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2 RUNNING HEAD: ANIMATION IN FOOD PHOTOGRAPHY

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4 **‘Hot stuff’: Making Food More Desirable**

5 **with Animated Temperature Cues**

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ABSTRACT

20 Nothing beats a comforting image of a bowl of hot soup with curls of rising steam unless it is
21 the actual soup, but the current paper is to talk about food photography. Despite the
22 recognition of the importance of food temperature depicted in food images, the effectiveness
23 of using visual cues on food photography to indicate temperature and potential managerial
24 outcomes are barely researched. This study explored whether the addition of visual
25 temperature cues to food images was effective in activating relevant temperature associations,
26 leading to downstream consequences, including food desirability, freshness perception and
27 willingness to pay (WTP), with a focus on thermal temperature cues. Three online
28 experimental studies were conducted showing that animated traces of steam added to food
29 images not only induced hot temperature perception of the food, but also increased food
30 desirability and freshness perception. Meanwhile, implied animation (i.e., static picture of
31 rising steam) did not produce any such effect. Further, food image appeal was found to be a
32 boundary condition for the effect of hot temperature cues: that is, when the food images is of
33 low appeal, traces of steam which increased hot temperature perception, in turn enhanced
34 freshness perception and food desirability, but not WTP. The effectiveness of animated steam
35 textures crossmodally enhancing thermal temperature perception and food desirability exerts
36 the potential in digital food creation and marketing.

37 KEYWORDS: FOOD APPEAL; SENSORY NUDGING; DIGITAL MARKETING;
38 TEMPERATURE; VISUAL TEXTURE.

39 1. Introduction

40 Temperature holds a significant role in shaping consumers' product evaluations and decision-
41 making processes (Hadi & Block, 2019; Park & Hadi, 2020; Spence, 2020a, 2020b; Zwebner,
42 Lee, & Goldenberg, 2014), particularly in the context of food appreciation and consumption
43 behaviours. In fact, previous research has identified myriad ways in which temperature, be it
44 ambient or product-related, can influence people's expectations and perceptions of food and
45 beverages. For example, studies have demonstrated that the physical temperature of food and
46 drink can profoundly impact their acceptability and people's preferences (see Abraham &
47 Diller, 2019; Brown & Diller, 2008, for reviews). Additionally, temperature has been shown
48 to affect perceived flavour intensity (Steen et al., 2017) and even aftertaste experiences
49 associated with consuming foods (Francis et al., 2005). More than people have realized,
50 temperature of food plays a crucial role in influencing food tastiness, with previous studies
51 showing that perceived food temperature has a significant positive effect on stimulating
52 appetite (Kokaji & Nakatani, 2021; Sakay, Masuko, & Yamanaka, 2022; Yamin, Mai, &
53 Werle, 2020) and positive evaluations of food (Magee, 2012; Pramudya & Seo, 2018).

54 Warm food temperatures improve the perception of a food's tastiness (Talavera et al.
55 2005; Yamin et al., 2020). For example, warm drinks can activate the insula taste cortex
56 (recognized by glucose taste stimuli) and improve pleasure (Rolls, 2010). Warm foods, made
57 mostly from cooking, increase the availability of glutamate, which is a major component of
58 taste preference (Sasaki, Motoyama & Mitsumoto, 2007). The pleasure of warm food
59 introduced into the mouth is also reflected in activations in the orbitofrontal cortex and
60 pregenual cingulate cortex, which represent the pleasantness of the taste and flavour of food
61 (Guest et al., 2007). Product temperature can be translated into perceived monetary value.
62 Known as the temperature-premium effect (Zwebner et al., 2014), for food products that are
63 typically served warm, high temperature expectations increase people's willingness to pay
64 (WTP) and desired serving amounts. The temperature-induced food consumption preference
65 stems from the spontaneous inference that warm foods are more filling and tastier than their
66 cold counterparts, thereby enhancing food desirability and people's preferences (Yamin et al.,
67 2020) and even their valuation of the food product (Zwebner et al., 2014).

68 Temperature, beyond engaging the somatosensory system, establishes intricate
69 crossmodal connections with visual information (McGlone & Spence, 2010; Spence, 2020a).

70 Colour has been extensively studied as a visual cue for temperature. Ho et al. (2014) and
71 others have systematically demonstrated the robust association between colours and
72 temperature, highlighting the warmth conveyed by red hues and the coldness implied by blue
73 (e.g., Arnheim, 1954; Fenko, Schifferstein, & Hekkert, 2010; Huang, Yang, & Liu, 2022; see
74 Spence, 2020b, for a review). Extending beyond colour, crossmodal mappings have been
75 delineated between visual textures and temperatures. Specific textures, such as crystalline and
76 flecked, exhibit a pronounced association with lower temperatures, while textures
77 characterized as striped and cracked are distinctly linked to higher temperatures (Barbosa
78 Escobar et al., 2023a, 2023b). When it comes to textures that indicate temperature, bubbles
79 and steam might come to mind. Researchers have experimented with adding bubbles and
80 traces of steam to food to enhance the sense of temperature (Suzuki et al., 2021; Yamin et al.,
81 2020). Steam is undoubtedly special as a visual indicator of high temperature, as it can
82 indicate high temperatures in almost all cases (see **Figure 1** for how ChatGPT used steam as
83 a visual cue for making food appear warm). For example, steam rising from the surface of
84 water is a sign of high temperature, and steam is also indicative of combustion. When it
85 comes to food specifically, it's not hard to imagine that freshly prepared food is always
86 accompanied by rising steam when it's served, and the craving for warm food can be fuelled
87 by the sight of a bowl of steaming soup, for example. In contrast, other cues such as bubbles
88 may arise from the movement of water, and fur-like textures are restricted to materials. The
89 current study will explore the role of steam textures on food, an important yet under-explored
90 visual temperature cue.



91 Advances in photo editing apps and social media platforms have introduced graphical
92 filters to enhance the visual aesthetics and warmth of food images (Bakhshi, Shamma,
93 Kennedy, & Gilbert, 2015). Notably, graphic editing techniques have evolved to dynamically
94 render food images online. One such technique, known as the 'steam effect', involves the
95 strategic use of strobes or flashes with high shutter speeds to add distinct textures of the
96 steam to food images. This effect aims to convey a sense of heat and freshness to viewers.
97 Previous studies have considered food freshness as a concept frequently used to describe
98 fruits and vegetables, for which time from harvest was one of the most important contributors
99 to the perception of freshness (Cardello & Schutz, 2003). In the current paper, we used
100 freshness to describe processed food, with the idea that the amount of time from ready-to-eat
101 state is what consumers perceived as the freshness of processed food. We expected that steam

102 textures on dishes would be considered as a cue that the dish is immediately cooked and
 103 therefore deliver the perception that the food is fresh.

104 **Figure 1**

105 *Digital retouch of food image with ChatGPT DALL-E.*

106

<p>T You give me a picture of curry</p>	<p>T You can you make the curry appear hot</p>
<p>G ChatGPT</p> 	<p>G ChatGPT</p>  <p>Here's the updated image of the curry, now appearing hot with visible steam.</p>

107 **Note.** Instructions were sent to ChatGPT in the chat box to provide a picture of the curry and
 108 to make the curry appear hot. Steam was automatically added by DALL-E as a visible
 109 temperature indication.

110 The current study highlights the increasing significance of image processing
 111 technology in the context of food photography on social media and the growing food e-
 112 commerce industry (Donthu & Gustafsson, 2020). Given the prevalent digital nature of the
 113 first encounter with food, visual imagery plays a pivotal role in mental simulation, activating
 114 sensory perceptions and potentially influencing consumer purchase intentions (Petit,
 115 Javornik, & Velasco, 2022; Spence et al., 2016; Velasco et al., 2023). While steam textural
 116 cues are obvious in delivering the meaning of food being hot and fresh, these cues were not
 117 easy to maintain or convey digitally (specifically in an animated format) in the past but can
 118 now be easily added to food images through available image processing techniques. The
 119 central argument of the current research is that digitally animated steam textures can evoke
 120 the concept of food warmth, a connection formed through prior food experiences (Fenko et
 121 al., 2010; Ketron & Spears, 2020; Spence, 2020a). Furthermore, given the established

122 literature on implied motion suggesting that implied motion can activate motion-sensitive
123 areas of the brain (Kourtzi & Kanwisher, 2000; Krekelberg et al., 2003), we wondered if a
124 static representation of rising steam can be as effective as the animated counterpart. This
125 exploration holds practical implications for the food industry, specifically regarding whether
126 a static steam effect printed on food images can enhance perception of temperature and food
127 desirability.


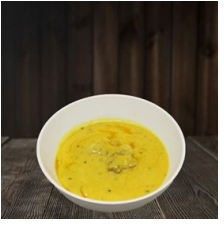

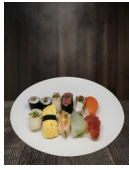

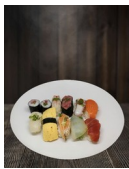

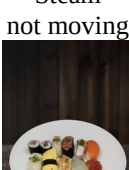
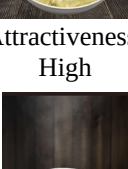


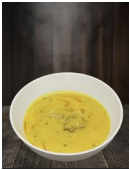

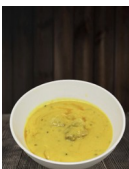
128 Despite the recognition of the importance of food temperature depicted in food
129 images, the effectiveness of using visual cues on food photography to indicate temperature
130 and potential managerial outcomes are rarely researched. Accordingly, several research
131 questions guided the current investigation: Is the addition of steam texture effective in
132 increasing the expected temperature of the food depicted? If so, how much does adding steam
133 texture affect food evaluation based on food images? Does perceived temperature contribute
134 to the perceived freshness of the food? Does enhancing perceived temperature give the
135 impression of good value for money? We expect that images showing traces of steam will
136 increase the perceived temperature of the food depicted, and thus increase favourability of the
137 food. In addition, we measured WTP and perceived freshness as key outcome variables to
138 investigate the temperature-premium effect of steam animation on food evaluation.

