the animation of the boiling motion. By doing so, we aligned the temporal average of the apparent brightness of the food across image conditions.

Two temperature levels for the curry were prepared and presented to each participant (temperature conditions). First, 100 ml of curry was poured into a container and heated at 65°C and 80°C for approximately 1 h in a pot using a low temperature cooker. Curry was tasted by the participants 3 min after being taken out from the pot. At that time, the temperature of the curry was approximately 50°C and 60°C, respectively.

[1]https://youtu.be/WFjxJJvDl_E
[2]https://youtu.be/TtsrUpw3tBw

As there were two factors (projection and temperature) and two levels (projection: boiling motion and single-color image; temperature: 50˚C and 60˚C), a total of four experimental conditions were prepared. The experiment was conducted within-participants design. The participants experienced all the conditions (50˚C-single-color image, 50˚C-boiling motion, 60˚C-single-color image, 60˚C-boiling motion) once in a counterbalanced order, then the participants sampled the curry four times.

An ultra-short throw projector (TH682ST, BenQ Corporation, Taiwan) was used to project the effects. The brightness of the projector was 3000 lm. **Figure 2** shows the experimental setup. The projector was set up at a height of 300 mm from the table surface. The curry was served on a skillet of 120 mm in diameter. The position of the skillet was predetermined, and the skillet was placed so that the image was projected on it. Participants were not allowed to move the skillet, but were only allowed to sit and observe, and to taste the curry with a spoon. The room where the experiment was conducted was lit with normal room lighting.

Pre-packaged curry (MIYAGI SEIFUN Co., Ltd., Japan) was chosen as a food stimulus because of its uniformity and incompatibility with the boiling effect. This curry is made by stewing fond de veau, tomatoes, onions, carrots, apples, etc. with curry powder. It has the common characteristics of Japanese curry, dark brown in color, with a thick and rich flavor. Owing to the consistent quality of commercially available curry, the effects of individual taste differences of a meal can be ignored in this experiment. Curry was served to the participants in a skillet to assure their comfort with the superimposed boiling effect.

Participants

Twenty-four participants (12 females and 12 men, mean age 26.4 years, standard deviation = 6.86 years, range = 20–43 years) were recruited for this study through the Internet. None of the participants reported any allergies to the food ingredients for the curry that was used in the study and all the participants had eaten curry before. In addition, the participants were paid 1,000 JPY (approximately 9.2 USD) per person.

Procedures

The participants were invited to a waiting place, they received an explanation of the study, and they signed a consent form. At that time, they were told that the purpose of the experiment was to evaluate the taste of the curry. The participants were instructed to have a sip of water to refresh their mouth and had to wait until the experiment was prepared.

Each trial in this experiment was conducted as follows. First, the participant moved from the waiting place to the experiment place. There was curry poured into a skillet on the table. The appropriate effect for the condition was projected on the curry. The participants were not informed that some images were being projected onto the curry. Next, the participant was asked to rate the taste (e.g., sweetness, sourness, and saltiness), spice level, smell, deliciousness, hotness, price, and appetite just from its appearance while looking carefully at the curry. Each item of the questionnaire featured a 101-grade Visual Analog Scale that ranged from 0 (not at all) to 100 (very much). The questionnaire was conducted for 2 min to control the temperature of curry each participant ate in each trial. After filling in the questionnaire, the participant tasted a scoop of curry and responded to the same questionnaire. Before the participant started to answer the questionnaire, the skillet was taken away and the projected effect was stopped. At the end, the participant drank a sip of water, moved to the waiting place, and rested for 2 min.

Each participant repeated this trial four times. Finally, the participants were told that the purpose of the experiment was to assess how their taste changes due to the projected effects. The experiment lasted for about 40 min for each participant.

Data Analysis

There were two factors in this experiment: the image and temperature of the food. These two factors each had two levels (projection: boiling motion and single-color image; temperature: 50˚C and 60˚C); thus, a 2 × 2 repeated measures ANOVA was performed for each item of the questionnaire, which was taken before and after tasting. For each item on the questionnaire, Bartlett's test was carried out to confirm the homogeneity of the variance. In addition, the Shapiro-Wilk test was also conducted for each factor and level to check the normality. If homogeneity of variance was not recognized or there was an abnormally distributing item, aligned rank transform (ART) was applied before ANOVA was performed and the results were reported with boxplot charts. ART was the procedure to transform non-parametric data to the format ANOVA can be applied. If the normality assumption is not violated, we just applied an ANOVA and showed the results as bar charts. When the interaction effect was significant, simple effects and an interaction contrast was examined. Multiple comparisons were also performed using the Wilcoxon signed-rank test, which applied Holm's method. All analyses were performed using R.

Results

In this experiment, most participants noticed that some images were projected onto the curry because the projector was located in a position where users could see it as shown in **Figure 2**. On the other hand, some participants did not notice the projection.

For the sweetness expectation before tasting (**Supplementary Figure S1A**), the homogeneity of the variance and normality were observed, and ANOVA was performed. No main effect of the image ($F(1,21) = 0.037$, $p = 0.849$, partial $\eta^2 = 0.002$) and temperature ($F(1,21) = 3.757$, $p = 0.065$, partial $\eta^2 = 0.140$) was observed. In addition, no interaction between the image and the temperature ($F(1,21) = 0.124$, $p = 0.728$, partial $\eta^2 = 0.005$) was observed. For the perceived sweetness after tasting (**Supplementary Figure S1B**), the Shapiro-Wilk test showed non-normality and when ART applied ANOVA was conducted, no main effect of the image ($F(1,23) = 0.205$, $p = 0.655$) and the temperature ($F(1,23) = 0.152$, $p = 0.700$) was observed. The interaction effect between the image and the temperature was also not observed ($F(1,23) = 0.001$, $p = 0.978$).

For the sourness expectation before tasting (**Supplementary Figure S2A**), the homogeneity of the variance and normality were

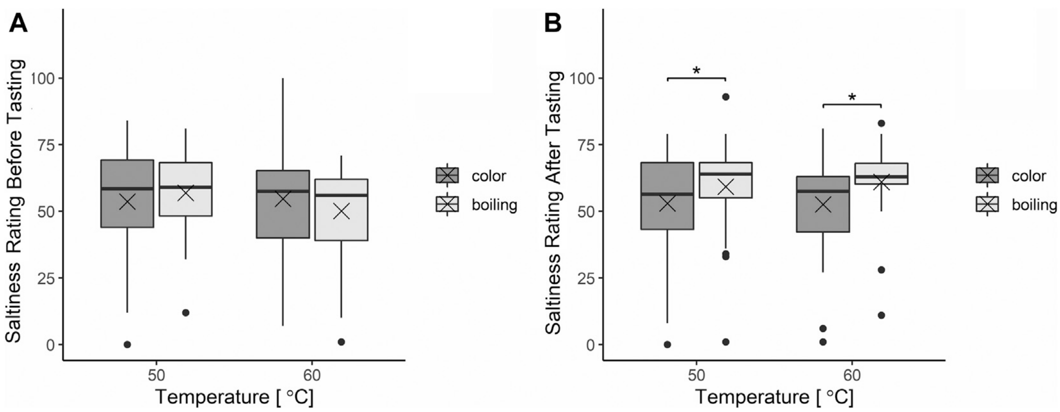

FIGURE 3 | (A) Saltiness ratings before tasting and **(B)** after tasting. The "*","**","***" marks represent the significant difference when $p < 0.05$, $p < 0.01$, $p < 0.001$, respectively. The error bars in the bar plots represent the standard error. For the box plots, the bold lines indicate the median, the boxes signify the range from the first quartile to the third quartile, the whiskers indicate the minimum and maximum values, the cross marks represent the mean average, and the points indicate the outliers.

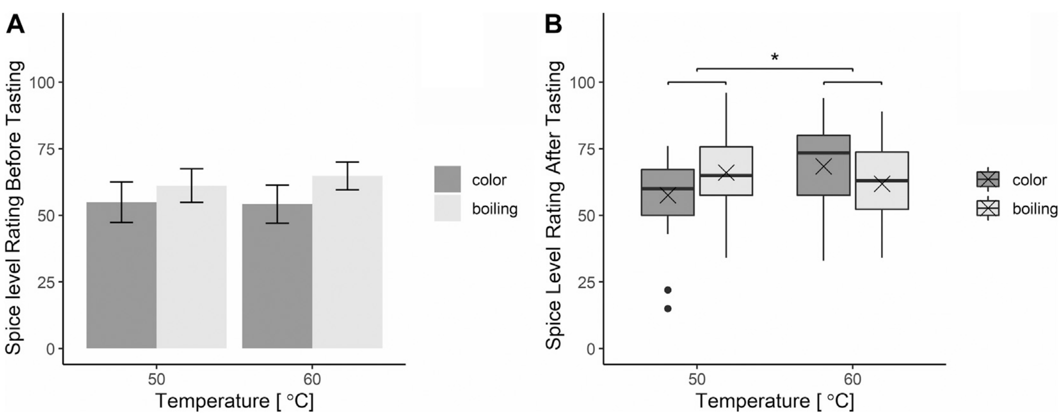

FIGURE 4 | (A) Spice level ratings before tasting and **(B)** after tasting.

observed, and ANOVA was performed. No main effect of the image ($F(1,21) = 0.041$, $p = 0.841$, partial $\eta^2 = 0.002$) and the temperature ($F(1,21) = 3.906$, $p = 0.060$, partial $\eta^2 = 0.145$) was observed. In addition, no interaction between the image and the temperature ($F(1,21) = 3.149$, $p = 0.0892$, partial $\eta^2 = 0.120$) was observed. For the perceived sourness after tasting (**Supplementary Figure S2B**), the Shapiro-Wilk test showed non-normality. When ART applied ANOVA was conducted, neither main effect of the image ($F(1,23) = 0.171$, $p = 0.683$) nor the temperature ($F(1,23) = 0.163$, $p = 0.690$) was observed. The interaction effect between the image and the temperature was also not observed ($F(1,23) = 1.797$, $p = 0.193$).

For the saltiness ratings before and after tasting, the Shapiro-Wilk test showed non-normality. ART applied ANOVA was conducted for the before tasting ratings (**Figure 3A**); no main effect of the image and the temperature and the interaction effect was observed ($F(1,23) = 0.018$, $p = 0.895$, $F(1,23) = 2.321$, $p = 0.141$, $F(1,23) = 0.914$, $p = 0.349$, respectively). When ART applied ANOVA was conducted for the after tasting ratings (**Figure 3B**), no main effect of the temperature ($F(1,23) = 0.000$, $p = 1.000$) and no interaction effect between the image and the temperature was observed ($F(1,23) = 0.005$, $p = 0.945$). However, the boiling effect significantly increased the perceived saltiness in comparison to the single color ($F(1,23) = 7.871$, $p < 0.05$).

For the spice level expectation before tasting (**Figure 4A**), the homogeneity of the variance and normality were observed, and ANOVA was performed. There was no effect of the image ($F(1,21) = 3.386$, $p = 0.079$, partial $\eta^2 = 0.128$) and the temperature ($F(1,21) = 0.216$, $p = 0.647$, partial $\eta^2 = 0.009$) . In addition, there was no interaction effect between the image and the temperature ($F(1,21) = 0.590$, $p = 0.450$, partial $\eta^2 = 0.025$). In terms of the perceived spice level after tasting (**Figure 4B**), the Shapiro-Wilk test showed non-normality and ART applied ANOVA was conducted. Although no effect of the image ($F(1,23) = 0.008$, $p = 0.929$) and the temperature ($F(1,23) = 1.642$, $p = 0.213$), the significant interaction effect was observed

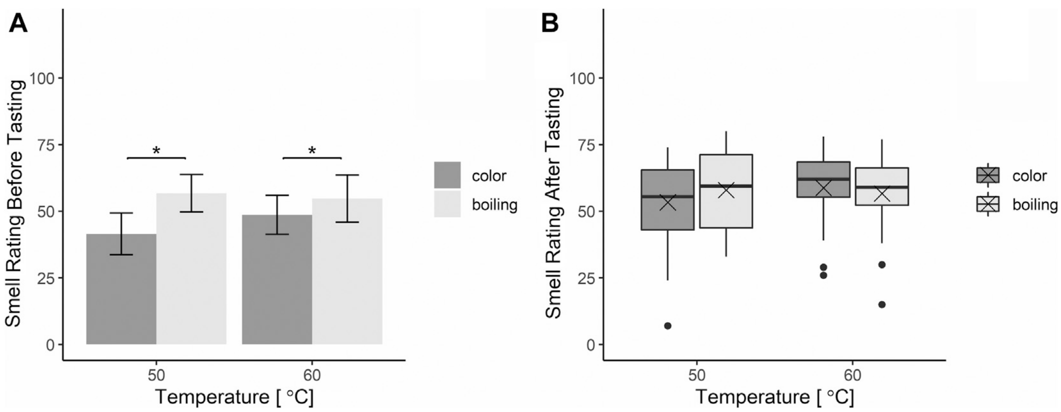

FIGURE 5 | (A) Smell ratings before tasting and **(B)** after tasting.

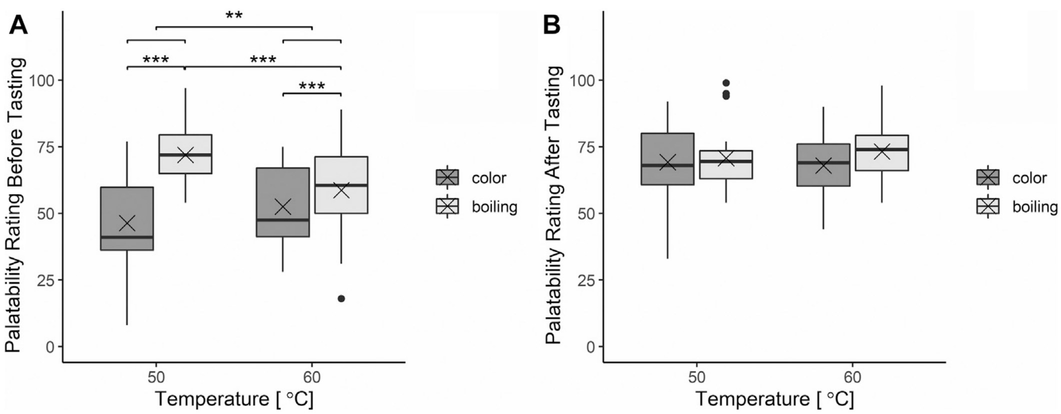

FIGURE 6 | (A) Palatability ratings before tasting and **(B)** after tasting.

($F(1,23) = 7.532$, $p < 0.05$). The test of the interaction contrast showed that there was the significant difference in the difference between projected images in 50°C condition and 60°C condition ($t(23) = 2.745$, $p < 0.05$). To be precise, in the 50°C condition, the curry with the boiling image was evaluated spicier. On the other hand, in the 60°C condition, the curry with the single color projected was evaluated spicier.

For the perceived smell before tasting (**Figure 5A**), the homogeneity of the variance and normality were observed, and ANOVA was performed. There was no main effect due to the temperature ($F(1,21) = 0.572$, $p = 0.457$, partial $\eta^2 = 0.024$) and there was no interaction effect between the image and the temperature ($F(1,21) = 1.285$, $p = 0.269$, partial $\eta^2 = 0.053$). However, the boiling effect significantly increased the perceived smell in comparison to the single color ($F(1,21) = 5.657$, $p < 0.05$, partial $\eta^2 = 0.197$). For the perceived smell after tasting (**Figure 5B**), the Shapiro-Wilk test showed non-normality and when ART applied ANOVA was conducted, there was no significant main effect of the image ($F(1,23) = 0.112$, $p = 0.740$) and the temperature ($F(1,23) = 0.575$, $p = 0.456$), and no interaction effect between the image and the temperature ($F(1,23) = 0.950$, $p = 0.340$).

In terms of rating if the food looked delicious before tasting (**Figure 6A**), the Shapiro-Wilk test showed non-normality and when ART applied ANOVA was conducted, a main effect of the temperature was not significant ($F(1,23) = 1.043$, $p = 0.318$). On the other hand, a main effect of the image was significant ($F(1,23) = 19.439$, $p < .001$) and the interaction effect between the image and the temperature was also significant ($F(1,23) = 10.733$, $p < 0.01$). The test of a simple effect of projection showed that the boiling effect significantly increased the estimation of palatability ($t(23) = 4.409$, $p < 0.001$). Multiple comparisons revealed that curry with the boiling effect looked more delicious than curry with the single-color effect at 50°C ($p < 0.001$), and that curry heated at 50 °C got higher palatability estimation than curry heated at 60°C when the boiling effect was projected ($p < 0.01$). Regarding the perceived palatability of the food after tasting (**Figure 6B**), the Shapiro-Wilk test showed non-normality. When ART applied ANOVA was conducted, there was no significant main effect (the image: $F(1,23) = 1.220$, $p =$

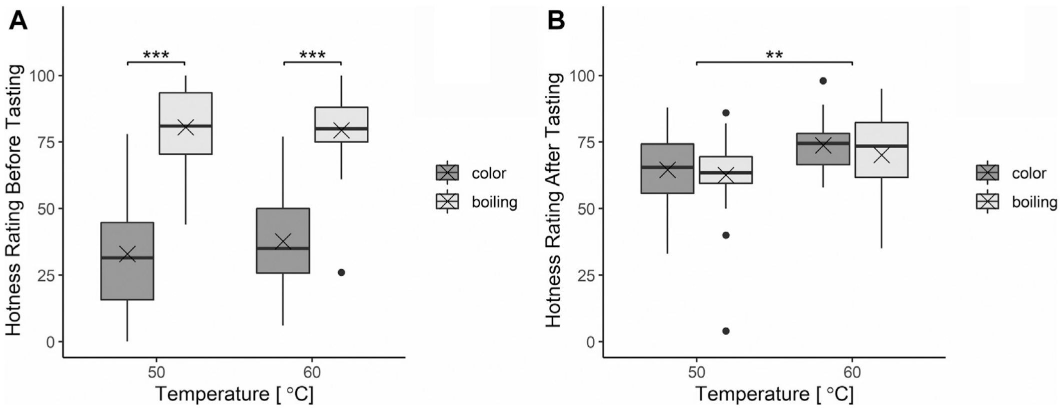

FIGURE 7 | (A) Ratings of the hotness of the curry before tasting and **(B)** after tasting.