139 **1.1 Overview of studies**

140 Three studies were conducted to investigate the research questions. Study 1 showed that
141 adding steam animation to food images was effective in enhancing the perceived temperature
142 of the dishes depicted. Steam textures, while seemingly subtle, were perceived as visual
143 indicators of high temperatures, and further enhanced food desirability. In Study 2, traces of
144 steam were added to both contextually consistent and contextually inconsistent foods. Study
145 2 showed that steam was a visual cue for high temperature, independent of contextual
146 plausibility. In addition, Study 2 compared the differences between the steam animation and
147 its implied motion and showed that implied animation was not effective in enhancing
148 temperature perception. As a test of boundary condition, Study 3 showed that steam
149 animation as an indicator of high temperature only improved the food desirability of
150 otherwise less appealing food images.

151 **Table 1**

152 Overview of the studies objectives and design.

	Objective	Design	Product	Conditions		
Study1	Steam animation as an effective way of inducing high temperature expectation Impact on food desirability	Single factor between-group design: Animated traces of steam above the food (present vs. absent)	Curry (Yellow)	Present  Steam moving	Absent 	
Study2	Steam as a visual cue indicating high temperature independent of context plausibility Temperature perception's impact on food evaluation	3 × 2 between-group design: Animated traces of steam above the food (present vs. implied motion vs. absent) Context plausibility (high vs. low)	Curry (Green): High plausibility with steam	Present	Plausibility: High  Steam moving	Plausibility: Low  Steam moving
				Implied motion	 Steam not moving	 Steam not moving
			Sushi Plate: Low plausibility with steam	Absent	 Steam moving	 Steam moving
				 Steam not moving	 Steam not moving	
Study3	Food attractiveness as a boundary condition	2 × 2 between-group design: Animated traces of steam above the food (present vs. absent) Food attractiveness (high vs. low)	Curry (Green): High in attractiveness Curry (Yellow): Low in Attractiveness	Present  Steam moving	Attractiveness: High  Steam moving	
			Absent	 Steam moving	Attractiveness: Low  Steam moving	

153

154 **2. Study 1**

155 Study 1 aims to establish the association between traces of steam hot food temperature. We
 156 adopted a single factor between-group experimental design. Two types of food images were
 157 used as the stimuli: food image with animated traces of steam above the food (steam

158 animation condition) vs. no steam control image (control condition). People evaluated the
159 images from two perspectives: temperature perception and food desirability (measured by
160 degree of liking, and purchase willingness). We expect that:

161 **Hypothesis 1 (H1):** Participants perceive the food with animated traces of steam to be
162 of higher temperature than no steam counterpart.

163 **Hypothesis 2 (H2):** Participants perceive the food depicted with animated traces of
164 steam as more desirable than no steam counterpart.

165 **Hypothesis 3 (H3):** Participants perceive warm food as more desirable. That said, the
166 perceived elevation in temperature is hypothesized to mediate the relationship between the
167 presence of steam textures (animated steam traces vs. no steam control) and the increased
168 food desirability.

169 2.1 Methods

170 2.1.1. Participants

171 An a priori power analysis was conducted using G*Power version 3.1 (Faul, Erdfelder, Lang,
172 & Buchner, 2007) for sample size estimation. Based on a medium effect size ($d = 0.5$), a
173 probability of $1 - \beta = 0.80$, and an α -value of 0.05, a sample size of 102 participants was
174 suggested for one-tailed between-groups t -tests. 109 participants from the U.S. were recruited
175 from the online participant recruitment platform, Connect ([Cloudresearch.com](https://www.cloudresearch.com)). The targeted
176 participants are adults without colour-blindness as colour perception may affect their
177 evaluation of food images. Two responses were eliminated due to either technical problems
178 or failed attention checks. Another nine participants were excluded as they quitted the survey
179 without completion of all questions, including temperature perception and manipulation
180 check. The final sample consisted of 98 participants (for the steam animation group, $N = 46$,
181 $M_{\text{age}} = 37.83$ years, $SD_{\text{age}} = 10.28$ years, 28 males, three vegan/vegetarian; for the control
182 group, $N = 52$, $M_{\text{age}} = 37.46$ years, $SD_{\text{age}} = 11.76$ years, 25 males, three vegan/vegetarian).
183 None of the participants were allergic to or had dietary restrictions towards the dish
184 displayed.

185 2.1.2. Stimuli and Procedure

186 Study 1 used an image of curry as the stimulus, primarily because curry is an affordable and
187 popular food option. The specific curry image was sourced from a high-resolution food image
188 database, meticulously curated with standardized recoding method for experimental research
189 (Toet et al., 2019). The image was edited to resemble a restaurant advertisement (Ad)
190 commonly seen on social media platforms. The curry image was processed with a steam
191 stimulator, developed by an image processing engineer in the research team, which can
192 adeptly overlay traces of continuously moving steam to input images. For the animation
193 condition, the stimuli featured a bowl of curry with continuously rising steam and in the
194 control condition the identical curry was presented without steam (see **Fig. 2**). The stimuli
195 were presented in the format of GIFs. Both the GIF stimuli and the steam stimulator are made
196 available at https://osf.io/cwzh6/?view_only=99027ded96ae4a0394226f2387f83e9d.

197 To enhance the ecological validity of the study, which used curry as the stimuli, the
198 experiment was scheduled for noon on a weekday, strategically chosen as curry (the food
199 stimuli used in the current study) is not a common choice for breakfast. **All participants were**
200 **recruited within an hour.** After providing informed consent, participants rated their hunger
201 levels at the moment and their familiarity with online food advertising as control variables.
202 After that, participants were randomly assigned to view a curry restaurant Ad either with or
203 without steam animation. **They then evaluated the food from various perspectives, including**
204 **level of liking, purchase willingness, and temperature perception.** Then participants were
205 asked to indicate whether the image was dynamic, which served as the manipulation check.
206 Demographic information, encompassing gender, age, dietary preferences, and allergies, was
207 also collected. Before concluding the session, participants had the opportunity to provide
208 feedback on the study and report any technical issues (e.g., text or image loading problems).

209 **Figure 2**

210 *Visual stimuli used in Study 1.*



211

212 Note. The left is the steam animation condition of which the curry image was edited to
 213 feature traces of steam continuously rising from the curry and the right is the control
 214 condition. For experimental condition, the steam was animated. Both stimuli were presented
 215 in GIF format.

216 2.1.3. Measures

217 Temperature perception was measured on a 7-point scale ranging from “1 = extremely cold”
 218 to “7 = extremely hot”. Food desirability was measured with four items targeting degree of
 219 liking and purchase willingness. Degree of liking was measured with one of the items from a
 220 three-item attitude scale (Madden et al., 1988) on a 7-point Likert scale ranging from “1 =
 221 dislike” to “7 = like”, which is widely used for evaluating consumer attitude (e.g., see Borau
 222 & Nepomuceno, 2019; Jublee, Kasilingam, & Stephen, 2023; Kim & Kim, 2021).
 223 Participants indicated their purchase willingness responding to three items adapted from
 224 previous literature on 7-point Likert scales (Rizzato et al., 2016): “How desirable did you find
 225 the dish to be?”, “How much would you like to eat this curry?”, and “How likely would you
 226 be to try the restaurant”, $M = 5.43$, $SD = 1.85$. An average score of the four items measuring
 227 degree of liking and purchase willingness was computed as the score of food desirability
 228 (Cronbach's $\alpha = 0.94$). We also conducted Principal Component Analysis (PCA) to further
 229 confirm that the four items measuring food desirability belong to one factor (see Appendix
 230 A). Participant's hungry level and familiarity with online food Ad were also measured on 7-
 231 point scales. The manipulation check item asked participants to rate the level of dynamism of
 232 food Ad they were exposed to on a 5-point scale (“1 = not at all” to “5 = a great deal”). All
 233 questionnaire items are detailed in **Table S1**.

234 2.1.4. Analysis

235 Randomization check was performed using *t*-tests for independent samples. Additionally,
 236 manipulation checks were conducted using *t*-tests to confirm that the animated traces of
 237 steam were successfully delivered to the participants. Subsequently, a series of independent
 238 sample *t*-tests was conducted to test the effect of animated steam textures on elevating
 239 temperature perception and food desirability. We further investigated the relationship
 240 between outcome variables. Specifically, we explored the role of temperature perception (i.e.,
 241 the immediate outcome of adding steam texture to food images), on food desirability, which
 242 is considered as the downstream consequence of adding temperature cue. Simple linear
 243 regression analysis was therefore conducted with temperature perception as the independent
 244 variable and food desirability as the dependent variable. Following regression analysis,
 245 mediation analysis was conducted using PROCESS v4.2 macro by Hayes (2022) with 10,000
 246 bootstrapped samples (Model 4), to examine the mediation effect of temperature perception
 247 on the relationship between manipulation of adding steam textures (animated traces of steam
 248 vs. no steam control; steam animation condition was coded as 1, and control condition was
 249 coded as 0) and food desirability. All analyses were conducted in SPSS v29.0 and PROCESS
 250 FOR SPSS.

251 2.2. Results

252 Regarding the randomization checks, participants in the two conditions were homogeneous in
 253 terms of their age ($M_{\text{steam}} = 37.83$ years, $SD_{\text{steam}} = 10.28$ years, $M_{\text{control}} = 37.46$ years, $SD_{\text{control}} =$
 254 11.76 years, $t(96) = 0.16$, $p = 0.436$), familiarity with online food Ad ($M_{\text{steam}} = 5.07$, $SD_{\text{steam}} =$
 255 1.48 years, $M_{\text{control}} = 5.44$, $SD_{\text{control}} = 1.27$, $t(96) = 1.35$, $p = 0.089$), and hungry level ($M_{\text{steam}} =$
 256 4.28 , $SD_{\text{steam}} = 1.78$, $M_{\text{control}} = 4.27$, $SD_{\text{control}} = 1.56$, $t(96) = 0.04$, $p = 0.484$). Regarding the
 257 manipulation checks, the steam animation group exerted higher perception of picture
 258 dynamism compared to the control condition, which confirmed successful manipulation
 259 processing images with the steam simulator ($M_{\text{steam}} = 3.04$, $SD_{\text{steam}} = 1.13$, $M_{\text{control}} = 1.90$,
 260 $SD_{\text{control}} = 1.33$, $t(96) = 4.53$, $p < 0.001$, Cohen's $d = 0.92$). Detailed descriptive results of each
 261 condition are reported in **Table S2** and **Table S3**.