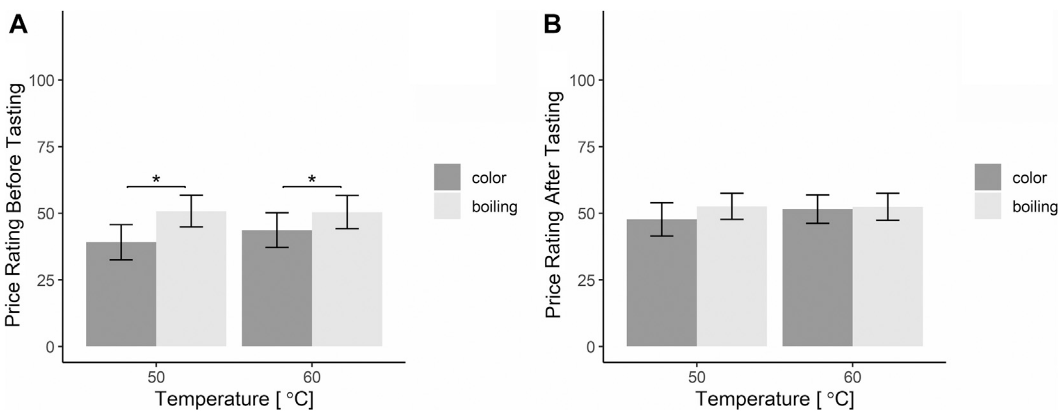

FIGURE 8 | (A) Price ratings before tasting and **(B)** after tasting.

0.281, the temperature: $F(1,23) = 0.269$, $p = 0.609$) and no interaction effect ($F(1,23) = 1.188$, $p = 0.287$)was observed.

For the hotness expectation before tasting (**Figure 7A**), the Shapiro-Wilk test showed non-normality. When ART applied ANOVA was conducted, no main effect of temperature ($F(1,23) = 0.339$, $p = 0.566$) and no interaction effect ($F(1,23) = 0.480$, $p = 0.495$) was observed; however, the boiling effect was shown to increase hotness expectation compared to the single color effect ($F(1,23) = 132.343$, $p < 0.01$). In terms of perceived hotness of the curry after tasting (**Figure 7B**), the Shapiro-Wilk test showed non-normality. When ART applied ANOVA was conducted, no main effect of the image ($F(1,23) = 0.710$, $p = 0.408$) and no interaction effect ($F(1,23) = 0.013$, $p = 0.911$) was observed. In contrast, participants rated the 60°C curry was hotter than the 50°C curry ($F(1,23) = 9.000$, $p < 0.001$).

When estimating the price before tasting (**Figure 8A**), the homogeneity of the variance and normality were observed, and ANOVA was performed. There was no main effect of the temperature ($F(1,21) = 0.323$, $p = 0.575$, partial $\eta^2 = 0.014$) and there was no interaction effect between the image and the temperature ($F(1,21) = 1.263$, $p = 0.273$, partial $\eta^2 = 0.052$). For the image, the boiling effect significantly increased the estimation of the curry price in comparison to the single color ($F(1,21) = 5.233$, $p < 0.05$, partial $\eta^2 = 0.185$). For the estimated price after tasting (**Figure 8B**), the homogeneity of the variance and normality were observed, and ANOVA was performed. There was no main effect for the image ($F(1,21) = 1.211$, $p = 0.283$, partial $\eta^2 = 0.050$) and the temperature ($F(1,21) = 0.931$, $p = 0.345$, partial $\eta^2 = 0.039$). In addition, there was no interaction effect between the image and the temperature ($F(1,21) = 0.717$, $p = 0.406$, partial $\eta^2 = 0.030$).

For the perceived appetite before tasting (**Figure 9A**), the homogeneity of the variance and normality were observed, and ANOVA was performed. There was no main effect of the temperature ($F(1,21) = 0.123$, $p = 0.729$, partial $\eta^2 = 0.005$). On the other hand, the boiling effect significantly fueled the participants' appetite in comparison to the single color ($F(1,21) = 15.754$, $p < 0.001$, partial $\eta^2 = 0.407$). There was an interaction effect between the image and the temperature ($F(1,21) = 4.991$, $p < 0.05$, partial $\eta^2 = 0.178$). Multiple comparisons revealed that

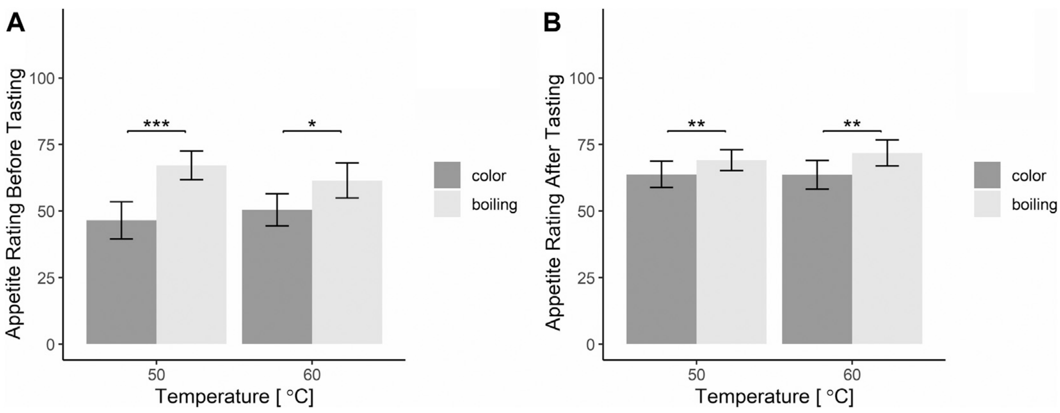

FIGURE 9 | (A) Appetite ratings before tasting and **(B)** after tasting.

the curry with the boiling effect stimulated the appetite more than the curry with the single color for both temperatures ($p < 0.001$ for 50°C, and $p < 0.05$ for 60°C). For the perceived appetite after tasting (**Figure 9B**), the homogeneity of the variance and normality were observed, and ANOVA was performed. There was no main effect of the temperature ($F(1,21) = 0.280$, $p = 0.602$, partial $\eta^2 = 0.012$) and there was no interaction effect between the image and the temperature ($F(1,21) = 0.415$, $p = 0.526$, partial $\eta^2 = 0.018$); however, the main effect of the image was significant ($F(1,21) = 8.332$, $p < 0.01$, partial $\eta^2 = 0.266$).

Discussion

The purpose of this study was to investigate the influence of the projected dynamic boiling texture when evaluating the dining experience. Since most of the participants were aware of the projection, it is considered that the results of this experiment basically showed the change in perception when the participants were aware of the projection of the boiling motion. We believe that it is important to investigate the effect of the projections when the participants were aware of the projections to understand the effect when the projections were actually used in dining and restaurants. On the other hand, the fact that most participants were aware of the projection may have biased their answers. Meanwhile, from the perceived of curry after tasting, it was shown that the participants rated curry was hotter at 60°C than at 50°C. Since they correctly rated the temperature of curry, their ratings were thought to be reliable.

From the results of this experiment, some of the taste expectations (smell, hotness, price, palatability and appetite) were increased when the participants saw the projected effect. Most of the taste expectations did not affect perceptions or value judgments after the tasting, but only appetite was found to be affected after the tasting. On the other hand, the perceived saltiness and spice level after tasting were affected by the projected effects, which were not influenced before tasting. The reason for this result can be attributed to the expectation effect.

In this study, the appearance of food was altered. This led to cause discrepancies between the expectations before tasting and the impressions after tasting the participants had. In such a situation, the participants' perceived sensation can be explained by the expectation effect (Anderson, 1973; Piqueras-Fiszman and Spence, 2015). Some sort of expectation effect occurs when there is a discrepancy between the expectation and the actual experience. When the discrepancy is small, assimilation is subject to occur, which is the effect to bring an experienced sensation to the expectation. This is called the assimilation effect. Meanwhile, the larger the differences are between the expectation and the actual experience, the more likely a contrast will occur when the difference is greater than a certain level. This is the effect to keep the experienced impression away from the expectation to expand the difference. This is called the contrast effect. Furthermore, when the difference is within a certain range, neither assimilation nor contrast can occur. The expectation effects including the assimilation and the contrast effects are widely reported in the literature regarding food products. It is shown that the perceived tastes are likely to be influenced by the expectations formed from the appearance of food (Shankar et al., 2010; Shermer and Levitan 2014) or labels (Wansink et al., 2005; Yeomans et al., 2008) before tasting. As some research report, both assimilation (Wansink et al., 2005; Shankar et al., 2010) and contrast (Cardello and Sawyer 1992; Yeomans et al., 2008; Shermer and Levitan 2014) are observed in dining experiences. In this study, adding motion information can increase the participants' expectations and some sort of expectation effect could occur; however, perceived taste could settle down near the actual experience, which could lead to little difference caused by the projected effects in the evaluation after tasting. This could be the reason why the participants had the same level of ratings for all the curry samples after tasting and evaluated temperature of curry correctly.

On the other hand, the appetite was determined to be high when the boiling effect was projected before and after tasting. Because the participants tasted only a scoop of curry in each trial, the physiological appetite could not be affected; hence, the increased appetite was maintained after the tasting. When evaluating the palatability before tasting, the boiling effect increase the estimation. As the interaction contrast and multiple comparisons suggested, the 50°C curry received the higher score than the 60°C when the boiling effect projected. This difference could be caused by the heating process. To keep the temperature of the curry uniform under each condition, the curry was heated at 80°C and 65°C for 1 h. This could change the components of the curry and affect the appearance. When comparing the pixel values of the heated curry photos, the curry heated at 80°C had a hue = 9.38, a saturation = 162.55, and a brightness = 120.88. Meanwhile, the curry heated at 65°C had a hue = 9.40, a saturation = 158.69, and a brightness = 122.47. Some research revealed that the expectations for food changed according to the differences in the chroma and brightness (Wei et al., 2012; Lee et al., 2013). In addition, the combination of continuously changing the brightness caused by the boiling effect and the minute difference in the curry color could influence the expectations for palatability.

Although estimation of spice level was not affected by the projected image nor the temperature, ratings after tasting showed the influence of the projected images. The increase in the perceived spice level could be explained by the mechanism of the spiciness sensation. The curry was added red pepper as a spice. The pungent component of red pepper is capsaicin, which evokes spiciness by activating TRPV1, a spiciness receptor in the oral cavity (Caterina et al., 1997; Zheng, 2013). TRPV1 also works as a temperature receptor and is activated at temperatures above 43°C. The activation energy of TRPV1 lowers with the rise in temperature; it leads to the increase of the number of activated receptors (Zheng, 2013), which is the reason why the pungent taste is perceived more strongly when the temperature rises. This perception characteristic 'the higher temperature is, the spicier a food is' will be learned. From this prior experience and unconscious knowledge, it is considered that appearance of piping hot food can be the key of predicting higher spiciness. Although no significant difference was observed in the effect of the projected images on the prediction of spice level, a marginally significant effect was observed. It suggested that expected spice level from its appearance was higher under the boiling effect texture than under the single-color image projection. At 50°C, there was not a large difference between expected and actual spice level of curry. It followed that assimilation effect brought experienced spicy sensation to the expectation in both projection conditions. In the case of curry at 60°C with the boiling effect projected, there was also not a large difference between expected and actual spiciness, and assimilation was evoked. On the other hand, in the case of single-color image projection condition at 60°C, the contrast seemed to be generated because of the larger gap between expected and actual spiciness; it led to higher evaluation of spice level. This could be the reason why the interaction effect between the image and the temperature was observed.

Estimation of saltiness was also not affected by the projected image nor the temperature but affected from the projected images after tasting. Previous research show that an angular shape is associated with saltiness compared to a round shape (Spence and Ngo 2012; Velasco et al., 2015; Huisman et al., 2016). The boiling effect was not in an angular shape but caused stimulating sensation, so the boiling effect could cause similar effect as an angular shape and reinforce the perception of saltiness during eating.

The experimental results showed that a projecting boiling texture on food does not cause much influence when eating food; however, some effects were observed before tasting. Considering the impact on participants before meals, especially on their appetite for food, it could be used for advertising purposes. Therefore, we conducted an empirical user study to investigate the effect of dynamic boiling texture on consumers' behavior on site.

EMPIRICAL USER STUDY

The aim of this study was to investigate the influence of the dynamic textures projected onto the food to determine the consumers' behavior. In Japan, it is popular in a restaurant to place food displays in the store front to attract customers and to draw them to the menu. This study explores the impact on the customers' behavior when dynamic textures are projected onto such displays.

Method

The study was conducted at 'Miraikan Kitchen' in 'Miraikan - The National Museum of Emerging Science and Innovation' in Tokyo, Japan. For this study, 'setsugen curry' was selected as the target dish, which was provided at the restaurant during a special exhibition held at Miraikan. The dish was sold for 1020 JPY (approximately 9.4 USD), which is a little bit more expensive than other items on the menu, which are typically in the range of 600 to 780 JPY (approximately 5.5 USD to 7.2 USD). In addition, 'setsugen' means snowfield in Japanese. As the name indicates, the curry is white in color with a little bit of yellow although the color of the curry is usually brown. Unlike our previous study, this dish featured deep-fried chicken and broccoli as toppings. To provide a natural appearance for this location, the projected texture had a little yellowish gray color (R = 104, G = 94, B = 58). The texture was partially masked to avoid projecting the texture on the toppings. The food showcase was placed at the entrance of the restaurant during the daytime for this investigation (**Figure 10**). The restaurant is a food-court style, long and narrow structure. Visitors can see the food showcases only at the entrance of the restaurant. The order-counter is far from the entrance, so the visitors can not see the food showcases while standing in line at the counter. By doing so, the effect of the difference in exposure time with the showcase due to longer waiting times etc., is less likely to appear. A projector was placed invisibly inside the food showcase, allowing projection mapping onto the food inside the case. Similar to previous experiment, two kinds of images were projected: one expressed a boiling motion and the other showed a single color (projection conditions) (**Figure 11**).

This survey was conducted over 4 days. The number of visitors usually differed greatly between a weekday and a holiday, but not so much between weekdays/holidays. Therefore, the food products under each projection condition were displayed in the showcase in front of the restaurant on one randomly

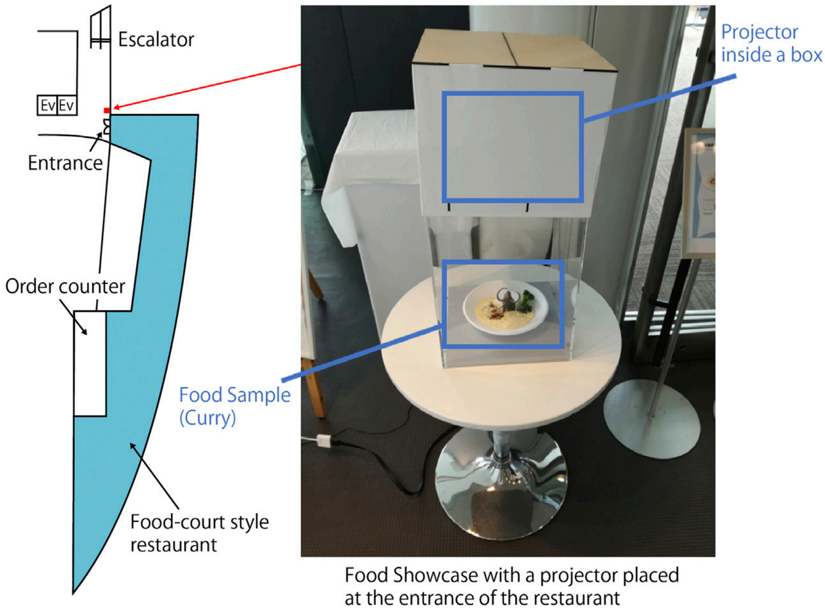

FIGURE 10 | Food showcase used in the study and where it was placed in the restaurant floor.

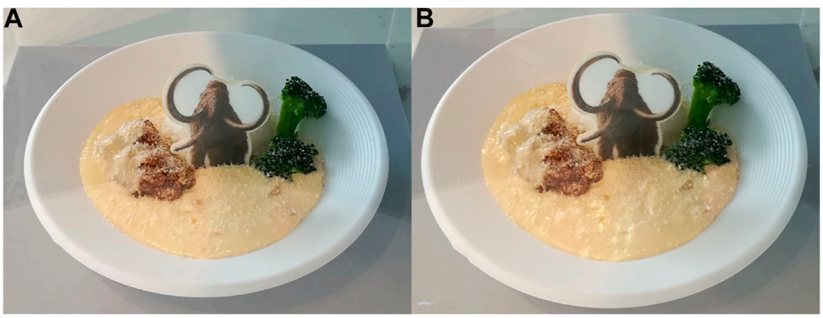

FIGURE 11 | (A) Curry with the single color projected and **(B)** with the boiling effect projected.

selected weekday and one randomly selected holiday. The number of customers at the restaurant and the number of orders of curry were counted, and the order rates (The number of orders/the number of customers) for the two conditions was compared.

Results

A total of 2353 people visited the restaurant during the study days and 216 plates of curry were ordered. For the days where a single-color texture was projected, 998 customers visited the restaurant, and 75 plates (0.075 plates per customer) were ordered. In contrast, for the days where the dynamic texture was projected, 1355 customers visited the restaurant, and 141 plates (0.104 plates per customer) were ordered. A test for the difference between the two rates showed that the order rate for the days in which the dynamic textures were projected was significantly higher than the other days ($z = 2.400$, $p < 0.05$, Cohen's Effect Size $h = 0.102$) (**Figure 12**).

Discussion

The objective of this study was to explore how dynamic textures on food influences the consumers' behavior. The results from this study indicate that the projection-based boiling effect has potential to lead consumers to purchasing behavior. This effect can be explained by the increased appetite due to the projection-based boiling effect. Some studies have reported that consumers buy more food when they feel hungry (Nisbett and Kanouse 1968; Gilbert et al., 2002). From the results of our laboratory experiment, it can be suggested that dynamic textures increase the appetite of consumers. As a result, the increased appetite is linked to hunger; thus, the dynamic textures may have been associated with consumers' willingness to buy.

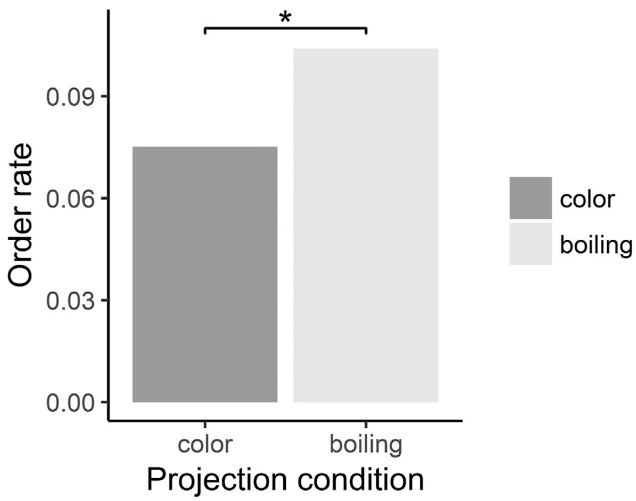

FIGURE 12 | Order rates of the curry. The "*" mark represents a significant difference where $p < 0.05$.

Furthermore, the results of our laboratory experiment indicate that the dynamic texture increases willingness-to-pay by consumers. It will provide consumers with the expectation that the target food is worth to purchasing from the viewpoint of pricing. Although the target food product (setsugen curry) was more expensive than the other plates the restaurant provided, the order rate of for such a costly meal was increased. It indicates that the dynamic texture has potential for the consumers to pay more for the meal.

In this experiment, evaluation of the curry after tasting was not investigated. Even so, since evaluation after tasting was not lowered by the projected boiling effect in the previous experiment, it is expected that the consumers were not disappointed with a gap between expected and real taste.

However, since this experiment was conducted in a week, there is a possibility that the consumers who visit the restaurant may differ depending on the day of the week. In addition, this experiment was carried out in the science museum, and customers might be attracted by the unusual presentation of menu using a novel technique. The fact that the results may have been conditioned by biases associated with some participants being particularly interested in the new technology is a clear implication of this empirical user study. This point needs to be verified further. Although the number of days to conduct the experiment was limited due to the constraints of the site, it is important to investigate how the effect changes when the technology is used for a long period of time, in order to investigate the effect of removing the novelty of the new technology. Similarly, due to the constraints of the site, it was not possible to investigate what kind of decisions were made by the people who actually ordered food at the restaurant through interviews or other means. It would be useful to conduct such a survey in the future in order to link purchasing behavior with consumer perception and judgment. Moreover, comparisons with past/usual sales will allow for more precise verification. It was not possible this time due to the circumstances of the restaurant. Then we will do more rigorous verification in the wild as future work.

GENERAL DISCUSSION

Conclusion

This article explores the dynamic textures' influence on the dining experience and the consumers' behavior. In the laboratory experiment, projecting the boiling effect was suggested to cause an expected increase in terms of the smell, hotness, price, palatability, and the appetite for curry before tasting. Although the proposed method raised the expectations before tasting the curry, it also showed that some effects were not observed during the actual tasting.

Meanwhile, the influence of the boiling effect on perceived saltiness and spice level were observed only after tasting (the reasons were discussed in the discussion of the experiment). Currently, excessive intake of salt is a serious problem (Mente et al., 2014; O'Donnell et al., 2014). According to the guideline of WHO, it is desirable to suppress salt intake less than 5 g per day (W. G. A. by the Guidelines Review Committee, 2012), but it is difficult to achieve the goal. Since dishes with the boiling motion texture are thought to be perceived saltier, this effect can help to reduce salt intake.

As described above, the boiling effect has a power to promote appetite and increase expected price. Moreover, as the result of the empirical user study suggested, these outcomes could prompt consumer to buy targeted food products. In Japan, there is a culture to display food samples in showcases at restaurants to attract customers. From this research, projecting dynamic textures could raise the consumers' expectations for the food; therefore, applying dynamic textures to food samples may attract more visitors. From this concept, in the empirical user study, dynamic textures were projected on a food display at a restaurant. Afterwards, the order rate of the targeted food was examined. The results indicate that the dynamic texture increases the order rate, which can be mediated by the increased appetite.

This study investigated the effect of the dynamic texture on the dining experience. This investigation revealed that the dynamic texture has potential to increase the expectation for the dishes and promote the consumers' purchasing intentions. Although the effect of static textures on food has been widely investigated, little knowledge has been provided about how dynamic textures affect the dining experience. By introducing this unique technique into the culinary industry, we believe that this study can introduce a new perspective into this research area. To stimulate the willingness of consumers to purchase items, marketers have applied various methods, such as changing labeling (Wansink et al., 2001; de Waal Malefyt, 2015), attractive catch copies (Elder and Krishna, 2009), and health claims (Peschel et al., 2019). This technique can provide a new approach to get consumers to purchase attractive food.

Limitations and Future Research

This study focused on the influence of the boiling effect projected on curry. As the influence of projecting other dynamic textures on other food items was not investigated in this study, it is necessary to consider whether the results of this research can be applied to other food products. We also have not tested the pure effect of dynamic texture projection by direct comparison with the condition without any projection or the blindfolded condition. In the current study, to investigate only the effect of dynamic texture by eliminating as much as possible the effect of changes in other visual features, we decided to use a static single-color image projection as the control condition. It would be interesting to compare with the blindfolded condition to verify the absolute impact of the total appearance realized by our projection mapping technique, including the dynamic texture, on food perception. Moreover, as stated in 3.3, the fact that most participants were aware of the projection may have biased their answers. Therefore, it is necessary to conduct a follow-up experiment to look into the bias by using a setup where the projection mapping is difficult to be aware of and by examining the difference in the effect when the type of the projected image is changed (ex. Food-related motion such as boiling vs. random motion).

In addition, this research also failed to clarify which component of the dynamic texture has an influence on the taste of food. In static images, Arce-Lopera et al. (2015) demonstrated the changes in the asymmetry of the luminance distribution, which is related to the freshness of the vegetables. Similarly, a relationship could be established between the dynamic texture of food and their characteristics, such as the speed of motion, temperature, or viscosity. For future studies, further examinations on the dynamic textures, such as the frequency, pattern, and contrast, and how it compares to expectations of taste, needs to be further explored. By applying a dynamic texture to food, this will make the meals more attractive to consumers.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The ethics committee in the Graduate School of Information Science and Technology, The University of Tokyo. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

Conceived and designed the experiments: YS, TN, TT, and MH. Performed the experiments: YS. Analyzed the data: YS and TN. Wrote the paper: YS, TN, TT, and MH.

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BRIEF RESEARCH REPORT
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What Am I Drinking? Vision Modulates the Perceived Flavor of Drinks, but No Evidence of Flavor Altering Color Perception in a Mixed Reality Paradigm

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It is well established that vision, and in particular color, may modulate our experience of flavor. Such cross-modal correspondences have been argued to be bilateral, in the sense that one modality can modulate the other and vice versa. However, the amount of literature assessing how vision modulates flavor is remarkably larger than that directly assessing how flavor might modulate vision. This is more exaggerated in the context of cross-modal contrasts (when the expectancy in one modality contrasts the experience through another modality). Here, using an embodied mixed reality setup in which participants saw a liquid while ingesting a contrasting one, we assessed both how vision might modulate basic dimensions of flavor perception and how the flavor of the ingested liquid might alter the perceived color of the seen drink. We replicated findings showing the modulation of flavor perception by vision but found no evidence of flavor modulating color perception. These results are discussed in regard to recent accounts of multisensory integration in the context of visual modulations of flavor and bilateral cross-modulations. Our findings might be important as a step in understanding bilateral visual and flavor cross-modulations (or the lack of them) and might inform developments using embodied mixed reality technologies.

Keywords: visual and flavor interactions, cross modulations, bilateral cross modulations, multisensory perception, virtual reality

INTRODUCTION

The quote "we eat with our eyes first" communicates the popular notion that vision has an impact in our perception of flavor, an idea confirmed through ingenious experimental setups and often used for marketing strategies (Velasco et al., 2018). Such perspective reflects a transition in our understanding of perception shifting from an independent view of the senses, toward a multisensory conception (Stein, 2012). In this multisensory framework it is accepted that input from one modality alters the perception of other modalities. This, together with long-term priors or associations, are constitutive aspects of perception (Lupyan and Clark, 2015; Piqueras-Fiszman and Spence, 2016). While taste and flavor are often used interchangeably in everyday language and even science, we here take the former to refer to sensations specifically arising from stimulation of the gustatory receptors, the latter as the perception arising from a combination of olfactory, gustatory and trigeminal sensations (see Spence et al., 2015 for a discussion on this distinction). Accordingly, there is evidence of many senses contributing to flavor perception (Stevenson and Mahmut, 2011; Spence, 2015; Piqueras-Fiszman and Spence, 2016). Particularly, colors of foods or beverages have shown to influence flavor perception and preference (DuBose et al., 1980; Clydesdale et al., 1992; Zellner and Durlach, 2003). The perceived sweetness of edibles, for example, has been enhanced by adding red color to a cherry-flavored solution; the more intense the color, the sweeter the flavor (Lavin and Lawless, 1998). Such effects are especially strong for colors and flavors with strong prior associations, like cherries that are associated with red and sweet or lemons with yellow and sour (Wieneke et al., 2018). This phenomenon has been refered to as a cross-modal correspondence (Spence, 2011), where a certain expectation about an attribute in one modality is transfered to another (e.g., redness/sweetness). These correspondences have been argued to be bidirectional (Deroy and Spence, 2013; Spence et al., 2015; Spence, 2019), such that, theoretically, both the redness of a cherry could enhance its perceived sweetness, and the sweetness could accentuate its perceived redness. Such correspondence might be a distinguishing factor between synesthesia and more universal multisensory associations (Deroy and Spence, 2013). Notably, this bidirectionality is not necessarily symetric, and may depend on individual reliance on sensory modalities (Deroy and Spence, 2013) and on the dominance of particular senses in humans (e.g., vision, which dominates many multisensory processes; Posner et al., 1976; Spence et al., 2001). Despite this assumption of bidirectionality in cross-modal correspondences, however, there is a large asymmetry between the number of studies investigating the influence of color on flavor perception, and those on how color might be influenced by flavor (Spence, 2019). Still, there are studies showing that certain basic tastes are indeed associated with colors (Saluja and Stevenson, 2018), as are linguistic references to taste (Spence et al., 2015), and that bidirectionality is present in other modalities (e.g., Mesfin et al., 2018). While relatively few endeavors have investigated bidirectional influences, even fewer—if at all— have aimed at investigating them in the context of cross-modal contrasts (i.e., contrasting the expectation from one modality to the experience in another modality; see Piqueras-Fiszman and Spence, 2015). For visual modulations of flavor in this context, for example, DuBose et al. (1980) showed that differently colored beverages were often misidentified, and Zellner and Durlach (2003) reported that beverages with the same flavor but varying in color were rated differently regarding their refreshment and liking. More recently, consistent findings of vision modulating flavor in virtual reality settings have been reported (Ammann et al., 2020). To our knowledge, however, no studies have investigated modulations on the other direction. We here thus aimed to study the potential bidirectionality of incongruent visuo-flavorous cross-modulations in an immersive and embodied mixed reality setup.

Across two tasks we examined how flavor perception could be modulated by vision and how color perception might be modulated by flavor, by comparing for each modality ratings after contrasting visuo-flavorous stimuli to ratings after unimodal stimuli. On a head mounted display (HMD), participants saw from the perspective of a male body a liquid being fed to them using a syringe, while they simultaneously were fed a liquid that contrasted the seen liquid (**Figures 1B,C**). To measure the effects of vision on flavor perception, participants judged the sweetness, sourness, bitterness and saltiness of the previously ingested liquid on visual analog scales (VAS). To measure how the ingested liquid's flavor might affect the perceived color of the seen liquid, they selected the color of the previously seen liquid on a color wheel. In accordance with previous literature, we hypothesized that the flavor associated with the visual cues would bias the flavor of the liquid in the direction of such visual attributes in the contrast (multimodal) condition compared to a unimodal condition. We hypothesized this effect based on the chosen stimuli would be specifically for the sweetness and bitterness but not on sourness and saltiness dimensions. To assess the potential bidirectionality for cross-modal correspondences, we expected participants to judge the color of the beverage (in the multimodal condition) biased toward the color association of the ingested liquid (in the unimodal condition).

METHODS

Participants

Thirty volunteers were recruited through a university mailing list considering the following criteria: being between 18 and 35 years old, not on diet, with normal or corrected-to-normal vision, no history of psychiatric, neurological or vestibular disease, nor food-related allergies, and not taking any medications. From the flavor perception part, two were excluded due to technical problems with the Oculus controller, resulting in a sample size of $N = 28$ (25 females; age: $M = 23.39$, $SD = 4.47$). From the color perception task, the same two plus an additional participant (due to feeling unwell) were excluded, resulting in a final sample size of $N = 27$ (24 females, age: $M = 23.44$, $SD = 4.62$). Participants provided informed consent, having been informed that the purpose of the study was to rate drinks, and received course credit.

Materials

Virtual Reality Setup and Visual Stimulation

An Oculus CV1 head-mounted display (HMD) and the corresponding Oculus Touch controllers were used. Unity 2018 was used for displaying a 235-degrees pre-recorded video portraying the first-person perspective of a real person and presenting the tasks. The videos were filmed from the perspective of a male actor and lasted approximately 20 s each (see **Supplementary Material** for an example). Visual stimulation on the HMD was reactive to head movements. As visuo-tactile synchrony next to a matching posture and a first-person

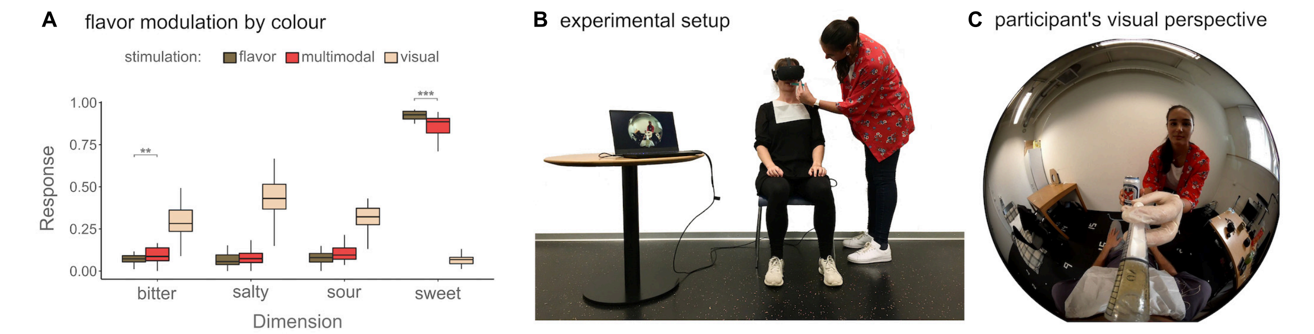

FIGURE 1 | (A) Median and interquartile range for the participants' mean flavor modulation by vision over all stimuli. Significance marks are indicated as follows: ***$p < 0.001$, **$p < 0.01$. **(B)** Shows the experimental setup during the multimodal contrasting condition for the color and flavor perception test (for illustration only, the real room corresponded to the one seen in **(C)**, and **(C)** the participants visual perspective during the experiment. Note that the seen liquid in **(C)** and the ingested liquid in **(B)** differed.

perspective have shown to enhance embodiment of the seen body (Maselli and Slater, 2013) regardless of the gender (Petkova and Ehrsson, 2008; Kilteni et al., 2015), at the beginning of each video participants were touched on the leg and simultaneously saw a corresponding touch on the virtual body. The VAS and color wheels to assess participants' ratings were displayed on the HMD and answered with head movements and the Oculus controllers, respectively.

Flavor Stimulation

To guarantee reproducibility, we used artificial flavor products from Plusaroma[1]. One drop of every flavor was dissolved in 12 ml water, except for the peppermint flavor (a single drop for 24 ml). Such quantities were based on an explorative phenomenal assessment. A 10 ml Braun syringe was used to provide the liquid.

Procedure

Experimental Design

The within-subject experiment was part of a larger study on visual/flavor conflicts on memory (not reported here, see **Supplementary Material** and the preregistered report at https://osf.io/xju3h/) and perception. The latter included both a color and a flavor perception block (see **Figure 2**) that were presented in a counterbalanced order and are reported here. In both blocks, participants saw the immersive videos from a first-person perspective in the HMD. The room, the furniture, their positioning, and the experimenter were identical in the real and the seen room for maximizing plausibility. Participants were required to match their body posture to that of the seen body in the headset and open their mouths whenever they saw the examiner approaching to feed them. The experimenter had previous extensive practice to ensure temporal synchrony between her actions and what participants saw. Given the location of the mouth from the visual perspective, slight temporal asynchronies when the syringe was close to the mouth were overlooked. Participants were asked to ingest the received liquid. Four flavorous and four visual stimuli were presented for the flavor perception task, and four alternative visual and flavorous stimuli for the color perception task. The contrasting stimuli for both tasks (described below) were chosen so that visual cues contrasted the flavor of the ingested product. To rule out any confounding variables, the stimuli were presented in a semi-counterbalanced manner, using four orders for each task. The overall procedure took approximately 1.5 h; the here reported part about 30 min.

Preparation

At the beginning of the overall procedure, participants seated on a chair positioned in the same location where the presented videos were previously recorded. After adjusting the HMD, to familiarize themselves with the tasks to follow they virtually saw the experimenter feeding them water while they were simultaneously fed water with a syringe. They were further instructed on selecting values on a VAS and options on a virtual color wheel before starting the experiment.

Flavor Perception Block

Participants saw on the HMD the examiner approaching to feed them while holding a liquid container (e.g., a beer can) and a syringe filled with the contained liquid (e.g., beer). Simultaneous to the feeding seen on the HMD, they were fed with 4 ml of an artificial flavor (flavorous stimuli), which tasted differently than the seen beverage (i.e., multimodal contrasting condition). The flavor stimuli were selected based on sweetness (i.e., apricot, vanilla, strawberry and cherry flavor), while the visual stimuli were associated with flavor dimensions other than sweetness (i.e., beer, vinegar, mayonnaise and tabasco sauce). After each exposure they rated the perceived flavor on a VAS (ranging from *not at all = 0* to *completely = 1*), which was displayed on the HMD after each condition with the questions *("How sweet did you experience this liquid," "How bitter did you experience this liquid," "How sour did you experience this liquid," "How salty did you experience this liquid*").