262 2.2.1. Main effects of steam animation

263 Independent sample *t*-tests were conducted separately for temperature perception and food
 264 desirability. The result revealed a significant effect of steam animation on temperature
 265 perception, $t(96) = 5.72$, $p < 0.001$, Cohen's $d = 1.16$. Participants in the steam animation
 266 group rated the perceived temperature of the curry higher than those in the no steam control
 267 group ($M_{\text{steam}} = 5.89$, $SD_{\text{steam}} = 0.95$, $M_{\text{control}} = 4.56$, $SD_{\text{control}} = 1.30$). Therefore, the results
 268 support **H1**, indicating that the integration of animated steam in food images is perceived to
 269 be associated with hot temperature.

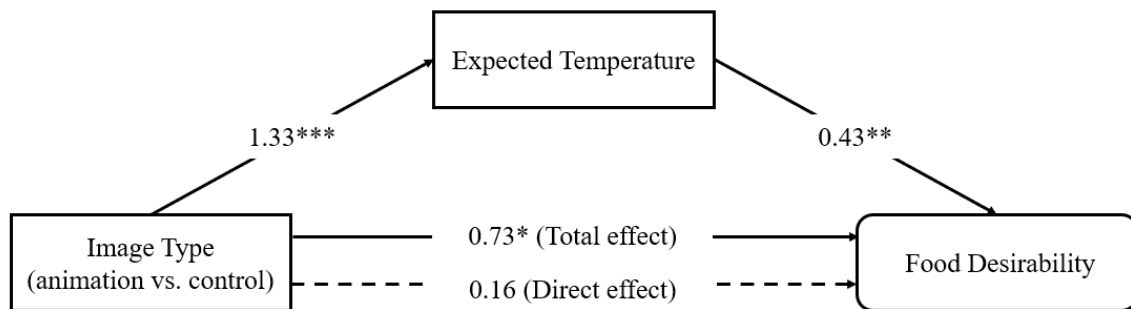
270 The results of independent sample *t*-test for food desirability revealed significant
 271 effect of steam animation on food desirability, $t(96) = 2.04$, $p = 0.022$, Cohen's $d = 0.41$.
 272 Participants in the steam animation group expressed higher desirability for the curry than
 273 those in the no steam control group ($M_{\text{steam}} = 3.97$, $SD_{\text{steam}} = 1.77$, $M_{\text{control}} = 3.24$, $SD_{\text{control}} =$
 274 1.79). The results support **H2**, showing that food depicted with animated traces of steam is
 275 viewed as more desirable than no steam counterpart.

276 *2.2.2. The mediation effect of steam animation on food desirability through temperature*
 277 *perception*

278 Linear regression result showed that temperature perception explained 11.5% of the variation
 279 in food desirability, $F(1, 96) = 12.51$, $p < 0.001$, $\beta = 0.34$. Based on the significant regression
 280 result, a mediation analysis was conducted using PROCESS v4.2 macro by Hayes (2017)
 281 with 10,000 bootstrapped samples (Model 4). The standardized coefficients of the path
 282 analysis are illustrated in **Fig. 3.**, confirming the hypothesized mediating role of expected
 283 temperature. At the 95% confidence level, the indirect effect of steam animation on food
 284 desirability was estimated to be 0.58 (95% CI [0.18, 1.06], bootstrap $SE = 0.22$). The
 285 mediation analysis showed that participants perceived the food image with animated traces of
 286 steam to be of higher temperature ($\beta = 1.33$, $SE = 0.23$, $t = 5.72$, $p < 0.001$). This, in turn, was
 287 associated with higher food desirability ($\beta = 0.43$, $SE = 0.15$, $t = 2.84$, $p = 0.005$). As the
 288 direct effect of steam animation on food desirability was not significant (direct effect = 0.16,
 289 95% CI [-0.64, 0.96], bootstrap $SE = 0.40$, $t = 0.39$, $p = 0.70$; total effect = 0.73, 95% CI
 290 [0.02, 1.45], bootstrap $SE = 0.36$, $t = 2.04$, $p = 0.044$), the results suggested that the expected
 291 temperature completely mediated the effect of steam animation on food desirability,
 292 supporting **H3**.

293 **Figure 3**

294 *The mediating role of temperature perception between the effect of steam animation on food*
 295 *desirability in Study 1(standardized coefficients for each pathway).*



296

297 Note. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Animation condition was coded as 1 and control
 298 condition was coded as 0.

299 2.3. Discussion

300 Results of Study 1 demonstrated that, within a controlled setting featuring the same food
 301 image, the addition of traces of animated steam can induce hot temperature perception of the
 302 dish (**H1**). This heightened temperature perception of the foodstuff then mediated the
 303 relationship between steam animation and increased food desirability (**H2 & H3**). Together,
 304 the animated texture featuring steam rising was found to an effective cue in enhancing the
 305 perceived temperature when incorporated in food images, resulting in a positive downstream
 306 effect, i.e. increasing the desirability of the food.

307 While people recognized the importance of depicting hot food temperature perception
 308 in pictures of warm food, the effectiveness of using visual cues on food photography as a
 309 temperature tactic has rarely been investigated experimentally. Results of Study 1 provided
 310 empirical support for incorporating traces of rising steam in enhancing the perception of
 311 warmth in food images. By showing that temperature perception can be crossmodally
 312 influenced by visual cue, our study added to the empirical evidence of vision-temperature
 313 crossmodal correspondence (see also Barbosa Escobar et al., 2023a, 2023b).

314

315 3. Study 2

316 The objectives of Study 2 are threefold. First, Study 2 aims to examine if steam texture as a
317 hot temperature visual cue is reliant on the context. In study 1, we overlaid steam texture on a
318 bowl of curry, which is often eaten at a warm temperature and gives off steam when it is
319 freshly made. Will steam texture still induce hot temperature perception when the display of
320 steam is of context? Previous literature on crossmodal associations between visual textures
321 and temperature concepts also noted the importance of context dependency (Barbosa Escobar
322 et al., 2022). In study 2, in addition to overlaying steam texture on curry, we also overlaid
323 steam texture on sushi, which is unlikely to be carry rising steam in most cases. By
324 comparing the temperature perception of the two foods (i.e., curry and sushi) with and
325 without the steam texture, we aim to illustrate whether steam is an independent visual cue for
326 high thermal temperature, or it is dependent on compatibility with context.

327 Second, Study 2 examines alternative explanation for the steam effect. More
328 specifically, we examine the arousal effect that animation may cause by introducing novel
329 visual stimuli (Banović et al., 2016; Bialkova et al., 2014; Gere et al., 2016; Guerreiro, Rita,
330 & Trigueiros, 2015; Schoormans & Robben, 1997; van Loo et al., 2015, 2018). Emotional
331 arousal levels have been found to be associated with product evaluation (Choi, Jung,
332 Oyunbileg, & Yang, 2016; Noseworthy, Di Muro, & Murray, 2014). Therefore, we measured
333 emotional arousal before and after viewing the stimuli to examine whether animated traces of
334 steam increased arousal and whether emotional arousal partly explains Study 1's finding that
335 addition of steam increases food desirability. Lastly, considering the varying findings in the
336 literature on the efficacy of incorporating implied motion in food photography (e.g., see Gvili
337 et al., 2015, 2017; Mulier, Meersseman, Vermeir, & Slabbinck, 2021; Yu, Droulers, &
338 Lacoste-Badie, 2022), the third aim of Study 2 is to compare the effectiveness of steam
339 texture (implied format vs. animated format) in heightening temperature perception.

340 Study 2 is a 2 (food type: warm vs. cold) × 3 (image type: steam animation vs.
341 implied steam vs. no steam control) between-group design. We explore if steam is a context-
342 independent temperature cue, and if it has to be animated to deliver its effect. In Study 2, in
343 addition to assessing temperature perception and food desirability, we also assess perceived
344 food freshness and willingness to pay (WTP). We expect that the steam effect on temperature
345 perception, freshness perception, food desirability and WTP to be the highest when the warm
346 food is presented with steam animation. The preregistration of Study 2 can be found at
347 https://aspredicted.org/LZ6_XC7.

348 3.1 Methods

349 3.1.1. Participants

350 An a priori power analysis was conducted using G*Power version 3.1 (Faul et al., 2007) for
351 sample size estimation. For ANOVA test for mains effect and interactions, based on a
352 medium effect size ($f = 0.25$), a probability of $1 - \beta = 0.80$, and an α -value of 0.05, a sample
353 size of 211 participants was suggested. 468 participants from the U.K. were recruited from
354 Prolific (<https://www.prolific.com/>). Same as Study 1, the targeted participants are adults
355 without colour-blindness as colour perception may affect their evaluation of food images. We
356 included the following yes/no questions at the end of the questionnaire as the manipulation
357 check: “I saw steam coming out of the food” and “The steam was animated”. After checking
358 participants’ responses to the manipulation check questions, a sample of 428 participants was
359 included in the analysis, with an average age of 42.09 years ($SD = 14.54$ years), and 37%
360 male. 55 participants reported a recent lack of appetite or allergies to the food items in the
361 image, however including them did not affect the study outcomes. Details of sample
362 demographics for the sample including and excluding those lack of appetite and with food
363 allergies, are provided in Appendix B.

364 3.1.2. Stimuli and procedure

365 Study 2 used images of curry and sushi as the stimuli (see **Fig.4**). Images were sourced from
366 the same food image database (Toet et al., 2019). The reason for replacing the picture of the
367 curry was that several participants in Study 1 commented in their feedback that the curry in
368 the picture looked disgusting and unappetising. For Study2, the stimuli were edited to
369 resemble a restaurant menu. Same as Study 1, the images were edited with the steam
370 simulator to incorporate constantly rising steam animation. For the implied animation
371 condition, we used one frame of the animated steaming picture and therefore the steam is
372 overlaid on the food but not moving. For control conditions, the same sets of stimuli were
373 presented without the steam. All stimuli were presented in the format of GIFs.