To establish a baseline for each presented flavor, after each contrasting trial, they tasted the same flavor again but without any visual cue (i.e., unimodal gustation condition, presented with

[1] www.plusaroma.ch

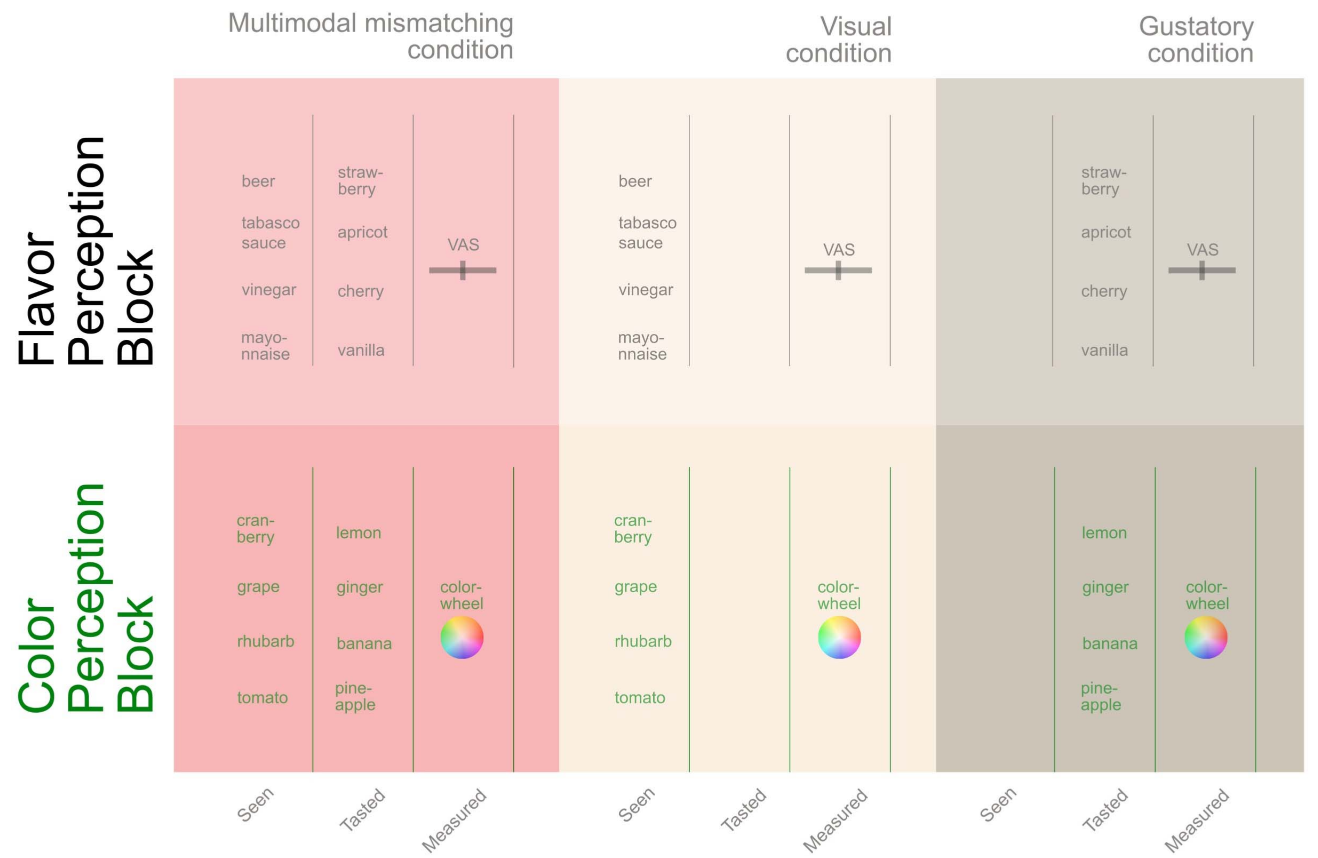

FIGURE 2 | Overview of the experimental design of the here reported experiment showing both the flavor perception and the color perception blocks, as well as the stimuli presented for each task. The blocks were presented in a counterbalanced order.

a black image on the HMD) followed by the same VAS. A baseline of the associated flavor for each visual stimulus was established by showing the same stimulus without any concomitant liquid (i.e., unimodal visual condition) followed by the VAS assessing the flavor of the seen liquid. See **Figure 2** for the experimental design and stimulus pairings, and **Figure 1** depicting how the stimuli were presented.

Color Perception Block

The same experimental setup was used for this block, yet this time the contrasting visual versus flavorous stimuli were chosen to differ with regard to the typically associated colors, and we assessed color instead of flavor perception (**Figure 2**). For the visual stimuli red liquids were chosen (tomato, grape, rhubarb and cranberry juice) while the ingested liquids were associated with yellow colors (pineapple, banana, lemon and ginger flavor). After each exposure, we used a color wheel to rate color of the previously perceived liquid (see Saluja and Stevenson, 2018 for a similar measure). The measure was displayed on the HMD and captured the red, green and blue color dimensions.

To establish a color-association baseline for each liquid, after each contrasting trial, they tasted the same flavor again without any visual cue (i.e., unimodal gustation condition) and judged its color on the color wheel. The color baseline was established by presenting the identical visual stimuli without any liquid (i.e., unimodal vision condition) and selecting its color. Participants chose a color after each multimodal contrasting condition (*"Which color do you think the liquid you just saw is?"*), unimodal gustation condition (*"Which color do you think the liquid you just tasted is?"*) and unimodal vision condition (*"Which color do you think the liquid you just saw is?"*).

Data Treatment

Data processing was performed using R 3.6.1 (R Core Team, 2020) and statistic tests using both R and JASP version 0.11.1. Alpha level was set at 0.05, or 95% confidence intervals. Data were tested for normality using Shapiro-Wilk tests and visual inspection. For parametric data the mean and standard deviation are reported as descriptive statistics, while for the non-parametric the median and interquartile are described. Rank-biserial correlation scores are reported as a measure of effect size. The averages of the four stimuli were coded by the mean of the four values for the multimodal and unimodal stimuli for each participant. For both tasks Wilcoxon signed-rank tests assessed whether the VAS responses and the selected colors differed between the multimodal and the unimodal condition of the manipulated modality. The baseline of the manipulating modality (i.e., vision when manipulating flavor perception and flavor when manipulating color perception) was used to confirm the direction of the perceptual change.

RESULTS

Modulation of Flavor Perception Through Vision

After taking the average of the four trials, a Wilcoxon signed-rank test assessed whether the responses on each of the VAS scales for the multimodal and the unimodal flavors differed significantly. The test revealed a significant difference between the multimodal sweetness (Mdn = 0.88, IQR = 0.09) and unimodal gustation sweetness (Mdn = 0.93, IQR = 0.05; W = 61, $p < 0.001$, $rB = -0.70$) and also between the multimodal bitterness (Mdn = 0.09, IQR = 0.07) and unimodal gustation bitterness (Mdn = 0.07, IQR = 0.04; W = 332, p = 0.002, rB = 0.64). No significant differences between the multimodal sourness (Mdn = 0.09, IQR = 0.07) and unimodal gustation sourness (Mdn = 0.07, IQR = 0.05; W = 281, p = 0.08, rB = 0.38) nor between multimodal saltiness (Mdn = 0.07, IQR = 0.05) and unimodal gustation saltiness (Mdn = 0.06, IQR = 0.06; W = 247, p = 0.17, rB = 0.31) were found. Wilcoxon signed-rank tests were additionally performed between the unimodal flavorous- and multimodal stimuli for each of the four different trials (see **Table 1**).

Modulation of Color Perception Through Flavor

A Wilcoxon signed-rank test assessed whether the color values from the multimodal and the unimodal visual stimuli significantly differed on any of the color dimensions (RGB). For the average over the four stimuli, the test revealed no significant difference between the multimodal redness (Mdn = 0.64, IQR = 0.12) and unimodal vision redness (Mdn = 0.63, IQR = 0.07; W = 234, p = 0.29, rB = 0.24), between the multimodal greenness (Mdn = 0.24, IQR = 0.06) and unimodal vision greenness (Mdn = 0.23, IQR = 0.08; W = 203, p = 0.75, rB = 0.07), also between multimodal blueness (Mdn = 0.41, IQR = 0.09) and unimodal vision blueness (Mdn = 0.41, IQR = 0.10; W = 163, p = 0.55, $rB = -0.14$). See **Table 2** for individual comparisons.

DISCUSSION

Using an embodied mixed reality setup, we investigated the influence of visual cues on flavor perception and that of flavor on color perception. Our results confirmed that visual information did modify the perceived flavor in the expected direction. As for the modulation of color by flavor, the data revealed no overall differences from baseline in the expected direction. These results thus show no evidence of bilateral cross-modal influences in the context of contrasting visuo-flavorous cues. We discuss the intricacies and considerations below.

Modulation of Flavor by Vision

To investigate the potential modulation of flavor by visual expectancies, we combined visual cues stereotypically associated with bitterness alongside flavorous stimuli generally associated with sweetness. As expected, and in line with vast literature (Clydesdale et al., 1992; Piqueras-Fiszman and Spence, 2015; Spence, 2019), participants rated the perceived sweetness significantly lower in the contrasting than in the unimodal gustation condition, and the perceived bitterness higher in the contrasting compared to the unimodal condition. No differences were found for the mean of all the trials in the dimensions of sourness and saltiness, which accordingly were not targeted by the chosen stimuli. Thus, the direction of this effect seems clearly driven by the visual expectancy. These results are in line with theories suggesting that prior information about the edibles before consumption generates dominant expectations that modulate the experience of flavor (Lupyan and Clark, 2015; Spence, 2016) and confirm existing literature of cross-modal modulations with contrasting stimuli qualities (DuBose et al., 1980; Clydesdale et al., 1992; Zellner and Durlach, 2003). Our study extends previous literature by showing that vision-driven modulations of flavor can be created in embodied mixed reality settings, confirming that such modulations are independent of the visual-stimulation medium (see also Ammann et al., 2020).

No Clear Modulation of Color by Flavor

Despite the dominant role of vision in human multisensory experience (Posner et al., 1976; Spence et al., 2001), various aspects of visual perception have shown to be modulated by other senses when there is a strong prior association between the two (e.g., Shams et al., 2000; Repp and Penel, 2002; Robinson and Sloutsky, 2013), and clear color associations to specific flavor and tastes have been reported (Spence et al., 2015; Saluja and Stevenson, 2018). However, much less is known about the potential of contrasting visuo-flavorous cues to modulate color perception (Spence, 2019). Participants ingested liquids associated with yellow or green while seeing a red liquid, to then judge the perceived color of the ingested liquid. There was no evidence of an effect of the contrasting visuo-flavorous cues on the perceived color in any of the color dimensions when taking the mean for all stimuli. The general null findings suggest no systematic modulation of color by flavor, further accentuating the dominant role of vision in human experience (Posner et al., 1976; but see also Hörberg et al., 2020). Interestingly, the colors associated with each of the flavorous stimuli (unimodal flavorous condition) were overly green. In fact, both green and yellow have been previously associated with sourness (Spence et al., 2015; Saluja and Stevenson, 2018), while our flavor selection was perhaps more heterogeneous (e.g., banana is not particularly salient in terms of sourness). Future studies are advised to limit the flavor selection of flavorous cues to a more homogeneous assortment in terms of basic taste dimensions to avoid any potential confounds (see Spence et al., 2015 for a distinction between associations in particular cases versus

TABLE 1 | Wilcoxon signed-rank tests comparing the perceived flavor between the flavorous unimodal and the multimodal stimulation during the flavor modulation task ($N = 28$; ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$).

Rated flavor		Sweetness multi vs. unimodal			Bitterness multi vs. unimodal			Sourness multi vs. unimodal			Saltiness multi vs. unimodal		
Visual item (packaging)	**Flavorous item (artificial flavor)**	***p***	***W***	***rB***	***p***	***W***	***rB***	***p***	***W***	***rB***	***p***	***W***	***rB***
Beer	Strawberry	0.007**	75.5	−0.60	0.03*	261.0	0.49	0.08	280.0	0.38	0.15	250.0	0.32
Tabasco sauce	Apricot	0.002**	60.0	−0.68	0.08	245.0	0.40	0.46	236.0	0.16	0.10	224.0	0.38
Vinegar	Cherry	0.003**	64.5	−0.66	0.04*	258.5	0.47	0.26	253.5	0.25	0.55	151.5	−0.14
Mayonnaise	Vanilla	<0.001***	43.5	−0.79	0.01**	237.0	0.35	0.16	248.5	0.31	0.04*	222.0	0.48

TABLE 2 | Color values in red, green, blue format, and visualization of the perceived colors for the color modulation task, significance marks represent the comparison between the visual and the multimodal cues (**$p < 0.01$, *$p < 0.05$).

Stimuli		Color visualization			Color values								
					Visual			Multimodal			Flavorous		
Visual	**Flavorous**	**Visual**	**Multimodal**	**Flavorous**	**Red**	**Green**	**Blue**	**Red**	**Green**	**Blue**	**Red**	**Green**	**Blue**
Cranberry	Lemon				0.63	0.17	0.30	0.66	0.19	0.31	0.65	0.68	0.40
Grape	Ginger				0.49	0.24	0.50	0.49	0.21**	0.46*	0.60	0.70	0.50
Rhubarb	Banana				0.73	0.40	0.59	0.73	0.45	0.63	0.61	0.69	0.50
Tomato	Pineapple				0.67	0.12	0.20	0.66	0.11	0.20	0.54	0.66	0.49

general cross-modal sensory features). As for the single item-pair showing significant changes (visual: grape, flavorous: ginger), the differences were in the opposite direction than expected (i.e., less green), thus not allowing us to make any conclusions for this change. A complete symmetry in bilaterality of cross-modulations was not expected, due to the general dominance of vision in our multisensory experience (Deroy and Spence, 2013; Spence, 2019) and its temporal precedence to flavor as found most natural conditions (see below). It has been theoretically argued that visual capture might be particularly strong in virtual reality due to the strength of the substitution of the visual field and optic flow (Roel Lesur et al., 2018), which could have further biased our results in favor of vision and might hinder generalization to other settings. Furthermore, color perception could potentially be modulated by here neglected aspects of flavor (such as textures or temperature) or natural flavors that might elicit a stronger association. Flavor is a multisensory construct and is not only defined by taste but also scents, textures, temperature, pain and sound (Yeomans et al., 2008). Here, we used water-based beverages, which limited the sensory stimulation of flavor to basic tastes and ortho- and retronasal stimulation of olfactory receptors (Koza et al., 2005), while other aspects were not modulated. Moreover, there might have been a potential floor and ceiling effect suggested by the comparatively high medians for sweetness and low for bitterness that could be accounted for by alternative, not so salient, stimuli or the ratio of artificial flavors and water used. Thus, the lack of evidence of color modulations here reported should not be taken as evidence for the general incapacity of flavor to manipulate color, but as a first step in elucidating the mechanics of potential bilaterality (or lack of it) in visuo-flavorous cross-modulations.

Limitations of the Experimental Design

While our objective was to analyze the potential bilaterality of cross-modal influences in the context of contrasting visuo-flavorous stimuli, our assessment between modalities was itself not symmetric. A complete analogy between modalities could be impossible due to the ecological nature of our senses. For example, in ecological settings as much as in our experiment, vision tends to temporally precede gustation which might bias the interaction in the direction of the earlier modality (Piqueras-Fiszman and Spence, 2015). Thus, aiming for a closer analogy is not necessarily desired as it might imply a reduced ecological validity. As for our paradigm, this lack of symmetry is particularly salient in two ways. First, in that visual associations were generated mostly through packaging, and thus relied on high-level cultural associations and linguistic cues, whereas flavor associations were stimulated through artificial liquids that could have been not recognized. In this sense, explicit recognition might have played a role in the varying results between tasks. In general, both clearly recognizable cues as well as potentially not-recognizable ones have methodological advantages and limitations, including the cognitive processes involved (Spence, 2016). As a second asymmetry in our paradigm, flavor perception was linguistically assessed (through questionnaires) while color was directly judged in a color wheel. The complexity of assessing flavor and taste perception directly, however, is a general problem in the field (Saluja and Stevenson, 2018; Payne et al., 2021), and the primary aim of our study was to provide first evidence on a potential modulation of color through flavor. However, an issue with assessing flavor perception linguistically as we did (VAS) is the difficulty to convey the effect as a more tangible parameter. For example, it's not clear how much sweeter in, say, estimated sugar spoons the perceptual change is. Future studies, however, might consider improving our design to account for these points.

Readers should note that the seen liquids may not have elicited a homogeneous expectation in terms of texture (e.g., beer and mayonnaise), an aspect that is not desirable as it might have, however, minimally—confounded our results (Yeomans et al., 2008). Lastly, this experiment was part of a larger study on visuo-flavorous conflicts (see **Supplementary Material**), which might have influenced our findings due to potential carry-over effects. However, between the first visuo-flavorous stimulation section of such study and the here reported experiment, a 30-min break was taken and different stimuli were used.

CONCLUSION AND OUTLOOK

While bilateral associations flavor and color have been reported (Piqueras-Fiszman and Spence, 2015; Saluja and Stevenson, 2018; Spence, 2019), we could not confirm our hypothesis of flavor modulating color perception in the context of contrasting cues. Our mixed-reality experimental setting, however, did replicate findings of modulations of flavor by vision in such new setting (DuBose et al., 1980; Clydesdale et al., 1992; Lavin and Lawless, 1998; Zellner and Durlach, 2003). Further investigating the bilaterality of cross-modal influences remains important for a thorough understanding of our multisensory system, and hopefully more research on these lines will emerge in the coming years. Our use of embodied mixed reality technologies provides an easily replicable setup for manipulating and studying visuo-flavorous perception that might serve future endeavors. In fact, alterations of embodiment seem to be at the forefront of potential applications given their potential to alter cognition, affect and behavior (e.g., Dijkerman and Lenggenhager, 2018), but where chemo-senses have been vastly disregarded (Roel Lesur et al., 2020). Adding to the palette of cross-modulations that can be created in embodied mixed reality settings (Kilteni et al., 2015), our evidence of visual modulations of flavor might inform this growing field.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://osf.io/xju3h.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of the Faculty of Arts and Social Sciences at the University of Zurich (Approval Number: 17.12.15). The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individuals for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

BL, MR, and LS designed the experiment, wrote the overall content of the article, and contributed to the statistical analysis and the results section. LS contributed with the data collection. MR programmed the tasks. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.641069/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Impossible (Food) Experiences in Extended Reality

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We introduce a model to think about impossible experiences in mixed and virtual reality, while emphasizing the role of said experiences in the context of food. This reality-impossibility model includes two continua, namely, the reality-fantasy character of objects and environments, and the extent to which they follow the laws of physics-other laws. We present a series of examples in each of the quadrants of the model and discuss both the research possibilities and implications of impossible experiences.