374 Study 2 was scheduled for noon as in Study 1. After providing informed consent,
375 participants rated their momentary hunger levels and frequency of dining out as control
376 variables. After that, participants were randomly assigned to one of the six conditions: curry
377 with animated steam, sushi with animated steam, curry with implied steam, sushi with

378 implied steam, curry without steam, and sushi without steam. They then evaluated the food
 379 from various perspectives, including temperature perception, freshness perception, food
 380 desirability, and WTP. Demographic information was also collected. Before concluding the
 381 session, participants provided feedback and report any technical issues.

382 Figure 4

383 Stimuli for Study 2.



384
 385 Note. For steam animation conditions, the stimuli (a & c) are presented with animated traces
 386 of rising steam; for implied steaming conditions, the stimuli are presented with traces of
 387 steam that is not moving; for control conditions (b & d), the same images are presented
 388 without steam.

389 3.1.3. Measures

390 For manipulation check, participants were asked to provide yes/no answers to two questions:
 391 “I saw steam coming out of the food” and “The steam was animated”. Frequency of dining
 392 out was measured with one item “How frequently do you visit restaurants or order
 393 takeaways?” (1 = very rare to 7 = very usual) Hungry level, temperature perception and food
 394 desirability were measured with the same items in Study 1. Cronbach’s α of the four items
 395 measuring food desirability is 0.89 in Study 2. Freshness perception was measured on another
 396 7-point scale on “1 = not fresh” to “7 = fresh”. WTP was measured with slider scales, with

397 the price on the menu as the median (see **Fig. S1**). For curry, the slider ranged from £2.5 to
 398 £22.5, and for sushi, the price slider ranged from £10 to £30. Emotional arousal was
 399 measured both before and after viewing the stimuli with one item “How are you feeling right
 400 now?” (1 = calm to 7 = excited). All items are specified in **Table S4**.

401 3.1.4. Analysis

402 A series of two-way ANOVAs were conducted to examine the effect of food type (warm vs.
 403 cold) and image type (steam animation vs. implied steam vs. no steam control) on
 404 temperature perception, freshness perception, food desirability and WTP. **Post hoc analyses**
 405 **were conducted with Bonferroni *t*-tests.** Of particular interest were the main effects of the
 406 factor image type and interactions with food type. All analyses were conducted in SPSS
 407 v29.0.

408 3.2 Results

409 There were no significant differences in age ($F(5, 422) = 1.04, p = 0.392$), hungry level ($F(5,$
 410 $422) = 0.71, p = 0.618$), frequency of eating out ($F(5, 422) = 0.43, p = 0.829$) and the
 411 emotional arousal before stimuli exposure ($F(5, 422) = 0.46, p = 0.805$) among the six
 412 conditions, indicating successful group randomization. Descriptive results are supplemented
 413 in **Table S4**.

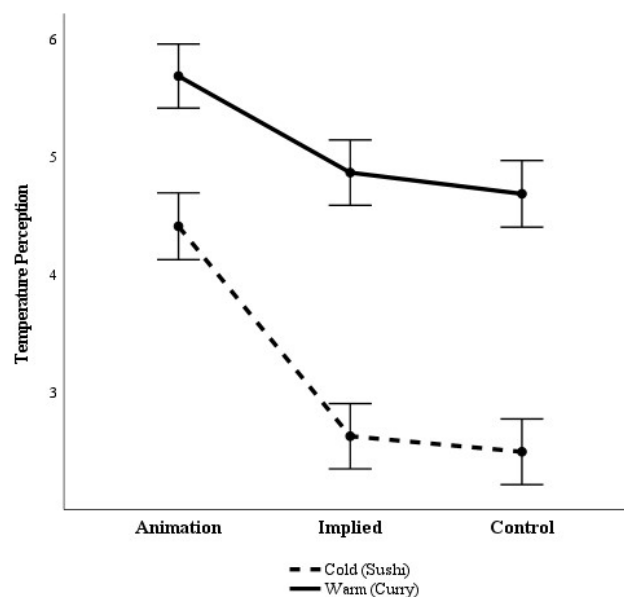
414 ANOVAs were first conducted with temperature perception as the dependent variable
 415 to examine the interaction effect of food type (warm vs. cold) and image type (steam
 416 animation vs. implied steam vs. control). Results revealed that there was a significant
 417 interaction effect of food type and images type ($F(2,422) = 7.36, p < 0.001, \eta^2 = 0.034$) as
 418 well as main effects of both food type ($F(2,422) = 269.88, p < 0.001, \eta^2 = 0.390$) and image
 419 type ($F(2,422) = 63.88, p < 0.001, \eta^2 = 0.232$). Post-hoc analyses showed that for warm food
 420 (i.e., curry), temperature perception of food with animated steam ($M = 5.68$) was significantly
 421 higher than with implied steam ($M = 4.86, p < 0.001$) and without steam textures ($M = 4.68, p$
 422 < 0.001), and no difference between the implied condition and control condition ($p = 1.000$).
 423 Similarly for cold food (i.e., sushi), temperature perception with animated ($M = 4.41$) was
 424 significantly higher than the implied condition ($M = 2.63, p < 0.001$) and control condition
 425 ($M = 2.49, p < 0.001$), and no difference between implied and control conditions ($p = 1.000$).
 426 From the results, steam textures proved to be a cue of thermal temperature independent of the

427 context. Notably, post hoc test results also showed that across each image type, curry was
 428 always perceived to have significantly higher temperature than sushi ($ps < 0.001$). **Figure 5**
 429 illustrated the interaction. Animated traces of steam added to food images increased the
 430 temperature more for sushi as sushi was perceived to be at lower temperatures without the
 431 steam. Additionally, our results showed that steam textures in implied motion did not
 432 increase temperature perception.

433 No significant effects of the factor image type, nor its interactions, regarding
 434 freshness perception, food desirability, WTP and change in emotional arousal were found.
 435 However, these results are reported in Supplementary Material (**Table S7**).

436 **Figure 5**

437 *Interaction effect of image type and food type on temperature perception in Study 2.*



438

439 Note. Scale of temperature perception ranges from 1 to 7. Bars represent 95% CIs.

440 3.3 Discussion

441 Study 2 provides additional evidence that animated steam texture is an effective visual cue of
 442 high temperature when incorporated in food images. More importantly, Study 2 shows that
 443 this visual temperature cue is independent of context. Even when added to the food that is
 444 unlikely to give off steam, animated steam textures are still considered to be a cue of high

445 thermal temperature. We show that temperature perception can be crossmodally influenced
446 by visual cue, especially when thermal temperature cannot be physically perceived. This
447 vision-based temperature cue can be applied to food photography to deliver the perception of
448 food being warm even when the temperature cannot be immediately perceived. For example,
449 some food options in the supermarkets (e.g., ready meals) are kept cold when they are on sale
450 but should be warm or hot when consumed. Given the importance of food temperature
451 perception (Yamin et al., 2020), it is practically beneficial to incorporate visual temperature
452 cues such as animated traces of steam to convey “warmth” in this case.

453 The second aim of Study 2 was to examine whether animated steam textures led to
454 increased emotional arousal, which can lead to increased food desirability. Our findings
455 suggest that animated steaming food images triggered higher temperature perception of the
456 food depicted compared to no steam images but did not trigger stronger emotional arousal.
457 Additionally, Study 2 results showed that rising steam presented in the implied motion format
458 did not increase temperature perception. There have been mixed results and discussions on
459 whether implied motion can hint at movement without explicitly showing it (Kourtzi &
460 Kanwisher, 2000; Krekelberg et al., 2003; Gvili et al., 2015, 2017; Xiong, Hu, & Ma, 2023;
461 Yu et al., 2022). However, in the case of steam textures, implied motion is not as effective as
462 its animated counterpart.

463 We assessed several downstream consequences of food being perceived at a higher
464 thermal temperature: freshness perception, food desirability, and WTP. The results of Study 2
465 showed that although the addition of animated steam increased temperature perception, it did
466 not make people feel that their food was fresher or more willing to pay for it. Though we
467 found that animated steam added to food images resulted in increased food desirability, this
468 downstream consequence was not reproduced in Study 2. Upon comparison of the descriptive
469 results of food desirability in Study 1 and Study 2, curry with animated steam was rated to be
470 of similar desirability ($M_{\text{study1}} = 3.97$, $SD_{\text{study1}} = 1.77$; $M_{\text{study2}} = 4.08$, $SD_{\text{study1}} = 1.48$); while the
471 curry in Study 1 without the steam was rated to be at a lower level of desirability than the one
472 in Study 2 ($M_{\text{study1}} = 3.24$, $SD_{\text{study1}} = 1.79$; $M_{\text{study2}} = 3.95$, $SD_{\text{study1}} = 1.43$). Of the eight written
473 responses received for Study 1, three mentioned that the curry looked unappealing, which
474 coincided with the difference in food desirability scores between the two studies. Therefore,
475 we hypothesize the appeal of a food image acts as a boundary condition for the positive
476 impact of heightened temperature expectations on food desirability. Specifically, we propose

477 that in the case of non-appealing food images, there is greater potential to enhance
478 palatability through the addition of animated steam. To further examine this hypothesis and
479 examine this hypothesis, Study 3 was conducted.

480

481 **4. Study 3**

482 Study 3 examines food image appeal as a boundary condition on the effect of enhanced
483 temperature perception making food more desirable. With a 2 (image appeal: high vs. low) ×
484 2 (image type: steam animation vs. no steam control) between-within design, we expect that
485 the heightened temperature perception caused by steam animation may only increase food
486 desirability for unappealing food image. Preregistration of Study 3 can be found at:
487 https://aspredicted.org/37K_Y2J.

488 **4.1 Methods**

489 *4.1.1. Participants*

490 For ANOVA tests for a 2 × 2 mixed design, based on a medium effect size ($f = 0.25$), a
491 probability of $1 - \beta = 0.80$, and an α -value of 0.05, a sample size of 66 participants was
492 suggested by power analysis. 149 participants from the U.K. were recruited from Prolific
493 (<https://www.prolific.com/>). Eight participants were disqualified due to technical issues
494 during the experiment. The same manipulation check questions were used as in Study 2.
495 After manipulation check and technical check, a sample of 141 participants was included in
496 the analysis, with an average age of 40.91 years ($SD = 13.06$ years), and 29% male. As in
497 Study 1 and Study 2, participants with food allergies and lack of appetite remained in the
498 sample. Details of sample demographics for the sample including and excluding those
499 participants, are provided in Appendix C.