Keywords: mixed reality, virtual reality, impossible, experiences, reality, extended

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INTRODUCTION

> *"Truth is a mobile army of metaphors, metonyms, anthropomorphisms, in short, a sum of human relations which were poetically and rhetorically heightened, transferred, and adorned, and after long use seem solid, canonical, and binding to a nation. Truths are illusions about which it has been forgotten that they are illusions."*
>
> – Fredrich Nietzsche

Concrete concepts provide a connection between what people think and how the world is (Johnson, 2008). Humans often resort to metaphors, comparisons, and idioms to give substance to abstract concepts and thus ground them in sensory experiences. For example, the concept "unicorn" is used as a metaphor to describe start-ups whose dazzling success seems impossible, and even a little magical. In the food sector, the metaphor "hair-silk is ice cream" leads people to generate taste inferences in the hair silk domain (Petit et al., 2016). Thus, metaphors often help to simulate things that do not exist, or that are physically impossible to do through concrete language (Marks, 1996; Gibbs and Matlock, 2008).

Today, new technologies are bringing these metaphors to life by making it possible to create seemingly "impossible experiences." Impossible experiences, that is, experiences that cannot occur in the physical world (e.g., talking with a virtual reality representation of oneself) and tend to involve fantasy (that is, unrealistic or improbable elements; e.g., in the world of Disney's fantasia), are increasingly allowed and facilitated by immersive, extended reality (XR), technologies such as augmented reality (AR), augmented virtuality (AV), and virtual reality (VR). However, although there are certain models and concepts that allow researchers and experience designers to think about fantastic experiences through immersive technologies (e.g., the immersion/fantasy typology developed by (Cowan and Ketron, 2019), there is no conceptual model to think, and guide the design of, impossible experiences. In this perspective article, we introduce the concept of impossible experiences and what we call the reality-impossibility model, which addresses the aforesaid gap.

IMPOSSIBLE EXPERIENCES AND THE REALITY-VIRTUALITY CONTINUUM

How to think about impossible experiences in the context of immersive technologies? The reality-virtuality continuum, which was introduced in the context of visual displays to characterize environments ranging from real to virtual (Milgram and Kishino, 1994), serves as a starting point. In this continuum, real physical environments are located on its left end. Mixed reality environments, which merge real and virtual environments (as in augmented reality and augmented virtuality) are located in its center, and fully virtual environments on its right end. Recently, the reality—virtuality continuum has been used to classify our experiences as a function of the level of digitalization that they involve (Velasco and Obrist, 2020). Said continuum ranges from real experiences, through those involving both real and digital elements (mixed reality), to those which are fully virtual. Mixed reality and virtual experiences, such as those involving XR technology, offer a number of opportunities to create novel experiences.

Mixed reality experiences can help to enrich our physical environments by adding digital elements (e.g., Javornik, 2016). They also allow us to recreate existing experiences that are difficult to access otherwise (e.g., being in a different location, such as the international space station or Earth lower orbit, Stepanova et al., 2019). Perhaps more interestingly, mixed and virtual reality make possible the creation of impossible experiences. In our view, these experiences do not follow the laws of physics (follow imaginary rules, e.g., objects falling up on Earth) and/or are characterized by the introduction of fantasy elements (e.g., visualizing a bear in the Ursa Major constellation).

While impossible experiences in XR are common in the realm of films and games (e.g., Zuo et al., 2019), these are relatively unexplored when it comes to eating. However, impossible experiences per se are not uncommon in eating (see Spence et al., 2020, for a review of magical food experiences). In the next sections, we specifically present our perspective on: 1) a model to classify and guide the design of impossible food experiences in mixed reality; 2) some examples of, and opportunities associated with, said experiences; and 3) the implications associated with them. This article may be of interest to researchers and practitioners interested in designing experiences that do not fully resemble reality and thus aim, through imagination, to create novel experiences for users.

A DESIGN MODEL TO CLASSIFY IMPOSSIBLE EXPERIENCES

Previous research has suggested a typology of VR research that involves the dimensions of realism–fantasy and immersion, which are instrumental to flow (e.g., Cowan and Ketron, 2019). However, said research has not covered impossible experiences, as we understand them. Indeed, the term "impossible," as defined in the Merriam-Webster dictionary, refers to "incapable of being or of occurring"[1]. In that sense, the first part refers to the visible elements, in other words, real-fantasy objects and environments; the second part of the definition refers to the invisible laws governing such objects and environments. Therefore, a more encompassing "impossible experiences" concept, must involve both the realism-fantasy continuum and also one that captures the extent to which the objects in the experience follow the laws of physics as we know them, that is, the laws of physics—other laws continuum (**Figure 1**). Whereas the first focuses on whether the elements that are part of an experience correspond to real objects and environments (e.g., say, presenting a horse that exists in real life vs. a unicorn that does not), the second focuses on whether interactions between objects are governed by the laws of physics (for example, both the horse and unicorn run on a grass field vs. they fly).

Altogether, these two continua compose what we call the reality-impossibility model (see **Figure 1**). XR technology becomes the digital, and immersive, means by which quadrants other than the real—laws of physics quadrant become possible. Importantly, immersion (Agrawal et al., 2020) and sense of presence (Schuemie et al., 2001), which are key variables in immersive technologies, are not part of the experience taxonomy but instead, in our view, may determine the compellingness of the experience (cf. Slater, 2018). Moreover, by focusing on the objects and their interactions, our model is agnostic to the way the experience is implemented (e.g., whether the experience involves augmented reality, augmented virtuality, or virtual reality, cf. Milgram et al., 1995).

Let us look at some examples of experiences that fall within each of the quadrants of the reality-impossibility model. The physical reality quadrant (quadrant 1) involves objects and environments which exist in reality and obey the laws of physics. Examples in this quadrant include those AR visualizations of foods that several companies are now utilizing to enhance the expectations of consumers before they order food online (Petit et al., 2021). Consumers can use a smartphone to overlap, say, a dish of food in their own physical environment through their cell phones to experience it as if it was in front of them, and thus, better imagine the consumption process. Another example here is National Geographic Explore VR[2], which allows the user to explore, through virtual reality, some of the most iconic natural locations on the planet.

In the other reality quadrant (quadrant 2), scenarios and experiences are real but do not follow the laws of physics. An example is the VR video tour of six real exoplanets created in collaboration with researchers at the University of Exeter (Exoplanet 360°, 2018)[3]. The video takes the viewer on a first-

[1]https://www.merriam-webster.com/dictionary/impossible
[2]https://www.oculus.com/experiences/quest/2046607608728563/?locale=en_US
[3]https://www.youtube.com/watch?v=qhLExhpXX0E

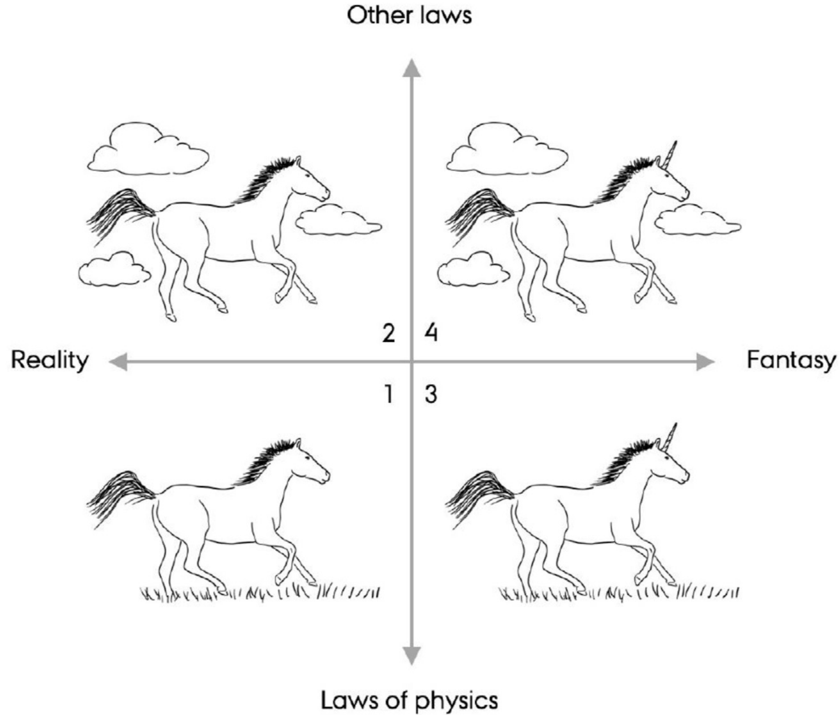

FIGURE 1 | The reality-impossibility model. The (1) Physical reality quadrant is both rooted in real scenarios and experiences follow the laws of physics (a horse that gallops), the (2) Other reality quadrant is rooted in real scenarios and experiences do not follow the laws of physics (a horse that flies), the (3) Physical fantasy quadrant is rooted in fantasy scenarios and follows the laws of physics (a unicorn that gallops), and the (4) Other fantasy is rooted in fantasy and do not follow the laws of physics (a unicorn that flies).

person perspective, guided tour of six exoplanets (reality) viewed from space, as well as from the surface of the planets in a short time span (other laws). The video shows short information highlights in text form, and different astrophysicists verbally present more in-depth information about each exoplanet. Whereas the immersive video presents a scientifically accurate representation of the planets, the transportation between the planets happens within seconds and some of the environments are likely hostile to sustain a visitor doing the guided tour as presented (other laws). Another example of this quadrant are the AR filters that can be found on social media such as Instagram and Snapchat, that allow people to see themselves (reality) as significantly older and/or younger in real time (other laws). In both cases, the forces that govern the experience and act onto the real objects defy the laws of physics. For instance, the concept of time as part of the narrative of the experience does not follow its normal speed forwards, or goes backwards.

The physical fantasy quadrant (quadrant 3) is characterized by the inclusion of fantastical elements in a world which still follow the laws of physics. An example is the *Tree* VR experience developed by members of MIT Media Lab's Fluid Interfaces group, in which the user embodies (fantasy) a forest tree (laws of physics) from seedling to its fully-grown form and lives through different significant events (Liu and Qian, 2017). During the experience, the user's body becomes the trunk, and their arms become the branches; the full experience incorporates bodily haptics, vibration, heat generators, and fans to enhance its immersiveness. In this case, while the scenario and objects obey the ordinary laws of physics (though the representation of the growing process is speeded up, as in a timelapse), the concept of the experience is fantastical (a human becomes a tree). An AR example is where TeamLab (an art collective), together with Sagaya[4] (a restaurant), designed a dining experience, in which they projected, via projection mapping, a fantastic representation of the different seasons on the dining table and room, while the diners ate.

Finally, the other fantasy scenario (quadrant 4) includes both fantastical elements and interactions which go beyond ordinary laws of physics. An example is the *Dreams of Dalí* VR experience[5], in which the user enters Dalí's painting (fantasy), Archaeological Reminiscence of Millet's "Angelus," as if it were another dimension, and explores a surreal world based on it (other laws, Dreams of Dalí, 2020) Another example here is Coca Cola's virtual reality for Christmas[6], a campaign developed by the brand in which users are immersed in Coca Cola's animated Christmas world (fantasy), whilst flying in Santa's sleigh (other laws), or Pokémon GO[7], the augmented reality game in which

[4]https://www.youtube.com/watch?v=yRJTRcfGmAk
[5]https://www.youtube.com/watch?v=F1eLeIocAcU
[6]https://www.youtube.com/watch?v=bTbfPALVQgs
[7]https://pokemongolive.com/en/

both fictional characters (fantasy), with their own, other, laws (e.g., self-levitating), are augmented into the physical reality.

It is important to mention that, although the quadrants may provide a guide to classify experiences in four discrete categories, the two axes of the model are continua. In that sense, experiences may vary in extent, along them. In addition, whereas the reality vs. fantasy continuum can possibly be measured by the extent to which the objects or context exist in real life, the continuum of laws of physics vs. other laws can be slightly more difficult to measure, considering that technologies may allow interactions (e.g., flying) otherwise not possible without technology, whilst at the same time complying with the laws of physics. On a similar note, it is important to distinguish whether the laws of physics are being broken as an integral part of the plot of the experience. For instance, in the interest of time, the experience may be speeded up at will, while this manipulation is not part of the narrative per se. As such, our experience design model, at present, provides a more qualitative representation/inspiration of the variations along the two dimensions, though future research may aim at developing measures for these variations.

IMPOSSIBLE XR EATING EXPERIENCES

What do impossible experiences mean in the context of eating and drinking? As immersive technologies become a part of eating and drinking, the potential for novel experience design with said experiences grows. Indeed, research has already suggested that a number of immersive technologies are being used for food experience design both in research and practice (Velasco et al., 2018).

The majority of XR eating research has focused, so far, on real scenarios obeying the laws of physics (quadrant 1). Using VR, for example, studies have explored drinking coffee while immersed in a coffee farm (Barbosa Escobar et al., 2021). Using stereoscopic AR interfaces, other studies have investigated altering the luminance distribution of a slice of cake (Ueda et al., 2020) and changing the apparent size of a cookie (Narumi et al., 2012). Furthermore, projective AR systems have been used to modify the food color of sponge cake and potato crisps in real time (Nishizawa et al., 2016) and modify the appearance of the cooking state of food in a Chinese hotpot with remote commensals (Foley-Fisher et al., 2010).

However, there are a few studies which have explored quadrant 2, with scenarios impossible to test in the real world either due to ethical issues or physical impossibility. For example, Ammann et al. (2020) used VR to set up a disgust sensitivity study where participants were asked to taste chocolate that either appeared on the table or came from the bottom end of a dog. While this would have been impossible to achieve in the real world, the researchers used VR to manipulate participants' disgust response while keeping the food identical. In another example, Wang et al. (2020) gave participants black coffee that was colored either dark brown or light brown in VR, creating coffee with "virtual milk" added. In this case, VR allowed the researchers to study how the brain integrates digitally presented visual information with physically presented chemosensory information.

Since much food research has traditionally focused on real products, quadrants 3 and 4, which involve imaginary scenarios, have, to the best of our knowledge, only been explored in the realm of HCI research. An example involving imaginary scenarios but obeying physical laws (quadrant 3) was shown in Harley et al. (2018), where participants had a picnic in Little Red Riding Hood's forest while the wolf approached from a distance. While we are not aware of any existing XR eating studies in quadrant 4, such experiences—for example eating novel foods in space—have been conceptualized, and systems associated with them devised (e.g., Obrist et al., 2019).

DISCUSSION AND CONCLUSION

What other impossible experiences can be designed? Going forwards, we hope to see many more XR eating experiences in quadrants 2, 3, and 4. Experiences in quadrant 2 can play more explicitly with breaking laws of physics, for instance with self-levitating or flying foods (though they may not break the laws of physics, see Vi et al., 2020). Moreover, food appreciation can be enhanced by building in further interaction points with the food, for instance with living serving ware or even the food itself. Another interesting avenue may lie in VR experiences in which the users embody an animal and experience different stages in its value chain, which could potentially have impactful effects in individuals' food-related behaviors, including diet and food waste generation. Experiences in quadrant 3, by exploring fantasy objects and environments, can potentially add value to food research by uncovering consumers' state of mind and emotions towards novel foods, or by helping people build a deeper experience with the past by tasting historical and/or extinct foods.

Quadrant 4 opens up the possibility of fantasy dining scenarios where the questions of where, when, who, and what to eat are all open to experimentation. For example, how would it feel like to eat in the World of Warcraft, whereby some of the laws of physics are also broken? Or how would it feel like to dine in one of Asimov's novels? We can also imagine a situation in which different quadrants of the model would be tested and see which quadrant is most likely to help individuals simulate impossible experiences. For example, what situation could make gruyere cheese best look like the Moon? - representing someone eating gruyere on the Moon (quadrant 2), - eating a piece of the Moon with wine and bread at the table (quadrant 3), or even eating a piece of the Moon with bread and wine, while gazing at the Earth from the surface of the Moon (quadrant 4). It may also be interesting to analyze whether XR can facilitate the embodiment of metaphors. Metaphors generally help people to represent abstract concepts in terms of more concrete ones (i.e., more grounded in bodily states), through the simulation of impossible experiences (Lakoff and Johnson, 1980; Gibbs and Matlock, 2008). Many metaphors relate to the food register (e.g., 'walking on eggshells', 'the apple of my eye', 'pork barreling', 'I'm in a pickle'). If instead of imagining them, it would be possible to live these impossible experiences through XR, what level of fantasy/reality best favored the understanding of these metaphors? In public health communication, metaphors such as "Are you pouring on the pounds?" are often used to create disgust and reduce food cravings (Puhl et al., 2013; Petit et al., 2016). What XR scenarios in quadrants 2, 3, and 4 may help people experience sodas in terms of pounds?

While the reality-impossibility model enables multiple scenarios for experimentation with foods, this, as other research in XR, carries certain ethical reflections that are worth examining. Quadrant 4, for instance, facilitates the creation of experiences that do not conform to any known experiences, and as such, their implications need to be carefully thought through, given that the realism of XR is achieving unprecedented levels. Slater et al. (2020) considered some questions worth reflecting on, which may well apply to impossible food experiences: Does realism in XR lead to confusion between the real and virtual? Does it lead to emotional and behavioral impact? What are the long-term effects of virtual impossible experiences?

The answers to these questions are not black and white and need further reflection. However, following Velasco and Obrist's (2020) three laws of multisensory experiences, one may argue that any impossible experience should 1) be used for good and must not harm others, 2) the participants should be treated fairly, and 3) the experience designer, the rationale, and the means through which the experience is created must be known.

In conclusion, impossible experiences in XR have already demonstrated their value in a wide spectrum of applications: to probe multisensory integration (e.g., Cornelio et al., 2021) and decision making (e.g., Ammann et al., 2020), optimize product/experience development (e.g., Obrist et al., 2019), and create "fun" consumer experiences (e.g., Barbosa Escobar et al., 2021; https://lepetitchef.com/; see also Wang et al., 2021, for a review).

Our perspective on impossible experiences and our suggested model present a first approach toward the conceptualization of impossible experiences. As such, it is critical for future research to further operationalize the continua and empirically support or challenge them, through qualitative and quantitative studies. XR provides a new space for creativity. While metaphors were limited to the ability of individuals to simulate experiences, by giving more space to the impossible, XR might improve our abstraction skills.

Going forward, we invite other researchers to join us to explore the vast space of opportunities in the realm of impossible experiences.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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With a Hint of Sudachi: Food Plating Can Facilitate the Fondness of Food

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Among the senses of food, our subjective sense of taste is significantly influenced by our visual perception. In appetite science, previous research has reported that when we estimate quality in daily life, we rely considerably on visual information. This study focused on the multimodal mental imagery evoked by the visual information of food served on a plate and examined the effect of the peripheral visual information of garnish on the sensory impression of the main dish. A sensory evaluation experiment was conducted to evaluate the impressions of food photographs, and multivariate analysis was used to structure sensory values. It was found that the appearance of the garnish placed on the plates close to the main dish contributes to visual appetite stimulants. It is evident that color, moisture, and taste (sourness and spiciness) play a major role in the acceptability of food. To stimulate one's appetite, it is important to make the main dish appear warm. These results can be used to modulate the eating experience and stimulate appetite. Applying these results to meals can improve the dining experience by superimposing visual information with augmented reality technology or by presenting real appropriate garnishes.