500 *4.1.2. Stimuli and Procedure*

501 Study 3 used the curry stimuli from Study 1 and Study2 (see **Fig. 6**). The procedure is the
502 same as Study 2. Participants were randomly assigned to one of the two between-group
503 condition (image type: steam animation vs. no steam control). In each group, participants saw

504 both types of curry in a randomized order. Participants first evaluated food appeal, followed
505 by evaluation of temperature perception, freshness perception, food desirability, and WTP.

506 4.1.3. Measures

507 Study 3 added a measure of food appeal before other outcome measure. Participants indicated
508 how much they agreed with the statement “The food in the picture looks appealing” from “1
509 = strongly disagree” to “7 = strongly agree”. In addition, other measures were the same as
510 Study 2 (see **Table S8** for details).

511 4.1.4. Analysis

512 Mixed-model ANOVAs were conducted for manipulation check of image appeal (high vs.
513 low) for green and yellow curry images with and without animated steam textures. ANOVAs
514 were then conducted to examine the effects of image type (steam animation vs. no steam
515 control, between-group factor) and its interactions with image appeal (high: green curry vs.
516 low: yellow curry, within-group factor) on food appeal, temperature perception, freshness
517 perception, food desirability and WTP. To replicate the mediational results in Study 1,
518 mediation analyses were conducted with 10,000 bootstrapped samples (Model 4), to examine
519 the mediation effect of temperature perception on the relationship between image
520 manipulation (steam animation condition was coded as 1, and control condition was coded as
521 0) and food desirability, separately for food images of high (i.e., green curry) and low appeal
522 (i.e., yellow curry). All the statistical analyses were performed using SPSS v29.0 and
523 PROCESS for SPSS.

524 **Figure 6**

525 *Stimuli used for Study 3.*



526

527 Note. For steam animation conditions, the stimuli (left column) are presented with animated
 528 traces of rising steam; for control conditions (right column), the same images are presented
 529 without steam.

530 4.2 Results

531 4.2.1. Effects of steam animation (image type) and image appeal

532 There were no significant differences in age ($t(139) = 1.39, p = 0.165$), hungry level ($t(139) =$
 533 $0.13, p = 0.898$) and frequency of eating out ($t(139) = 1.58, p = 0.117$) between the two
 534 groups, indicating successful group randomization. Descriptive results are supplemented in
 535 **Table S9.**

536 ANOVA results of food appeal showed that there was no interaction effect of image
 537 type and curry image on the ratings of food appeal, $F(1,139) = 0.03, p = 0.854$, and no
 538 significant effect of image type, $F(1,139) = 1.07, p = 0.302$, but a significant main effect of
 539 curry, $F(1,139) = 46.03, p < 0.001, \eta^2_o = 0.249$. These results suggest that green curry was
 540 perceived as more appealing compared to yellow curry, with or without the animated steam
 541 texture superimposed, which aligns with our hypothesis that green curry image is perceived
 542 to be more appealing than the yellow curry image. Therefore, it is confirmed that green curry

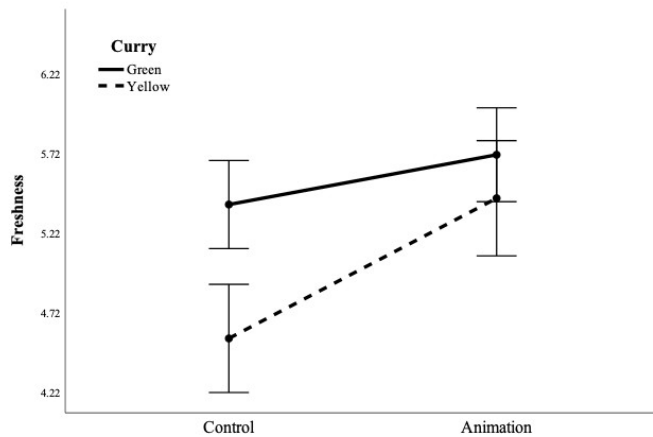
543 image is a stimulus of relatively high appeal (without steam, $M = 4.01$, with steam, $M =$
 544 4.23), while the yellow curry image has a relatively low level of attractiveness (without
 545 steam, $M = 3.05$, with steam, $M = 3.32$).

546 Same as Study 1 and Study2, there was a significant main effect of image type on
 547 temperature perception, $F(1,139) = 47.73$, $p < 0.001$, $\eta^2 = 0.256$, but no interaction effect of
 548 image appeal and image type ($F(1,139) = 1.06$, $p = 0.305$) or main effect of curry ($F(1,139) =$
 549 0.70, $p = 0.404$). These results showed that animated steam textures can significantly elevate
 550 temperature perception despite image appeal. For freshness perception, there was a
 551 significant interaction effect of image type and image appeal (see **Fig.7**), $F(1,139) = 9.07$, $p =$
 552 0.003, $\eta^2 = 0.061$, and a significant main effect of image type, $F(1,139) = 8.18$, $p = 0.005$, η^2
 553 = 0.056, and image appeal, $F(1,139) = 34.89$, $p < 0.001$, $\eta^2 = 0.201$. Post-hoc results showed
 554 that freshness perception of low appeal image significantly increased when animated steam
 555 was added ($M = 5.44$) compared to control condition ($M = 4.56$, $p < 0.001$), but no difference
 556 between the two image type conditions for high appeal image (animation group, $M = 5.71$;
 557 control, $M = 5.40$, $p = 0.129$). For food desirability, there was a borderline significant
 558 interaction effect of image appeal and image type, $F(1,139) = 3.83$, $p = 0.052$, $\eta^2 = 0.027$, a
 559 significant main effect of curry ($F(1,139) = 45.23$, $p < 0.001$, $\eta^2 = 0.246$) and no main effect
 560 of animation ($F(1,139) = 2.86$, $p = 0.093$). Post-hoc results revealed that food desirability of
 561 low appeal image significantly increased with animated steam ($M = 3.84$) compared to
 562 control condition ($M = 3.21$, $p = 0.017$), but no difference between the two image type
 563 conditions for high appeal image (animation group, $M = 4.39$; control, $M = 4.22$, $p = 0.516$).
 564 For WTP, there was a significant main effect of image appeal, $F(1,139) = 32.97$, $p < 0.001$,
 565 $\eta^2 = 0.192$, but neither an interaction effect ($F(1,139) = 1.27$, $p = 0.262$) nor a main effect of
 566 image type ($F(1,139) = 0.032$, $p = 0.858$) was detected.

567 **Figure 7**

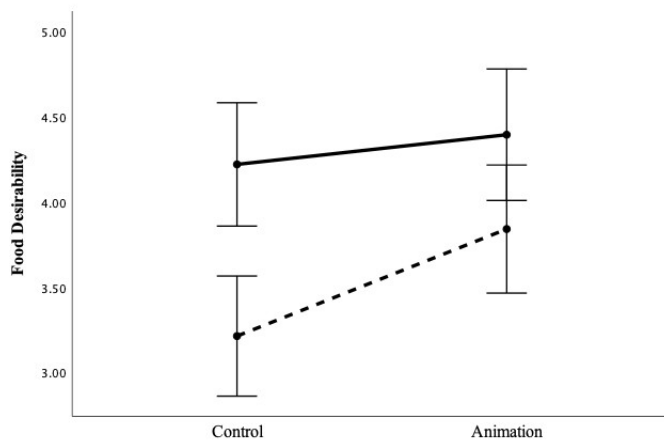
568 *Interaction effect of image type and image appeal on freshness (a) and food desirability (b) in*
 569 *Study 3.*

570 a.



571

572 b.



573

574 Note. Green curry represents high image appeal condition, and yellow curry represents low
 575 image appeal condition. Scale of temperature perception ranges from 1 to 7. Bars represent
 576 95% CIs.

577 4.2.2. *The mediation effect of steam animation on food desirability through temperature*
 578 *perception*

579 Mediation analyses were conducted separately for each image appeal condition (high: green
 580 curry vs. low: yellow curry). The standardized coefficients of the path analyses are illustrated
 581 in **Fig. 8**. For high image appeal condition, at the 95% confidence level, the indirect effect of
 582 steam animation on food desirability was estimated to be 0.70 (95% CI [0.41, 1.03], bootstrap
 583 $SE = 0.16$). Mediation analysis showed that participants perceived the green curry image with
 584 animated steam to be of higher temperature ($\beta = 0.89$, $SE = 0.19$, $t = 5.85$, $p < 0.001$). This
 585 increased temperature perception led to enhanced food desirability ($\beta = 0.50$, $SE = 0.11$, $t =$
 586 5.87 , $p < 0.001$). As the direct effect of steam animation on food desirability was not

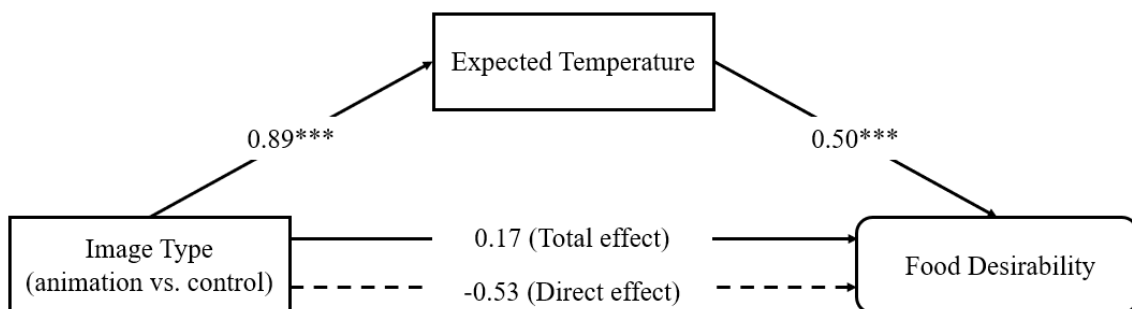
587 significant (direct effect = 0.53, 95% CI [-1.05, 0.00], bootstrap $SE = 0.27$, $t = 1.96$, $p = 0.52$;
 588 total effect = 0.17, 95% CI [-0.35, 0.70], bootstrap $SE = 0.27$, $t = 0.65$, $p = 0.516$),
 589 temperature perception completely mediated the influence of image type (animation vs.
 590 control) on food desirability. This result is aligned with Study 2, in which we did not find a
 591 total effect of image type on food desirability.