Keywords: visual perception, food pairing, food plating, image analysis, sensory science

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INTRODUCTION

Visual information on food significantly influenced our daily life. For example, Arce-Lopera et al. (2012) suggested that luminance distribution affects the judgment of freshness perception of strawberries; Murakoshi et al. (2013) further showed that changes in luminance distribution and visual freshness perception correlate with degradation time even when there are individual differences in foods. These studies reported a significant relationship between freshness and the desire to eat.

The sense of sight plays a major role in determining what consumers find attractive (Schifferstein et al., 2020). For instance, when food is presented in a more pleasant way, people enjoy the food on the plate more (Zellner et al., 2014). Zellner et al. (2011) have also shown that neatly served foods are preferred over foods that are served less neatly.

Previous food studies have investigated how appetite can be aroused not only by the sense of taste but also by the sound, color, and shape of the plate (Roballey et al., 1985; Harrar and Spence, 2013). For example, increasing the visual contrast on a plate (e.g., changing the color of the plate) has been reported to significantly increase food and drink intake in patients with Alzheimer's disease (Dunne et al., 2004). Using plates and glasses that contrasted with food increased food consumption by 25% and beverage consumption by 84% (Dunne et al., 2004). Furthermore, human-food interaction research is conducted on the eating experience by manipulating the appearance of food. In particular, XR technology can be used, such as augmented reality (AR), virtual reality (VR), and projection mapping (Narumi et al., 2011, 2012; Suzuki et al., 2021). The results of those studies indicate that XR technology has the potential to change consumer behavior and dining experiences.

Main dishes are dishes whose main ingredients are sources of protein such as meat, fish and soybeans, which play an important role in a balanced diet of nutrients, including the supply of high-quality protein (Gabriel et al., 2018). The main dish used in this experiment was fried chicken (Karaage in Japanese), whose garnishing ingredients are frequently placed next to the main dish. This is the national dish of Japan. Deep-fried dishes, such as fried chicken, contain fat (Marangoni et al., 2015), which should be consumed by elderly people and can provide a large amount of energy in a small quantity.

Garnishes often play completely different roles in different cultures and dishes and can be widely discussed in terms of colors, shapes, numbers, quantities, sizes, varieties, arrangements, flavors, tastes, satiety, and aromas (McCrickerd et al., 2012; Carney et al., 2018; Spencer and Guinard, 2018). Some ingredients are intended to be eaten, while others are mainly used to add color to a dish. In this paper, we define "garnish" as a solid food. Liquid condiments such as mayonnaise and other sources were excluded from this study. Garnishes on the plates were not determined by the number of pieces but by the amount of garnish that would fill the blank space next to the main dish.

There have been studies of visual appetite stimulants and surrounding colors and other factors; however, few cases have investigated the significance of the immediate element of the surrounding environment of the main dish: the garnish. Therefore, this study tested the effect of peripheral visual information, garnish, on the sensory impression of the main dish. We conducted a sensory evaluation experiment to study the impressions of food photographs and conducted multivariate analysis to exploratorily structure the sensory values.

In this study, we conducted an experiment to find the structural model of appetite stimulants. This study focused on the multimodal mental imagery evoked by the visual information of food served on a plate and examined the effect of the peripheral visual information of garnish on the sensory impression of the main dish. When looking at the visual stimulus images, we speculated that not only the color obtained from the visual information but also the freshness of the food and the impression of dryness and wetness estimated by looking at the images might affect the stimulated appetite for the main dish. In this article, we use the term "visual appetite stimulants" to describe the effect of appetite increase when images of a dish are observed. This study clarifies the possibility that even the combination of a garnish and a main dish, which is not intended to be eaten or has never been experienced, can change the stimulated appetite for the main dish.

This research contributes to the field of investigating the relationship between material perception via vision and perception of food/eating behavior. Although research on estimating the caloric value of food in images taken with mobile devices has been widely conducted (Domhardt et al., 2015; Dinic and Stutz, 2017; Fang et al., 2019), research on the relationship between visual appetite stimulants and garnishes and information superposition has rarely been investigated. Additionally, the key findings from this study are useful for consumer services to optimize food purchasing decisions based solely on appearance when purchasing lunchboxes or prepared foods at supermarkets or delicatessens or by looking at photographs of dishes on the menu or online delivery. In these situations, consumers are likely to make judgments based on past experience and food appearance. This research is also helpful for those who are suffering from eating disorders.

MATERIALS AND METHODS

Participants

The study participants included 15 students (11 women and 4 men; mean age, 22.0 years; SD, 1.37 years; age range, 21–26 years). Each participant had normal color vision and normal or corrected-to-normal visual acuity. The SFC Research Ethics Committee on Human Experimentation of Keio University, Shonan Fujisawa Campus (approval # 302), approved the experimental protocol. Informed consent, in writing, was collected from each participant prior to the experiment.

Stimuli

We created 26 types of stimuli, including the no-garnish plate: unchanged plates with one main dish (fried chicken) (**Figure 1**). The 25 types of garnishes included ingredients such as lemon and parsley, which are commonly used for garnishing. Additionally, we used seaweed, eschalot (rakkyo in Japanese), and sweet ingredients, which are uncommonly used. The ingredients were selected based on the results of a 10-participant pilot study with 30 types of garnishes. Of these garnishes, 25 were chosen from the perspective of color, nutritional balance, crop classification (leafy vegetables, fruits, etc.) and flavor. The ingredients excluded from the results of the preliminary study included seaweed, potato chips, corn, mushrooms, kimchi, pickles (gherkins), white rice, crème fraîche, and fried noodles.

Procedures

Participants evaluated each of the 26 images using a visual analog scale (VAS). The 11 adjective pairs are presented below. The order of the stimuli was randomized across participants, and the participants could view the reference images at any time during the experiment. The participants provided their evaluations on a full-screen browser using Google Forms (Google LLC).

The eleven adjective pairs used in sensory evaluation were as follows:

- Freshness/fresh – not fresh
- Drying/dry – not dry
- Wetness/wet – not wet
- Warmth/warm – not warm
- Sourness/sour – not sour
- Sweetness/sweet – not sweet

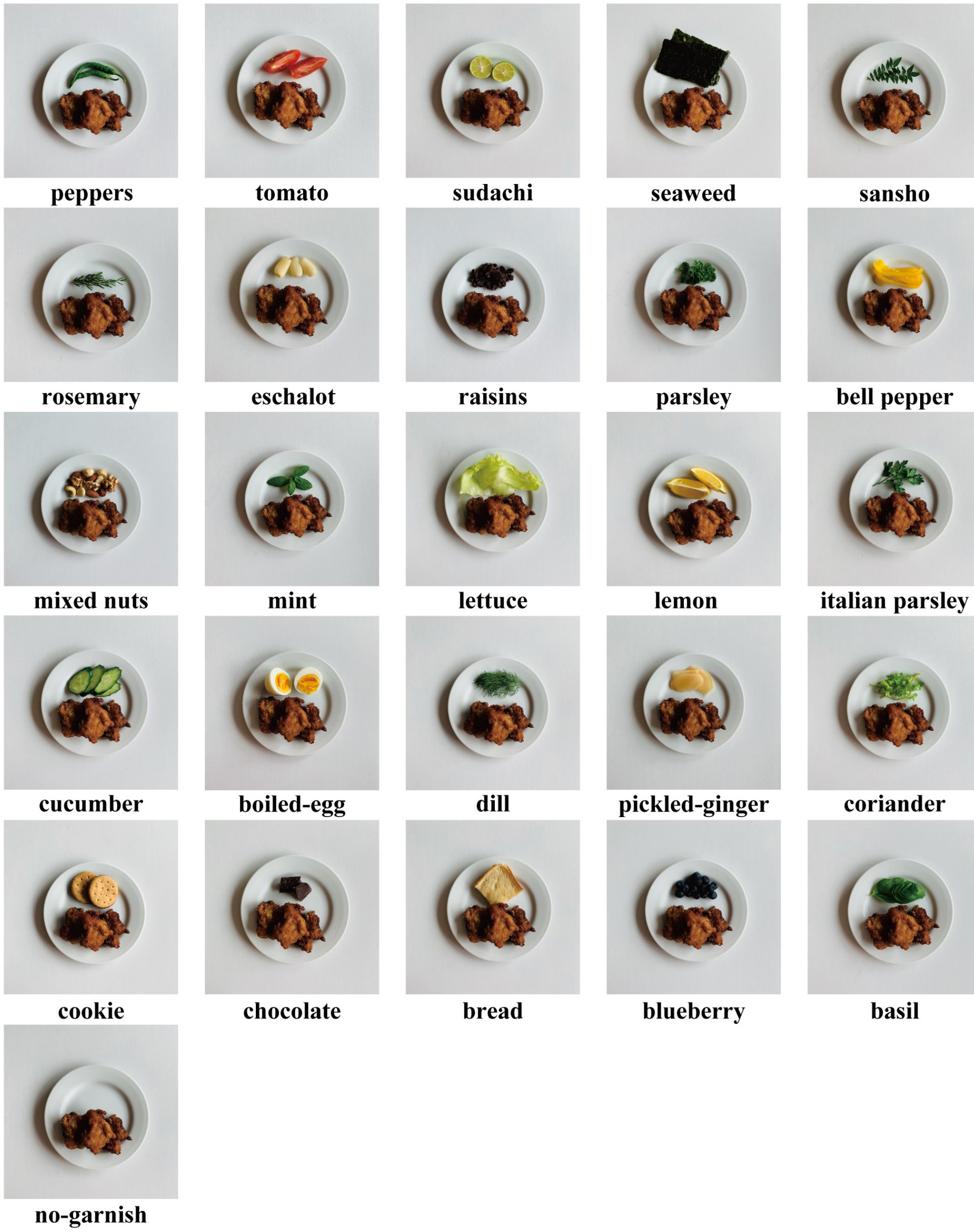

FIGURE 1 | Visual stimuli used in sensory evaluation experiments. We created 26 types of stimuli, including the no-garnish plate: unchanged plates and main dish (fried chicken). The ingredients were selected based on the results of a 10-participant pilot study with 30 types of garnish. Of these, 25 were chosen from the perspective of color, taste, and nutrition.

- Saltiness/salty – not salty
- Looking/nice-looking – nasty looking
- Fondness/like – dislike
- Deliciousness/tasty – not tasty
- Appetite/want to eat – do not want to eat

Statistical Analysis

Factor Analysis

We analyzed the eleven abovementioned adjective pairs. Factor analysis employed the principal component method and varimax rotation. For multivariate analysis, we used Microsoft Excel (Version 16.44) and SPSS Statistics (Version 26.0.0.1). The data were collected using Google Forms (Google LLC) and organized. The mean values were calculated using Excel.

Multiple Regression Analysis

We applied multiple regression analysis to the values and excluded "looking," "fondness," "deliciousness," and "appetite," which were positioned as higher-order variables, and we conducted multiple regression analysis using the factor scores.

Principal Component Analysis

We also conducted principal component analysis of the covariance matrix without rotation.

Cluster Analysis

To clarify how the types of garnish were classified, we conducted cluster analysis (Ward Linkage) using the principal component scores of principal component 1 (PC1) and principal component 2 (PC2).

RESULTS

Factor Analysis

The factor loadings were 80.7%, and **Table 1** lists each factor's cumulative contribution rates. Factor 1 was the "warm and non-sweet factor." This factor was affected by the warmth and appearance of the dishes. Appetite and favorability were associated with warmth and good appearance. Factor 2 was the "fresh and refreshing factor," where wetness, freshness, and sourness simultaneously occurred. These factors affect appetite. Factor 3 was the "saltiness factor." In the preliminary questionnaires of this experiment, lemon was the first that came to mind when asked about fried chickens' garnish (**Supplementary Table 1**). Additionally, we calculated means (standard deviations) and ranking for "appetite" (**Supplementary Table 1**). Based on factor analysis and the results in **Table 1**, boiled eggs, bread, cookies, and mixed nuts, which contain little moisture, are less likely to stimulate appetite that foods that are relatively wet. Thus, choosing a moist garnish might stimulate appetite. The factor scores were standardized such that the mean was 0 and the standard deviation was 1 for each factor (**Table 1**).

TABLE 1 | The results of factor analysis show the elements that change the impressions of the main dishes from the viewpoint of temperature, taste, and freshness.

Evaluation item	Factor 1	Factor 2	Factor 3
Appetite	0.939	0.232	0.014
Deliciousness	0.933	0.244	0.04
Fondness	0.890	0.284	0.012
Looking	0.886	0.372	−0.234
Warmth	0.845	0.015	−0.002
Sweetness	−0.626	−0.031	−0.002
Wetness	0.260	0.953	−0.076
Drying	−0.339	−0.891	−0.045
Freshness	0.554	0.715	−0.356
Sourness	−0.085	0.699	0.267
Saltiness	0.024	0.071	0.797
Contribution ratio (%)	4.933	3.041	0.898
Cumulative contribution ratio (%)	44.849	72.495	80.654

The factor loading was 80.7%. Factor 1 was affected by the warmth and appearance of dishes. In Factor 2, wetness, freshness, and sourness co-occurred. We named Factor 1 the "warm and non-sweet factor." Factor 2 was the "fresh and refreshing factor," and Factor 3 was the "saltiness factor."

Multiple Regression Analysis

To investigate the factors that stimulated appetite, we performed multiple regression analysis using the factor scores, which excluded "looking," "fondness," "deliciousness," and "appetite," (**Supplementary Table 2**), as they were positioned as higher-order variables (**Table 2**). Since this research is an exploratory study, we positioned "looking," "fondness," "deliciousness," and "appetite" as higher-order variables compared to "freshness," "drying," "wetness," "warmth," "sourness," "sweetness," and "saltiness," which are related to impressions received from taste, temperature, and appearance. We decided to perform multiple regression analysis by first separating the variables related to the sensation itself (sour, dry, wet, etc.) and the overall evaluation variables (stimulation of appetite as a result, etc.). Each of variance inflation factor (VIF) obtained in the analysis was less than 10 (**Table 3**). This result is shown in the path diagram in **Figure 2**. According to these analyses, Factor 1 and 2 scores had a statistically significant effect on appetite. Moreover, Factor 2 had a greater influence on appetite than Factor 1 based on the high correlation coefficient scores. Thus, the effects of temperature and taste on the balance of flavors were significantly related to appetite.

Principal Component Analysis

Principal component analysis was conducted on all 11 variables divided into two groups: physical and sensitivity factors. The principal component loadings were analyzed by the principal components within the variance-covariance matrix.

TABLE 2 | We performed factor analysis excluding "looking," "fondness," "deliciousness," and "appetite" for multiple regression.

Evaluation item	Factor 1	Factor 2	Factor 3
Wetness	0.976	0.190	−0.044
Drying	−0.914	−0.237	0.061
Freshness	0.770	0.492	−0.314
Sourness	0.686	0.180	0.265
Warmth	0.098	0.841	−0.001
Sweetness	−0.088	−0.616	−0.024
Saltiness	0.051	0.038	0.874
Contribution ratio (%)	2.874	1.455	0.939
Cumulative contribution ratio (%)	41.053	61.844	75.266

TABLE 3 | Multiple regression analysis shows that Factor 1 and 2 scores had a statistically significant effect on appetite.

	Standardized coefficient	*t*	Sig.	VIF
Appetite (constant)		55.561	< 0.001	
Factor Score 1	0.272	2.512	0.02	1.004
Factor Score 2	0.801	7.382	< 0.001	1.006
Factor Score 3	0.004	0.033	0.974	1.003

Standardized coefficient, t-test value and significance, and collinearity statistics for each factor are listed. In this analysis, All of VIFs < 10 were obtained. The Factor 2 standardized coefficient was 0.80.

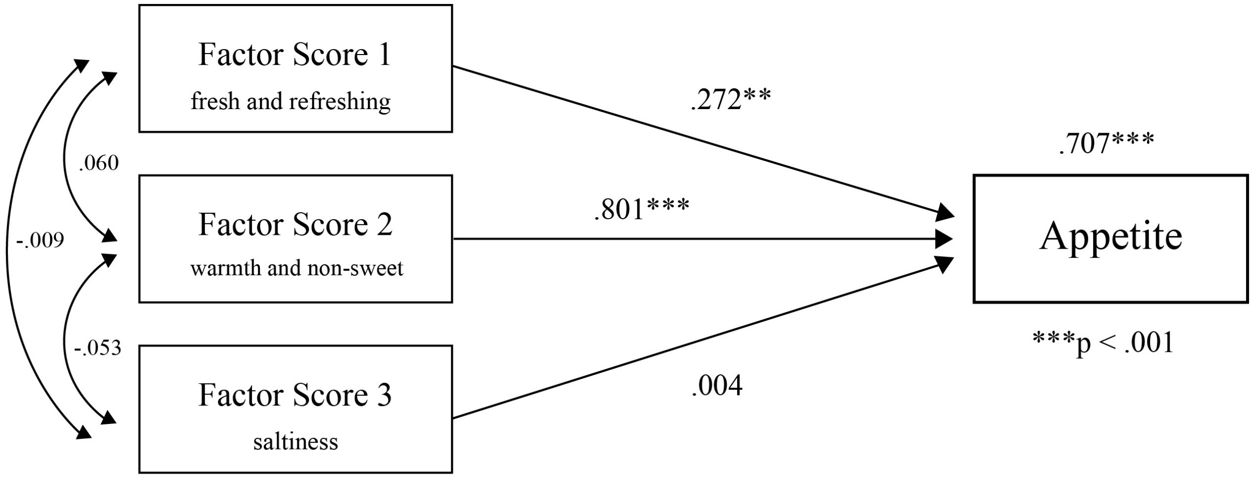

FIGURE 2 | Factor 2 has more influence than Factor 1 on appetite from the high correlation coefficient scores. We named Factor 1 the "fresh and refreshing factor." Factor 2 was the "warm and non-sweet factor," and Factor 3 was the "saltiness factor." ** and *** denotes $P < 0.01$ and $P < 0.001$, respectively.

Physical factors: dryness/wetness/warmth/sourness/sweetness/saltiness

Two main principal components were identified (**Table 4**). PC1 extracted "moisture," "sourness," and "saltiness," while PC2 extracted "sweetness" and "coolness." We named PC1 the "complementary moisturization and refreshment component," and PC2 was the "strong influence of sweet garnish."