592 For low image appeal condition, the indirect effect of steam animation on food
 593 desirability was estimated to be 0.62 (95% CI [0.32, 0.93], bootstrap $SE = 0.16$). Mediation
 594 analysis revealed that animated steam increased temperature perception ($\beta = 0.99$, $SE = 0.19$,
 595 $t = 6.71$, $p < 0.001$), which then increased food desirability ($\beta = 0.40$, $SE = 0.11$, $t = 4.42$, $p <$
 596 0.001). There was a significant total effect (see **Fig.8**, 95% CI [0.11, 1.14], bootstrap $SE =$
 597 0.26 , $t = 2.41$, $p = 0.017$) but not a significant direct effect (95% CI [-0.54, 0.57], bootstrap
 598 $SE = 0.28$, $t = 0.04$, $p = 0.965$). This result replicated Study 1, in which we found a significant
 599 effect of image type on food desirability.

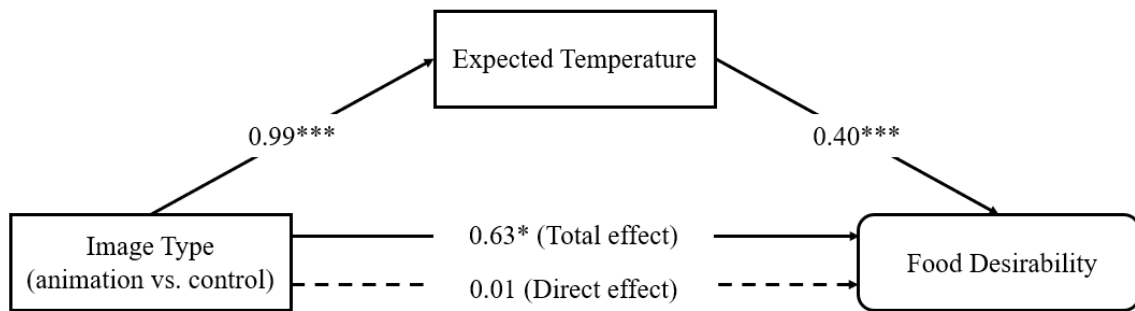
600 **Figure 8**

601 *The mediating role of temperature perception between the effect of steam animation on food*
 602 *desirability in Study 3 (standardized coefficients for each pathway) for image of high appeal*
 603 *(a) and low appeal (b).*

604 a.
 605



606
 607 b.



608

609 Note. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Animation condition was coded as 1 and control
610 condition was coded as 0.

611 4.1 Discussion

612 Study 3 examines the effect of animated steam textures on several downstream outcomes
613 including freshness, food desirability and WTP, and whether image appeal is a boundary
614 condition for the effect. By comparing image of high and low appeal, either with or without
615 steam animation, we found that animated steam textures enhance freshness perception, food
616 desirability, but only for image of low appeal. Noted here we defined freshness as how
617 freshly made people feel about the dish. These further consequences of the visual textures
618 signalling high thermal temperature is important: using food temperature as a heuristic cue
619 ultimately can increase food freshness perception and desirability for the food but not WTP
620 for the food. These findings inspire implications for digital food marketing, pointing out the
621 importance of delivering a sense of high thermal temperature (for warm food) and the
622 potential benefits of heightened temperature perception.

623

624 5. General Discussion

625 This research, encompassing three studies, examine whether temperature perception can be
626 modified crossmodally by visual temperature cues and the downstream consequences. In this
627 particular research, we looked into digital food and steam textures as a visual cue of high
628 thermal temperature. Three online experiments were conducted: Study 1 establishes that
629 animated steam is an effective visual cue indicating high thermal temperature; Study 2 shows
630 that such a visual temperature cue is independent of context and can convey high thermal

631 temperature even when the food is not supposed to give off steam; Study 3 complements
632 Study 1 and 2 by showing that steam animation as an effective visual cue of high thermal
633 temperature, leads to increased freshness perception and food desirability, but only for food
634 images of low appeal. Across these studies, several key findings highlight both the efficacy
635 and limitations of embedding visual temperature cue in digital food images.

636 Our results showing traces of steam, when added to food images, can deliver a sense
637 of high thermal temperature even when temperature cannot be sensed physically. This
638 observation adds to the existing literature on crossmodal associations by showing that
639 temperature perception can be crossmodally modified with visual cue (Barbosa Escobar et al.,
640 2023a, b; Spence, 2011, 2020a). The current research extends prior research by showing that
641 individuals can rely on past food experiences and generate crossmodal correlation for
642 temperature when this information is lacking in digital food photography (Spence, 2011). As
643 Spence (2020a) pointed out, temperature-based crossmodal associations are not universally
644 automatic but can be task-dependent, it will be interesting to further investigate whether
645 visual cues signalling temperature perception in one scenario (e.g., food consumption) are
646 functioning the same in other scenarios.

647 This study highlights the importance of food temperature. Much as previous literature
648 has shown the importance of temperature in influencing consumer product evaluations (Hadi
649 & Block, 2019; Park & Hadi, 2020; Spence, 2020a; Zwebner et al., 2014), the present study
650 underlines the importance of temperature perception in food appreciation. Simply
651 heightening temperature perception can increase people's desirability for food when they
652 look at the photos, especially when the image does not appear appealing. More than people
653 have realized, temperature of food plays a crucial role in stimulating appetite (Kokaji &
654 Nakatani, 2021; Sakay et al., 2022; Yamin et al., 2020) and positive evaluations of food
655 (Magee, 2012; Pramudya & Seo, 2018). Additionally, we show that images of warm food
656 being perceived to have high thermal temperature delivers a sense of food freshness. That
657 said, people feel that the food is more recently made when its digital picture is simply
658 attached traces of moving steam. This finding can inspire digital food presentation across
659 contexts, including for online 2D images, AR, and VR food assets, and food packages of
660 frozen foods, where food freshness can hardly be perceived.

661 The comparison between implied motion and animated steam raised important
662 questions about the applicability of static visual enhancements. Contrary to expectations,

663 implied motion did not significantly impact temperature expectations or food preferences,
664 diverging from previous research on implied motion's influence on food perception (e.g.,
665 Amar, Gvili, & Tal, 2021; Cian, Krishna, & Elder, 2014; Li & Liu, 2021; Mulier et al., 2021;
666 Suzuki et al., 2021; Xiong et al., 2023). This divergence from earlier studies, which have
667 posited mental simulation as a crucial mechanism through which implied motion impacts
668 food-related expectations (Detenber, Simons, & Bennett, 1998; Li et al., 2019; Pessoa & De
669 Weerd, 2003), suggests the limitation in the effectiveness of implied motion within the
670 context of food photography. While past studies have highlighted mental simulation as a key
671 pathway through which implied motion influences expected food experiences (Detenber et
672 al., 1998; Li et al., 2019; Pessoa & De Weerd, 2003). The lack of significant impact on
673 perceived temperature and food preferences in our study indicates a potential deviation from
674 established patterns, necessitating further exploration into how implied motion affects various
675 perceptual dimensions and contexts differently.

676 The results of the present study suggest practical implications for the application of
677 food photography technology in enhancing the visual appeal of food (Piqueras-Fiszman &
678 Spence, 2015; Sakay et al., 2022). Consistent with the findings of Kokaji & Nakatani (2021),
679 the importance of portraying the main dish as warm to stimulate appetite is reaffirmed. More
680 importantly, the current study sheds light on the potential of animated textures, such as a
681 steam effect, in elevating the desirability for food items that might initially appear
682 unappealing. The findings of Study 3 demonstrated that steam animation's impact on food
683 desirability and freshness is modulated by the inherent appeal of the food image. This
684 suggests that enhanced thermal temperature perception yields greater benefit for food images
685 that are inherently less appealing. Such insights are important for informing digital food
686 marketing strategies, especially in promoting unconventional food choices like ready-to-eat
687 meals and frozen food products. Incorporating animated visual elements might prove
688 instrumental in overcoming initial hesitations on the freshness and deliciousness of such
689 products and therefore enhancing the market appeal of these culinary offerings. Despite the
690 positive impact on sensory perceptions and desirability, steam animation did not influence
691 WTP. One possible explanation for the null findings on WTP is that the current study
692 incorporated animated steam in food images for an online menu, which may have delivered a
693 strong sense of artificialness. Future research in digital food marketing should, therefore,
694 investigate deeper into contextual factors that might augment consumers' WTP. Such
695 investigations can illuminate the conditions under which visual enhancements like steam

696 animation can effectively translate into increased valuation of food products, offering
697 valuable insights for optimizing digital marketing strategies in the food industry.

698 The present study opens avenues for future research into the complex dynamics of
699 visual enhancements of temperature perception for digital food. We have showed that
700 animated visual temperature cue in food photography can crossmodally influence temperature
701 perception, it will be interesting for future research to encompass field experiments across
702 diverse settings, such as investigating the impact of digital food presentation on billboards,
703 television screens, and online banners. Such studies will extend the understanding of
704 consumer responses to visual temperature cues in everyday environments. Additionally, the
705 exploration of diverse food categories, ranging from fresh to pre-packaged, and restaurant
706 meals, is essential to explore the generality of the current findings. Another promising
707 direction is the investigation of contextual factors influencing the perception of temperature-
708 related visual cues. The role of environmental temperature, for instance, may be crucial in
709 determining the perceived authenticity of steam animation in food imagery (Motoki et al.,
710 2018). There are individual differences that could potential moderate the steam effect. For
711 example, the degree to which consumers accept or resist technological enhancements in
712 digital imagery can profoundly affect their perception of and response to such modifications.
713 Investigating this interplay between individual attitudes and the impact of dynamic visual
714 elements like steam animation will be instrumental in helping marketers tailor their strategies
715 to diverse consumer segments. Finally, future studies could incorporate variables such as
716 cultural differences in food perception, the context of consumption, and the synergy of
717 multiple sensory cues. This broader approach contributes to build a more comprehensive
718 understanding of how visual temperature cues influence consumer behaviour in digital
719 settings.