Sensitivity factors: freshness/deliciousness/looking/fondness/appetite

Only PC1 was extracted from the sensitivity factors (**Table 5**). PC1 contained "good looking," "appetite," "delicious appearance," "palatability," and "freshness." Therefore, PC1 indicates "freshness from the kitchen."

Physical factors and sensitivity factors: drying/wetness/warmth/sourness/sweetness/saltiness/freshness/deliciousness/looking/fondness/appetite

We conducted principal component analysis of the physical and sensitivity factors (**Table 6**). PC1 extracted "good appearance," "delicious," "fond," "appetite," and "non-sweet," while PC2 extracted "sourness" and "saltiness."

The number of axes of the principal components was determined by referring to the scree plot (the horizontal axis represents the principal components, and the vertical axis represents the eigenvalues) (**Supplementary Figure 1**). The cumulative contribution of PC2 accounted for 82.0% of the total contribution, which exceeded 80%. From this, the number of axes in the principal component was determined to be two. PC1 can be regarded as representing "freshness from the kitchen," while PC2 represents "balance of flavors." Principal component scores were calculated. The data were standardized so that the mean was 0 and the standard deviation was 1 for each factor (**Table 6**).

Among the types of garnish, sudachi (citrus fruit) was found to be the most suitable for balancing the taste of the main dish (fried chicken) and making it look like it was freshly prepared. Lemon was found to be a suitable garnish for the main dish. Furthermore, we created a scatter plot based on the principal component scores and superimposed the images of the main dish and the garnish on the two-dimensional

TABLE 4 | Result of principal component analysis: principal component loadings of six adjective pairs.

Evaluation item	PC1	PC2
Wetness	0.852	−0.166
Drying	−0.782	0.167
Sourness	1.049	0.43
Saltiness	0.080	0.031
Sweetness	−0.167	0.834
Warmth	0.102	−0.410
Contribution ratio (%)	2.481	1.105
Cumulative contribution ratio (%)	55.521	80.248

PC1 extracted "moisture," "sourness," and "non-saltiness," while PC2 extracted "sweetness" and "non-warmth." Results of principal component analysis except fondness/appetite/deliciousness/looking/freshness. We named PC1 the "complementary moisturization and refreshment component," and PC2 the "the strong influence of sweet garnish."

TABLE 5 | Results of principal component analysis except wetness/dryness/sourness/saltiness/sweetness/warmth.

Evaluation item	PC1	PC2
Looking	1.100	0.196
Appetite	0.691	−1.167
Deliciousness	0.834	−0.202
Fondness	0.795	−0.146
Freshness	0.535	0.344
Contribution ratio (%)	3.301	0.247
Cumulative contribution ratio (%)	89.326	96.004

PC1 extracted "good appearance," "appetite arousing," "delicious," "fond," and "fresh." We named PC1 "fresh from the kitchen."

TABLE 6 | Result of principal component analysis: principal component loadings of all eleven adjective pairs.

Evaluation item	PC1	PC2
Looking	1.067	−0.289
Deliciousness	0.779	−0.259
Fondness	0.744	−0.234
Appetite	0.641	−0.220
Freshness	0.579	0.100
Drying	−0.697	−0.408
Wetness	0.713	0.486
Warmth	0.405	−0.269
Sweetness	−0.554	0.401
Sourness	0.451	1.035
Saltiness	0.009	0.084
Contribution ratio (%)	4.714	1.978
Cumulative contribution ratio (%)	57.735	81.959

PC1 extracted "good appearance," "delicious," "fond," "appetite," and "non-sweet," while PC2 extracted "sourness" and "saltiness." PC1 can be regarded as representing "fresh from the kitchen," and PC2 represents "balance of flavors."

plane to visualize the relationship between the main dish and garnish (**Figure 3**).

Cluster Analysis

Figure 4 shows the dendrogram of the cluster analysis (Ward Linkage) using principal component scores of PC1 and PC2. The dendrogram classifies the 26 types of garnishes into three main clusters: "color," "dryness and taste," and "moisture and taste." In addition, coriander/basil/lettuce/parsley fell under the green vegetable cluster that we named the "green cluster", and the bread/cookies/mixed nuts cluster and chocolate/raisins cluster were in the "dry and sweet cluster." The sudachi/lemon cluster was named the "moist and sour cluster." Thus, the three main clusters included the "green cluster;" "sweet, sour, and spice cluster," and "wet and dry cluster."

DISCUSSION

Garnishes Can Work as Appetite Stimulants

Multivariate analysis revealed four elements that changed the participants' impressions of the main dishes. The factor and cluster analyses showed that color, moisture, and taste (sourness and spiciness) play a major role in the impressions of main dishes. Visual attributes, such as the color of the plate, affected the sweetness intensity, perceived flavor, and overall preference of the dish. A study by Piqueras-Fiszman et al., 2013 showed that a strawberry-flavored mousse served on a white plate was perceived as 15% more intense, 10% sweeter, and was 10% more liked when compared to the same dessert served on a black plate. Evidence for physiological changes in the food because of the color, shape, and material of the tableware, such as the plate and cutlery, is also provided by Spence et al. (2012). This study shows that not only

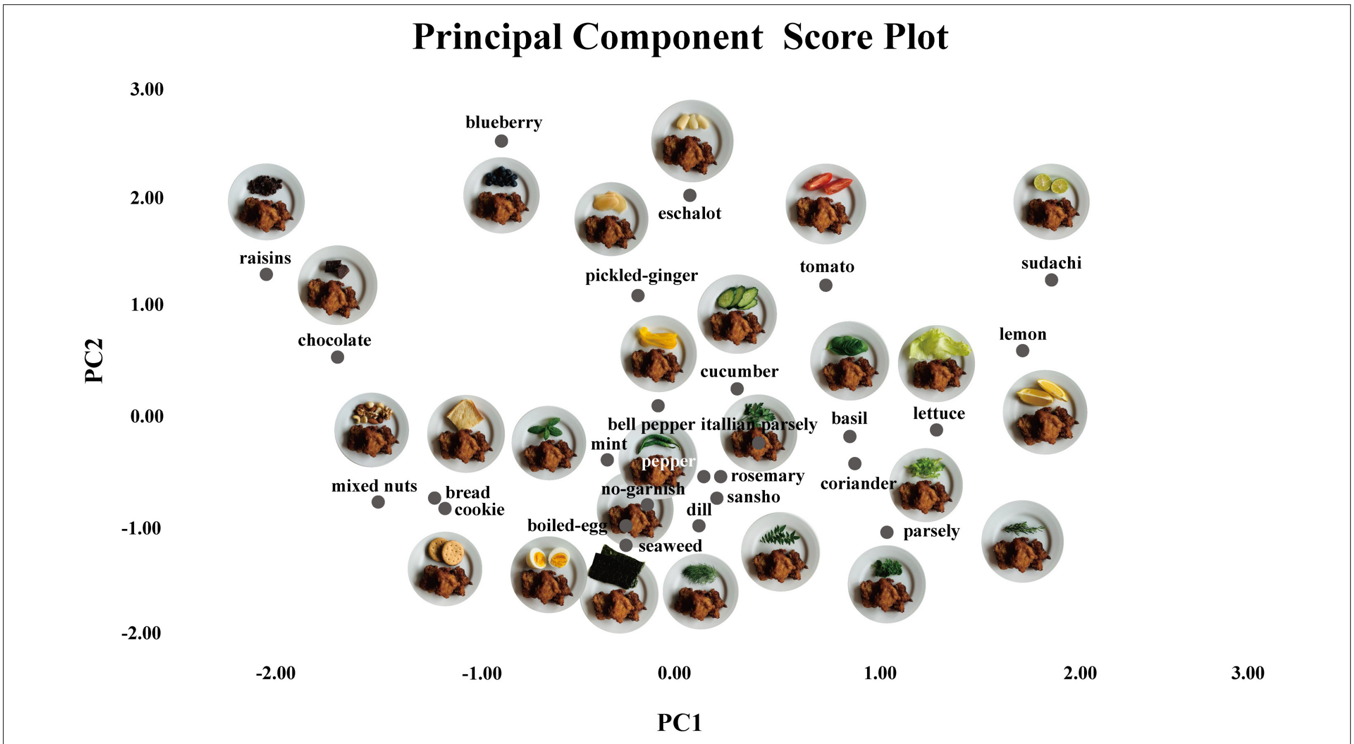

FIGURE 3 | We created a scatter plot based on the principal component scores and superimposed the images of the main dish and the garnish on a two-dimensional plane to visualize the relationship between the main dish and the garnish. Similar-colored garnishes were located close together in this plot. The results of the sensory evaluation showed that sudachi (citrus fruit) was the most suitable garnish to balance the taste of the main dish.

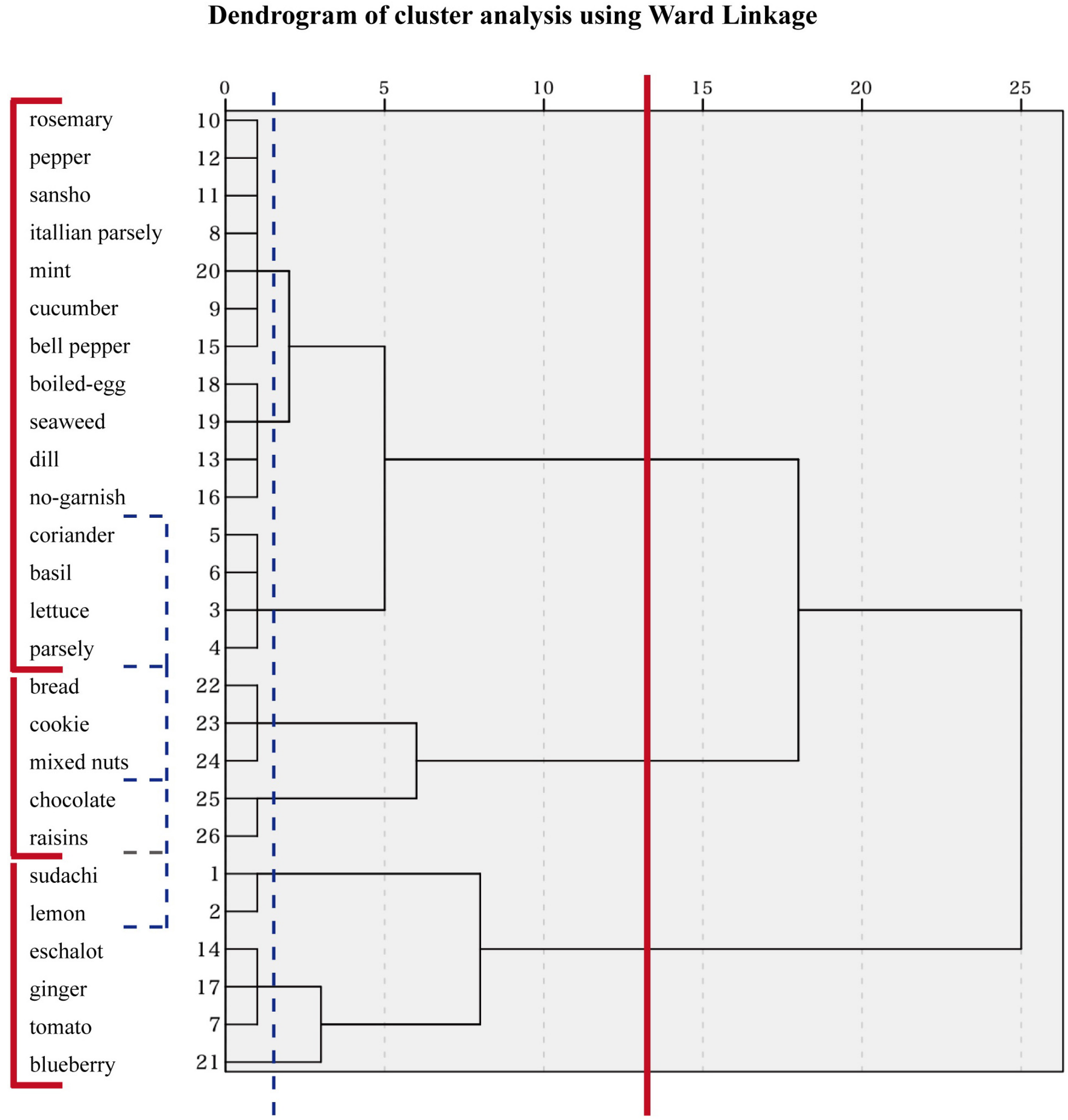

FIGURE 4 | Cluster analysis classified the 26 types of garnish into 3 clusters. The solid line indicates three main clusters, and the dashed line shows more precise clusters in this figure.

the main dish but also the food plating and cutlery can modulate an eating experience. In this research, multiple regression and principal component analyses indicated that to stimulate one's appetite, it is important to make the main dish appear warm. This indicates that even if the main food is not actually warm, garnish gives observers an impression of warmness in the main dish. It is also plausible that the effect of the color of the ingredients may increase the perception of warmth. Additionally, sour and moist garnishes can affect the appetite because they can balance the flavors of the main dish.

The multivariate analysis results can be linked to the development of methods implemented to modulate eating experiences and stimulate appetite. For fried foods (e.g., fried chicken), we found ways in which the appearance of the meal contributes to the stimulation of one's appetite. The current research methodology can be further applied in studies of not only fried food but also boiled, grilled, stir-fried, and steamed food. Methods in which the appearance of a meal contributes to visual appetite stimulants and the design guidelines for meals can contribute to making meals more attractive through the superimposition of information with XR technology, such as AR and VR, or by presenting real objects (**Figure 5**). Previous research reported that the standard deviation of the luminance distribution of food images influences the perceived visual texture and flavor experience by using AR (Ueda et al., 2020). The development of a real-time modification system without an AR marker could be applied to modify garnishes or the color of dishes. We consider that smart glasses can be applicable for AR of food affection. For example, updated versions of Google Glass and Microsoft Hololens were released in 2019.

FIGURE 5 | Four representative elements that change the impressions on the main dishes. The results of multivariate analysis showed that color, taste (sourness and spices), and moisture significantly affected the acceptability of a garnish. Additionally, sour and moist types of garnishes balance the taste of the main dish. To stimulate appetite, it is important to make the main dish appear warm, even if it is not fresh.

Although these AR smart glasses are still exploratory, several studies have used smart glasses (Jiang et al., 2018; Chicchi Giglioli et al., 2019; Ueda et al., 2020). For food applications, Ueda et al. (2020) used the method with headgear without AR markers. Jiang et al. (2018) also reported a real-time system for estimating the nutrition of foods using Google glass. Our results contribute to superimposing images of food in restaurants with AR technology presentation, similar to wearing glasses. Especially under the spread of COVID-19, at-home eating has been increasing, so we expect that the mental burden of wearing AR/MR glasses or smart glasses while eating will decrease. Moreover, some people are willing to adapt to information technology while dining alone.

Visual appeal and presentation of a dish can modulate the appetite of those eating it. Several studies have pointed out the importance of the visual presentation of food (i.e., food plating) in the perception of appetite (Michel et al., 2014). The current study supports the claims from previous research and the importance of a garnish. Our exploratory factor analysis showed the hypothetical model that describes the structural relationship between the induced cross-modal perception from visual presentations of food and appetite. Using structural equation modeling (SEM), we plan to conduct another study to test this hypothesis and quantify the overall structures. Additionally, to generalize our claim, further research should include the analysis of individual differences between participants.

Food choice is not solely determined by visual appearance, but when purchasing lunchboxes or prepared foods at supermarkets or delicatessens or by looking at photographs of dishes on the menu or online delivery, consumer mainly choose foods based on food visual appearance. In these situations, we are likely to make judgments based on past experiences and food appearance. Thus, the results of this study will contribute to such situations.

Limitation and Future Research

Food is closely tied to our past experiences. For example, people who have eaten lemons may taste a sour flavor in their mouths when they see them, but people who have never eaten lemons are unlikely to taste any sourness when they see them. This study takes into account the fact that there is a possibility that people know the taste of each garnish, and the study is based on that assumption. Thus, we interpreted the results as those of having the participants respond to their visual impressions when the participants were presented with the images. However, we did not test the case where the participants observed the garnish for the first time. If unknown material was placed next to the main dish, the participants' response could be different from that of the current study.

Food garnishes play an important role both explicitly and implicitly. Freshness can be inferred from image statistics of the food (Wada et al., 2010; Arce-Lopera et al., 2012, 2015), and the magnitude of subjective freshness correlates with the parameters of the image statistics (mean, standard deviation, skewness, and kurtosis). In this study, our analysis suggested that the subjective ratings of freshness can influence the appetite of the person for the main food of the dish (**Figure 2**). If the perception of the garnish placed next to the main food could also affect appetite, we would be able to modulate appetite by changing the visual impressions evoked by the garnish. For example, following our results, we could be garnishing fried chicken (Karaage) with sudachi to stimulate appetite, and garnishing the meal with raisins will decrease appetite. Just as the color of the tableware can change one's appetite (Dunne et al., 2004), garnishes in the surrounding environment can play a role in getting a person with a small appetite or an eating disorder to eat.

Augmented reality visualization of a served food improves the simulation of the eating process over 3D visualization, which has a positive influence on consumer intention to purchase products (Petit et al., 2021). In the same way, our first impression is visual when buying products or in our desire to eat. Our study possibly contributes to optimizing served foods presented in AR to stimulate consumer appetites.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the SFC Research Ethics Committee on Human Experimentation of Keio University, Shonan Fujisawa Campus (approval # 302). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

NK conducted the experiments, data analysis, and manuscript writing. MN supervised the research project. Both authors conceived and wrote the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.699218/full#supplementary-material

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A Reflection on the State of Multisensory Human–Food Interaction Research

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We present a perspective article on the state of multisensory human–food interaction (MHFI) research and lay out some reflections for research and development in this area of inquiry, based on a revision of the different spaces that we have co-created with researchers in this space. We begin by conceptualizing and defining MHFI, before moving onto presenting some of its major themes, as well as possible ways in which such themes can guide future research in the area. This article provides key definitions and foundations for the area of MHFI, as well as a first point of contact for those interested in it.

Keywords: multisensory, human–food interaction, technology, senses, foundations

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INTRODUCTION

The emerging field of Human–Food Interaction (HFI) is thought to be an area of Human–Computer Interaction (HCI) research that addresses our interactions with food (Comber et al., 2014). HFI specifically focuses on the role of technology in supporting and enriching food practices throughout the food chain, that is, from growing, through experiencing, to disposing (Khot and Mueller, 2019).