720

721 **6. Conclusion**

722 This study explored the possibility of modifying temperature perception of food with visual
723 temperature cue. Specifically, we investigated animated steam textures as a cue of high
724 thermal temperature. Through a series of online experimental studies, we demonstrated that
725 animated steam traces are effective in evoking perceptions of warmth and enhancing
726 freshness perception and food desirability when people look at the food images. Importantly,

727 our results also uncovered the role of image appeal as a boundary condition for the effect of
728 temperature cues. While animated steam enhanced freshness perception and desirability for
729 food images of low appeal, this effect was contingent on the initial attractiveness of the
730 image. By demonstrating the efficacy of digital animation in enhancing food desirability and
731 moderating temperature perception, this study provides valuable insights for practitioners
732 seeking to optimize their food photography strategies to engage and motivate consumers.

733

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REFERENCES

- 742 Abraham, J., & Diller, K. (2019). A review of hot beverage temperatures-satisfying consumer
743 preference and safety. *Journal of Food Science*, 84(8), 2011-2014.
744 <https://doi.org/10.1111/1750-3841.14699>
- 745 Amar, M., Gvili, Y., & Tal, A. (2021). Moving towards healthy: Cuing food healthiness and
746 appeal. *Journal of Social Marketing*, 11(1), 44-63. <https://doi.org/10.1108/JSOCM-03-2019-0038>
747
- 748 Arnheim, R. (1954). *Art and Visual Perception: A Psychology of the Creative Eye*. Berkeley,
749 CA: University of California Press.
- 750 Bakhshi, S., Shamma, D., Kennedy, L., & Gilbert, E. (2015). Why we filter our photos and
751 how it impacts engagement. *Proceedings of the International AAAI Conference on Web and*
752 *Social Media*, 9(1), Article 1. <https://doi.org/10.1609/icwsm.v9i1.14622>
- 753 Banović, M., Chrysochou, P., Grunert, K. G., Rosa, P. J., & Gamito, P. (2016). The effect of
754 fat content on visual attention and choice of red meat and differences across gender. *Food*
755 *Quality and Preference*, 52, 42-51. <https://doi.org/10.1016/j.foodqual.2016.03.017>
- 756 Barbosa Escobar, F., Velasco, C., Byrne, D. V., & Wang, Q. J. (2023a). Crossmodal
757 associations between visual textures and temperature concepts. *Quarterly Journal of*
758 *Experimental Psychology*, 76(4), 731-761. <https://doi.org/10.1177/17470218221096452>
- 759 Barbosa Escobar, F., Velasco, C., Byrne, D. V., & Wang, Q. J. (2023b). Assessing
760 mechanisms behind crossmodal associations between visual textures and temperature
761 concepts. *Journal of Experimental Psychology. Human Perception and Performance*, 49(6),
762 923-947. <https://doi.org/10.1037/xhp0001131>
- 763 Bialkova, S., Grunert, K. G., Juhl, H. J., Wasowicz-Kirylo, G., Stysko-Kunkowska, M., &
764 van Trijp, H. C. M. (2014). Attention mediates the effect of nutrition label information on
765 consumers' choice. Evidence from a choice experiment involving eye-tracking. *Appetite*, 76,
766 66-75. <https://doi.org/10.1016/j.appet.2013.11.021>
- 767 Borau, S., & Nepomuceno, M. V. (2019). The self-deceived consumer: Women's emotional
768 and attitudinal reactions to the airbrushed thin ideal in the absence versus presence of
769 disclaimers. *Journal of Business Ethics*, 154(2), 325-340. <https://doi.org/10.1007/s10551-016-3413-2>
770
- 771 Brown, F., & Diller, K. R. (2008). Calculating the optimum temperature for serving hot
772 beverages. *Burn*, 34(5), 648-654. <https://doi.org/10.1016/j.burns.2007.09.012>
- 773 Cardello, A. V., & Schutz, H. G. (2003). The concept of food freshness: Uncovering its
774 meaning and importance to consumers. In K. R. Cadwallader & H. Weenen (Eds.), *Freshness*
775 *and Shelf Life of Foods* (pp. 22-41). Washington, D.C.: American Chemical Society.
- 776 Choi, N. H., Jung, J. M., Oyunbileg, T., & Yang, P. (2016). The impact of emotional arousal
777 levels and valence on product evaluations: From regulatory goal perspective. *European*
778 *Journal of Marketing*, 50(1/2), 78-99. <https://doi.org/10.1108/EJM-09-2013-0481>
- 779 Cian, L., Krishna, A., & Elder, R. S. (2014). This logo moves me: Dynamic imagery from
780 static images. *Journal of Marketing Research*, 51(2), 184-197.
781 <https://doi.org/10.1509/jmr.13.0023>

- 782 Detenber, B. H., Simons, R. F., & Bennett, G. G. (1998). Roll 'em!: The effects of picture
783 motion on emotional responses. *Journal of Broadcasting & Electronic Media*, 42(1), 113-
784 127. <https://doi.org/10.1080/08838159809364437>
- 785 Donthu, N., & Gustafsson, A. (2020). Effects of COVID-19 on business and research.
786 *Journal of Business Research*, 117, 284-289. <https://doi.org/10.1016/j.jbusres.2020.06.008>
- 787 Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical
788 power analysis program for the social, behavioral, and biomedical sciences. *Behavior*
789 *Research Methods*, 39(2), 175-191. <https://doi.org/10.3758/BF03193146>
- 790 Fenko, A., Schifferstein, H. N., & Hekkert, P. (2010). Looking hot or feeling hot: What
791 determines the product experience of warmth? *Materials & Design*, 31(3), 1325-1331. <https://doi.org/10.1016/j.matdes.2009.09.008>
- 793 Francis, L. L., Chambers, D. H., Kong, S. H., Milliken, G. A., Jeon, I. J., & Schmidt, K. A.
794 (2005). Serving temperature effects on milk flavor, milk aftertaste, and volatile compound
795 quantification in nonfat and whole milk. *Journal of Food Science*, 70(7), s413-s418.
796 <https://doi.org/10.1111/j.1365-2621.2005.tb11485.x>
- 797 Gere, A., Danner, L., de Antoni, N., Kovács, S., Dürschmid, K., & Sipos, L. (2016). Visual
798 attention accompanying food decision process: An alternative approach to choose the best
799 models. *Food Quality and Preference*, 51, 1-7.
800 <https://doi.org/10.1016/j.foodqual.2016.01.009>
- 801 Guerreiro, J., Rita, P., & Trigueiros, D. (2015). Attention, emotions and cause-related
802 marketing effectiveness. *European Journal of Marketing*, 49(11-12), 1728-1750.
803 <https://doi.org/10.1108/EJM-09-2014-0543>
- 804 Guest, S., Grabenhorst, F., Essick, G., Chen, Y., Young, M., McGlone, F., ... & Rolls, E. T.
805 (2007). Human cortical representation of oral temperature. *Physiology & Behavior*, 92(5),
806 975-984. <https://doi.org/10.1016/j.physbeh.2007.07.004>
- 807 Gvili, Y., Tal, A., Amar, M., Hallak, Y., Wansink, B., Giblin, M., & Bommelaer, C. (2015).
808 Fresh from the tree: Implied motion improves food evaluation. *Food Quality and Preference*,
809 46, 160-165. <https://doi.org/10.1016/j.foodqual.2015.07.015>
- 810 Gvili, Y., Tal, A., Amar, M., & Wansink, B. (2017). Moving up in taste: Enhanced projected
811 taste and freshness of moving food products. *Psychology & Marketing*, 34(7), 671-683.
812 <https://doi.org/10.1002/mar.21014>
- 813 Hadi, R., & Block, L. (2019). Warm hearts and cool heads: Uncomfortable temperature
814 influences reliance on affect in decision-making. *Journal of the Association for Consumer*
815 *Research*, 4(2), 102-114. <https://doi.org/10.1086/701820>
- 816 Hayes, A. F. (2022). *Introduction to mediation, moderation, and conditional process*
817 *analysis, second edition: A regression-based approach*. Guilford Publications.
- 818 Ho, H.-N., Doorn, G. H. V., Kawabe, T., Watanabe, J., & Spence, C. (2014). Colour-
819 temperature correspondences: When reactions to thermal stimuli are influenced by colour.
820 *PLoS ONE*, 9(3), Article e91854. <https://doi.org/10.1371/journal.pone.0091854>
- 821 Huang, Y., Yang, L., & Liu, M. (2022). How to display products available in multiple color
822 saturation: Fit between saturation and position. *Psychology & Marketing*, 39(4), 809-819.
823 <https://doi.org/10.1002/mar.21622>