A Google Scholar search of "Human–Food Interaction" up to 2010 results in 18 research articles; however, the same search between 2010 and 2020 results in 508 (up to September 22, 2021). This, of course, is not an exhaustive index of the size of the field (perhaps some works might not talk directly about HFI, yet still be part of the field), considering that before researchers started to use the term HFI, research was already being conducted within HCI on human–food interaction (Grimes and Harper, 2008). Yet, this is initial evidence that HFI has grown significantly over the last decade. HFI has given rise to three communities of researchers, namely, Food CHI focusing on food and interaction design; another group of researchers focusing on artificial intelligence (AI) approaches to HFI; and Multisensory Human–Food Interaction (MHFI), which highlights the multisensory aspects of HFI (see Bertran et al., 2019, for an exhaustive survey of the field of HFI).

In the present article, we present our perspective on MHFI based on the work of multiple workshops and a special issue that we have co-created. While this area of research is still in its infancy, we have seen an increasing interest in fields as diverse as HCI, psychology, sensory science, and marketing, as well as an emerging effort to study the intersection between the senses, food, and technology (e.g., Velasco et al., 2018; Crofton et al., 2019; Petit et al., 2019). Last year, the specialized ACM International Conference on Multimodal Interaction (ICMI) workshop on MHFI was conducted for the fourth time (Velasco et al., 2020), yielding a total of 32 research articles across the four workshops. In addition, one special issue has been presented (with another one currently in course), together with the journals *Frontiers in Psychology*, *Computer Science*, and *Nutrition*, resulting in a total of nine articles. Importantly, contributions to MHFI have not been limited to this workshops and special issues.

There have been other initiatives in which research and ideas on the senses, food, and technology have been presented and discussed, such as three Data Engineering meets Intelligent Food and Cooking Recipe (DECOR, http://research.nii.ac.jp/decor/decor2020.html) workshops (2018–2020), EAT—The ICMI 2018 Eating Analysis and Tracking Challenge (https://icmi.acm.org/2018/index.php?id=challenges#eat), ACM Conference on Human Factors in Computing Systems (CHI) Play 2019 Session on Gustatory and Other Sensations, CHI Play 2019 Workshop: Chasing Play Potentials in Food Culture to Inspire Technology Design, the 1st (https://sites.google.com/dis.uniroma1.it/avi2018/co-located-events/satellite-events/the-future-of-computing-food) and 2nd (https://sites.google.com/view/fcfws2/) workshops on the Future of Computing and Food, Internet of Food (https://ieee-iotj.org/special-issues/), IoT4Food (https://www.iof2020.eu/latest/events/2020/03/iot4food), and the Play Food Children workshop at Interaction Design and Children 2020 (https://playandculture.food.blog/). In addition, this year, there was a CHI workshop entitled "The Future of Human–Food Interaction" (https://www.humanfoodinteraction.org/), which also has a dedicated special issue in the International Journal of Gastronomy and Food Science.

For all the aforesaid reasons, we thought it was time to present an article to reflect on the state of the MHFI research area from our perspective, and to contribute to the discussion on current advances and future directions, by considering where it comes from and where it is heading to. To this end, this perspective article focuses on the following aims: (1) define MHFI and present its current state, (2) reflect on the opportunities and challenges to develop this interdisciplinary area of inquiry, (3) reflect on the way forward to maximize the transfer of MHFI research into practice, and (4) present some general conclusions and takeaways. In addressing these aims, we hope to provide a starting point for reflection and discussion on the future developments of the MHFI area for those interested in this emerging topic.

THE STATE OF MHFI RESEARCH

Defining MHFI

As suggested by Velasco and colleagues (2018), the growing interest in HFI to capitalize on multisensory processes to create, modify, and enhance our food-related experiences may be explained, at least in part, by two observations. First, eating and drinking are among the most multisensory events in our everyday lives. Indeed, we interface with food through most, if not all our senses (Prescott, 2015; Spence, 2017). Second, technology is ubiquitous and there are growing efforts toward developing multisensory technologies, that is, technologies that are designed to stimulate the human senses beyond audition and vision allow researchers and practitioners to precisely control sensory quality, quantity, and delivery (e.g., haptic stimulation in mid-air, digitally-controlled smell delivery, electric taste devices; Cornelio et al., 2021; Covaci et al., 2018; Obrist et al., 2017; Velasco and Obrist, 2020). This context paved the way for MHFI as an area of inquiry. As such, it was conceived to focus mainly on the understanding of the multisensory process associated with our interaction with food (mostly eating) and on capitalizing on them when designing novel technologies and food interaction systems (Nijholt et al., 2016).

It is clear, however, that the initial scope of MHFI need to be broadened as the area progressed. First, our interactions with food are not limited to eating. Indeed, research from different fields have characterized the food interaction journey as consisting of different stages such as growing/purchasing, cooking, eating, and disposing (Choi et al., 2014; Schifferstein, 2016). Secondly, the world is currently facing multiple challenges concerning food including, but not limited to, unsustainable food practices, food and climate change, food waste, obesity, (mal) nutrition, and hunger (FAO, 2018). With this in mind, MHFI can contribute beyond eating (e.g., nudging, expectations development, and disposing), to tackle other interaction stages (pre-eating and post-eating), as well as important food-related challenges that humanity faces (e.g., associated with health and sustainability). In fact, MHFI can connect research on the senses, food, and multisensory technologies to design any kind of food interaction and experience.

So how should we define MHFI? We follow the definition of Choi et al. (2014) of HFI as the interrelationship between self and food, though we include others (a social element) as part of our definition, considering that HFI can also involve food interactions between selves, mediated by technology (e.g., commensality, see Spence et al., 2019). Therefore, we define MHFI as a research area that studies the role of the senses in the interrelationship between self, others, and food, and that capitalizes on such understanding to modify existing and/or create new self–others–food interrelationships through technology. Note that the fact that food experiences are multisensory in nature makes HFI multisensory per se; however, the term MHFI involves the word "multisensory" as it places the senses at the center of, and emphasizes their role in HFI research and practice. While MHIF is a multidisciplinary area of study as defined above, it is worth mentioning that there is extensive research on multisensory perception and its relationship to food in fields such as psychology and sensory science (e.g., Prescott, 2015; Spence, 2017) and thus MHFI can build on such research to modify existing and/or create new self–others–food interrelationships through technology.

Here, it is important to mention that, in HCI, interaction is defined as any communication between a user and a computer, be it direct or indirect (Hornbæk and Oulasvirta, 2017). As such, MHFI also involves communication as part of it. Importantly, however, MHFI can also be about designing interactive interfaces between humans and digital technology and about designing interactive experiences (Spence et al., 2019). It is perhaps useful to think about MHFI as multisensory experiences in HFI. In other words, "In the context of HFI, multisensory experiences refer to impressions formed by specific food-related events, whose sensory elements (e.g., intrinsic and extrinsic to the food, see, for example, Wang et al., 2019) have been carefully crafted by someone for a given receiver (e.g., diners). For instance, to create the impression of a taste, say "sweet", colors, textures, and specific smells can be considered in a specific event." (Velasco and Obrist, 2021, p. 3). Given that experiences are only one part of MHFI, this definition may be broadened as follows: MHFI refers to self–food interrelationships formed by specific food-related events, whose sensory elements have been carefully designed by somebody for a given receiver or group of receivers.

Major Themes in MHFI

To formulate our perspective on the current state of MHFI research, we revisited the various contributions to our four ICMI workshops on MHFI, as well as one research topic in *Frontiers* ($n = 41$). We identified key themes, associated with the research and development process of the area, that emerged from the articles (see **Supplementary Appendix SA1**, for the titles of the articles and themes identified). Although the number of articles is relatively small, it is representative if one considers that MHFI focuses only on a subset of research of HFI (see *Introduction*). Importantly, because this article is intended to reflect upon our perspective in MHFI, the sample of articles serves that purpose.

After reviewing these articles, we identified, through a series of iterations, five major themes. Below, we present a summary of such themes and the proportions of articles in each theme (see also **Supplementary Appendix SA1**).

1) Data collection and analyses: Articles in which a system for data collection and/or analyses are presented. Number of articles = 5 (12.3%).
2) Psychological mechanisms: Articles presenting studies designed to better understand psychological mechanisms associated with MHFI (e.g., crossmodal effects on flavor perception, such as the influence of, say, auditory stimuli on perceived taste intensity). Number of articles = 13 (31.7%).
3) Design studies: Articles studying design approaches and frameworks. Number of articles = 5 (12.2%).
4) Augmentation and interfaces: Articles focused on food augmentation processes and interfaces. Number of articles = 7 (17.1%).
5) Applications—Commensality, education, entertainment, and/or health: Articles studying interactions specifically targeting one of these areas. Number of articles = 11 (26.8%).

The majority of articles (about a third) have focused on psychological mechanisms, followed by specific applications in commensality, education, entertainment, and/or health, followed by augmentation and interfaces, design studies, and data collection and analyses. Here, it is worth mentioning that research and development in MHFI can capitalize on existing research from other fields (e.g., research on the neuroscience of flavor perception to develop new systems; Prescott, 2015).

Foundations of MHFI: Connecting Fields, Research, and Practice

Following our analyses of the articles and the key themes that we identified, we see that there is possibility for guiding research in MHFI in such a way that it starts from an understanding of MHFI psychological processes, which result in applications (**Figure 1**).

In **Figure 1**, we present the themes associated with progress in MHFI. The first and second themes consist of elucidating psychological mechanisms and data collection and analytical methods, both of which support the human understanding foundations of MHFI. The third theme consists of design studies to develop frameworks and the fourth theme on the development of specific interfaces and augmentation technologies, both of which support the user interaction foundations. These technological interfaces can then be used to target specific applications in various areas such as commensality, education, entertainment, and/or health, which constitutes the fifth theme. Note that it is possible that specific interfaces are already designed with applications in mind, though.

It is perhaps worth illustrating with a now classic example of MHFI, namely, the Chewing Jockey, which is a system that monitors mastication and synchronizes sound-delivery to it (Koizumi et al., 2011). This technology capitalized (1. Psychological mechanisms) on previous studies developed to understand and document the role of auditory cues on modulating texture and taste perception (Zampini and Spence, 2004). Said studies have suggested, for instance, that the crispiness of potato chips can be enhanced by chewing sounds or white noise with a high-pass filter (see also Spence, 2015, for a review). Based on this idea and aiming to redesign the eating experience (3. Design studies and frameworks), Koizumi et al. (2011) developed the chewing jockey technology (4. Interfaces and augmentation). Once this interface was designed, the authors moved on to specific applications (5. Applications). Here, the authors suggested at least two applications. The first consisted of using the system to enhance texture perception for the elderly (health), and the second, to design novel fun interactions (entertainment), such as mapping the sounds of screaming sounds to gummy bear chewing. While this study did not fully capitalize on available design frameworks for sound augmentation (3), it follows general experience design guidelines. In addition, while data collection (2) was not a part of it, given that the system uses a chewing tracking system, it is possible to collect data, as well (see also Lin et al., 2020, FoodFab and Narumi et al., 2011 Metacookie, for other examples).

All in all, the possible themes associated with research and development in MHFI allow researchers and practitioners to think of how to connect everything from basic research on multisensory influences on self–others–food interrelationships all the way to possible applications. It is important to mention here that one of the key characteristics of this area of research and practice is its interdisciplinary nature, involving fields such as, though not limited to, psychology and neuroscience, sensory science, HCI, and marketing. This interdisciplinary work can guarantee the strong conceptual and practical foundations of every step of the research and development process (**Figure 1**).

RESEARCH DIRECTIONS AND CONCLUSIONS

MHFI is a nascent area of research and, as such, there are multiple unanswered questions and directions for research that need to be addressed. For example:

FIGURE 1 | Possible themes associated with research and development in MHFI.

- What human problems can MHFI design help with? (e.g., help children to enjoy and engage with food in new interactive ways, help enhance flavor experiences for the elderly often suffering of reduced sensory abilities, augment food experiences in outer space where food could be perceived as bland).
- How do we move from lab-based research explorations to real-world deployments of MHFI applications/technologies to improve people's lives?
- What are some key ethical reflections and responsibilities around MHFI design?

Considering those questions, we reflect below upon some key areas for future research and development in the area of MHFI, especially based on the discussions in our workshops and special issues. We also reflect on how to approach MHFI research and put it into practice.

Areas of Future Development

Direct Interaction With Food: Designing Experiences That Enhance the Eating Experience

Designing technology around the ingestion process, we can use the senses to highlight flavor as well as influence appetite. For instance, for the elderly (Doets and Kremer, 2016), work in MHFI may contribute to making up for losses in smell and taste perception as well as promote desire to eat. MHFI could also solve challenges around eating in extreme situations (e.g., space exploration) where technology and psychological understanding are needed to create new ways of eating (Obrist et al., 2019). Referring to our framework (**Figure 1**), this area relies on making use of existing knowledge in psychological mechanisms to develop design frameworks, interfaces, and applications to support people's eating experiences.

Social Aspect: Designing Interaction With Others Around Food

Food is a means for socialization and sharing (Niewiadomski et al., 2019). The social aspects around food can include food growing, producing, purchasing, preparation, eating, sharing, and disposing (Velasco and Obrist, 2021). Remote commensality is a special area of interest (e.g., Ceccaldi et al., 2020), which can be enhanced by considering the multisensory processes associated with social dining (Spence et al., 2019).

Change Attitude Towards Food: Designing Food Interaction to Nudge People

Beyond direct ingestion, how can we use the senses to change people's mindset about specific foods (de Vries et al., 2020; Zhao et al., 2016)? This could be influencing their food-based decision-making—including attitude towards certain foods, purchase intentions, and disposal habits (Cadario and Chandon, 2020; Hollands et al., 2017). For example, the integration of augmented reality and other visually enabling technologies in the process of food purchases can influence the way in which people develop purchase intentions (Petit et al., 2021; Velasco et al., 2018; Toet et al., 2017). MHFI has already seen several theoretical developments, but what is missing is the integrated use of novel technologies and data collection mechanisms that can measure large quantities of real-world data.

Digital Augmentation: Technology Enabled Food Interaction Experiences

An increasing number of digital technologies are being developed to stimulate our chemical senses and thus create new MHFIs and/or to study multisensory processes (Cornelio et al., 2021). Indeed, there is increasing interest in the way in which technologies can be used to create and/or augment eating and drinking experiences digitally (Spence et al., 2017; Vi et al., 2017). Note, however, that augmentation is not limited to the chemical senses. Indeed, a wide range of research directions and applications (e.g., context enhancement, food structure and texture, and sensory augmentation) have been forwarded for augmented reality in food interactions (see Narumi, 2016; Crofton et al., 2019). With respect to the pipeline framework, this is an exciting area with many new interface developments. However, what is less clear are how such interactions can spread outside the lab and be deployed in the real world.

Ethical Considerations: Responsible Innovation Around Food Interaction

Recently, Velasco and Obrist (2021) indicated that, as there is scope for development in MHFI, there are also key responsibilities, and thus, we need to consider the ethical implications of this area of research. This is particularly important when moving from lab-based explorations into real-world deployments. What are key ethical reflections in MHFI? Consider the abilities of digital technologies like food 3D printers and virtual and augmented (VR/AR) reality. Those technologies enable us to create/design realities that are not matching the physical world. For example, we can now change the appearance of food to make it look more appetizing, or we can change the infill structure of 3D printed food to affect people's feeling of satiety (as in FoodFab by Lin et al., 2020). We can create food perception illusions that can deceive people, but in this case benefit the person (eating less, which in light of a global challenge of obesity can be considered a desirable intervention). However, who decides about the beneficiaries and when it is ok to create such experiences? While this will require ongoing discussion on the topic, it is key to treat receivers of MHFIs fairly by considering their differences and similarities, avoiding biases, and ensuring accessibility of technology (see also Choi et al., 2014). This is an overarching concern that touches upon all elements of the pipeline framework.

Open a Dialogue on How to Approach MHFI in Research and Practice

While the themes identified in **Figure 1** are all important, the question remains how research should be conducted going forward. Should researchers target one specific step, or should all five be considered in order for a study to be considered MHFI? Moreover, how should researchers from different disciplines approach a potential MHFI research topic? Should it grow organically from the ground up, where people should focus on first developing psychological mechanisms? Or should researchers identify problem areas that are needed, then look up research on psychological/neurological mechanisms upon which to develop the technological application? Developments from the four MHFI workshops have shown that in 2016, the focus was on augmentation and interfaces, but with time, the focus has shifted towards the two ends of the research pipeline: Either towards psychological mechanisms or final applications (**Supplementary Appendix SA1**).

The list of questions raised is evidence of the idea that we are only at the beginning of understanding and exploring the areas and themes around MHFI, and while we wish to provide answers, it is more our intention to open up a dialogue with the community, and as part of that, in effect, continue our past efforts (workshops, special issues), with this perspective article.

MHFI applications are often developed in the laboratory. Brands have recently focused on AR mobile applications to highlight the sensory aspects of their products (Jacobsen et al., 2021). How can the area move research and development from just workshop demos to wider adoptability? Should we engage companies as collaborators, or encourage entrepreneurship among MHFI researchers? Should people work with relevant stakeholders (e.g., hospitals and schools) with an interest in putting research into practice? These questions deserve discussion. Notably, our position is that, in order to make MHFI research relevant in both basic and applied research, in theory development and practical implications, having relevant stakeholders involved will be critical, from consumers, through researchers, to firms and/or other applied contexts. What is more, as the area develops, it will be important to develop both qualitative reviews and meta-analyses that help shape the foundations of MHFI beyond our perspective.

CONCLUSION

We presented here our perspective on the state of MHFI research. We started by placing it in the broader context of HCI and more particularly HFI, and then defining it. Building on the four ICMI workshops on MHFI, as well as one research topic in *Frontiers*, we identified five key themes of research in this area, namely, (1) data collection and analyses, (2) psychological mechanisms, (3) design studies, (4) augmentation and interfaces, and (5) applications—commensality, education, entertainment, and/or health. These themes can constitute a compass for the interdisciplinary development of this area, from basic research to practice.

In addition to these themes, we described some key areas of research we believe will be crucial in the development of MHFI, which include: (1) designing experiences that enhance the eating experience, (2) interaction with others around food, (3) changing mindsets and attitudes, (4) interfaces and technologies, and (5) ethics.

We believe that research in MFHI should be approached in a way that connects basic and applied research, and which results, in the end, in applications, potentially co-developed with stakeholders in the applied world.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All the authors listed made a substantial, direct, and intellectual contribution to the work and approved it for publication.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomp.2021.694691/full#supplementary-material

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