- 824 Jublee, D. I., Kasilingam, D., & Stephen, G. (2023). Investigating the impact of brand vs
825 cause interaction on cause related advertisements. *Journal of Retailing and Consumer*
826 *Services*, 75, Article 103524. <https://doi.org/10.1016/j.jretconser.2023.103524>
- 827 Ketron, S., & Spears, N. (2020). Schema-ing with color and temperature: The effects of
828 color-temperature congruity and the role of non-temperature associations. *Journal of*
829 *Retailing and Consumer Services*, 54, Article 102021.
830 <https://doi.org/10.1016/j.jretconser.2019.102021>
- 831 Kim, D. Y., & Kim, H.-Y. (2021). Trust me, trust me not: A nuanced view of influencer
832 marketing on social media. *Journal of Business Research*, 134, 223-232.
833 <https://doi.org/10.1016/j.jbusres.2021.05.024>
- 834 Kokaji, N., & Nakatani, M. (2021). With a hint of Sudachi: Food plating can facilitate the
835 fondness of food. *Frontiers in Psychology*, 12, Article 699218.
836 <https://www.frontiersin.org/articles/10.3389/fpsyg.2021.699218>
- 837 Kourtzi, Z., & Kanwisher, N. (2000). Activation in human MT/MST by static images with
838 implied motion. *Journal of Cognitive Neuroscience*, 12(1), 48-55.
839 <https://doi.org/10.1162/08989290051137594>
- 840 Krekelberg, B., Dannenberg, S., Hoffmann, K. P., Bremmer, F., & Ross, J. (2003). Neural
841 correlates of implied motion. *Nature*, 424(6949), 674-677.
842 <https://doi.org/10.1038/nature01852>
- 843 Li, K., Bi, Y., Wang, Y., Zhang, M., Liu, Y. J., Yang, H., & Lin, F. (2019). The disentangled
844 sub-processes involved in implied motion contributing to food freshness: The neural evidence
845 from ERPs. *Advances in Cognitive Psychology*, 15(3), 185-198. [https://doi.org/10.5709/acp-](https://doi.org/10.5709/acp-0267-9)
846 [0267-9](https://doi.org/10.5709/acp-0267-9)
- 847 Li, S., & Liu, P. (2022). Will “moving” food tastes better? Effect of dynamic food image in
848 print advertising on food taste perception. *Journal of Sensory Studies*, 37(1), Article e12719.
849 <https://doi.org/10.1111/joss.12719>
- 850 Magee, R. G. (2012). Warmth and color online: Physical temperature and web page colors in
851 impression formation. *Journal of Media Psychology*, 24(3), 124-133.
852 <http://doi.org/10.1027/1864-1105/a000070>
- 853 McGlone, F., & Spence, C. (2010). The cutaneous senses: Touch, temperature, pain/itch, and
854 pleasure. *Neuroscience and Biobehavioral Reviews*, 34(2), 145-147.
855 <https://doi.org/10.1016/j.neubiorev.2009.08.008>
- 856 Motoki, K., Saito, T., Nouchi, R., Kawashima, R., & Sugiura, M. (2018). The paradox of
857 warmth: Ambient warm temperature decreases preference for savory foods. *Food Quality and*
858 *Preference*, 69, 1-9. <https://doi.org/10.1016/j.foodqual.2018.04.006>
- 859 Mulier, L., Meersseman, E., Vermeir, I., & Slabbinck, H. (2021). Food on the move: The
860 impact of implied motion in pictures on food perceptions through anticipated pleasure of
861 consumption. *Foods*, 10(9), Article 9. <https://doi.org/10.3390/foods10092194>
- 862 Noseworthy, T. J., Di Muro, F., & Murray, K. B. (2014). The role of arousal in congruity-
863 based product evaluation. *Journal of Consumer Research*, 41(4), 1108-1126.
864 <https://doi.org/10.1086/678301>

- 865 Park, J., & Hadi, R. (2020). Shivering for status: When cold temperatures increase product
 866 evaluation. *Journal of Consumer Psychology*, 30(2), 314-328.
 867 <https://doi.org/10.1002/jcpy.1133>
- 868 Petit, O., Javornik, A., & Velasco, C. (2022). We eat first with our (digital) eyes: Enhancing
 869 mental simulation of eating experiences via visual-enabling technologies. *Journal of*
 870 *Retailing*, 98(2), 277-293. <https://doi.org/10.1016/j.jretai.2021.04.003>
- 871 Pessoa, L., & De Weerd, P. (Eds.). (2003). *Filling-in: From perceptual completion to cortical*
 872 *reorganization*. Oxford University Press.
- 873 Piqueras-Fiszman, B., & Spence, C. (2015). Sensory expectations based on product-extrinsic
 874 food cues: An interdisciplinary review of the empirical evidence and theoretical
 875 accounts. *Food Quality and Preference*, 40, 165-179.
 876 <https://doi.org/10.1016/j.foodqual.2014.09.013>
- 877 Pramudya, R. C., & Seo, H.-S. (2018). Influences of product temperature on emotional
 878 responses to, and sensory attributes of, coffee and green tea beverages. *Frontiers in*
 879 *Psychology*, 8, Article 2264. <https://doi.org/10.3389/fpsyg.2017.02264>
- 880 Rizzato, M., Di Dio, C., Fasano, F., Gilli, G., Marchetti, A., & Sensidoni, A. (2016). Is food
 881 desirability affected by social interaction? *Food quality and preference*, 50, 109-116.
 882 <https://doi.org/10.1016/j.foodqual.2016.02.005>
- 883 Rolls, E. T. (2010). The affective and cognitive processing of touch, oral texture, and
 884 temperature in the brain. *Neuroscience & Biobehavioral Reviews*, 34(2), 237-245.
 885 <https://doi.org/10.1016/j.neubiorev.2008.03.010>
- 886 Sakay Rodriguez, O. E., Masuko, S., & Yamanaka, T. (2022). The impression of
 887 deliciousness through food photography - A photographer's approach to test the commonly
 888 manipulated factors and the interactions on the food image creation process. *International*
 889 *Journal of Affective Engineering*, 21(1), 67-76. <https://doi.org/10.5057/ijae.TJSKE-D-20-00076>
- 891 Sasaki, K., Motoyama, M., & Mitsumoto, M. (2007). Changes in the amounts of water-
 892 soluble umami-related substances in porcine longissimus and biceps femoris muscles during
 893 moist heat cooking. *Meat science*, 77(2), 167-172.
 894 <https://doi.org/10.1016/j.meatsci.2007.02.025>
- 895 Schoormans, J. P. L., & Robben, H. S. J. (1997). The effect of new package design on
 896 product attention, categorization and evaluation. *Journal of Economic Psychology*, 18(2),
 897 271-287. [https://doi.org/10.1016/S0167-4870\(97\)00008-1](https://doi.org/10.1016/S0167-4870(97)00008-1)
- 898 Spence C. (2011). Crossmodal correspondences: A tutorial review. *Attention, Perception, &*
 899 *Psychophysics*, 73(4), 971-995. <https://doi.org/10.3758/s13414-010-0073-7>
- 900 Spence, C. (2020a). Temperature-based crossmodal correspondences: Causes and
 901 consequences. *Multisensory Research*, 33(6), 645-682. <https://doi.org/10.1163/22134808-20191494>
- 903 Spence, C. (2020b). Atmospheric effects on eating and drinking: A review. In H. Meiselman
 904 (Ed.), *Handbook of eating and drinking* (pp. 257-276). Cham, Switzerland: Springer.
 905 https://doi.org/10.1007/978-3-319-75388-1_119-1
- 906 Spence, C., Okajima, K., Cheok, A. D., Petit, O., & Michel, C. (2016). Eating with our eyes:
 907 From visual hunger to digital satiation. *Brain and Cognition*, 110, 53-63.
 908 <https://doi.org/10.1016/j.bandc.2015.08.006>

- 909 Steen, I., Waehrens, S. S., Petersen, M. A., Münchow, M., & Bredie, W. L. P. (2017).
 910 Influence of serving temperature on flavour perception and release of Bourbon Caturra
 911 coffee. *Food Chemistry*, 219, 61-68. <https://doi.org/10.1016/j.foodchem.2016.09.113>
- 912 Suzuki, Y., Narumi, T., Tanikawa, T., & Hirose, M. (2021). Taste in motion: The effect of
 913 projection mapping of a boiling effect on food expectation, food perception, and purchasing
 914 behavior. *Frontiers in Computer Science*, 3, Article 662824.
 915 <https://doi.org/10.3389/fcomp.2021.662824>
- 916 Talavera, K., Yasumatsu, K., Voets, T., Droogmans, G., Shigemura, N., Ninomiya, Y., ... &
 917 Nilius, B. (2005). Heat activation of TRPM5 underlies thermal sensitivity of sweet
 918 taste. *Nature*, 438(7070), 1022-1025. DOI: 10.1038/nature04248
- 919 Toet, A., Kaneko, D., de Kruijf, I., Ushiyama, S., van Schaik, M.G., Brouwer, A.-M., Kallen,
 920 V., & van Erp, J.B.F. (2019). CROCUFID: A cross-cultural food image database for research
 921 on food elicited affective responses. *Frontiers in Psychology*, 10, Article 58.
 922 <https://doi.org/10.3389/fpsyg.2019.00058>
- 923 van Loo, E. J., Caputo, V., Nayga, R. M., Seo, H.-S., Zhang, B., & Verbeke, W. (2015).
 924 Sustainability labels on coffee: Consumer preferences, willingness-to-pay and visual attention
 925 to attributes. *Ecological Economics*, 118, 215-225.
 926 <https://doi.org/10.1016/j.ecolecon.2015.07.011>
- 927 van Loo, E. J., Grebitus, C., Nayga Jr., R. M., Verbeke, W., & Roosen, J. (2018). On the
 928 measurement of consumer preferences and food choice behavior: The relation between visual
 929 attention and choices. *Applied Economic Perspectives and Policy*, 40(4), 538-562.
 930 <https://doi.org/10.1093/aep/ppy022>
- 931 Velasco, C., Altarriba Bertran, F., Obrist, M., Wang, Y., Mueller, F. 'F.', & Deng, J. (2023).
 932 Editorial: The future of human-food interaction. *International Journal of Gastronomy and*
 933 *Food Science*, 32, Article 100739. <https://doi.org/10.1016/j.ijgfs.2023.100739>
- 934 Xiong, S., Hu, N., & Ma, Y. (2023). The influence of implied motion on expected taste
 935 perception of advertised foods: The mental simulation perspective. *Food Quality and*
 936 *Preference*, 111, Article 104968. <https://doi.org/10.1016/j.foodqual.2023.104968>
- 937 Yamin, A. P., Mai, R., & Werle, C. O. C. (2020). Make it hot? How food temperature
 938 (mis)guides product judgments. *Journal of Consumer Research*, 47(4), 523-543.
 939 <https://doi.org/10.1093/jcr/ucaa017>
- 940 Yu, J., Droulers, O., & Lacoste-Badie, S. (2022). Why display motion on packaging? The
 941 effect of implied motion on consumer behavior. *Journal of Retailing and Consumer Services*,
 942 64, Article 102840. <https://doi.org/10.1016/j.jretconser.2021.102840>
- 943 Zwebner, Y., Lee, L., & Goldenberg, J. (2014). The temperature premium: Warm
 944 temperatures increase product valuation. *Journal of Consumer Psychology*, 24(2), 251-259.
 945 <https://doi.org/10.1016/j.jcps.2013.11.003>