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Validation of food visual attribute perception in virtual reality

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ABSTRACT

This study aimed to test the validity of visual representations of food products in virtual reality by comparing descriptions of a set of actual vs. virtual cookies. This validation is key to future applications of virtual reality in sensory studies. Ten commercial cookies were virtualized by photogrammetry then configured inside virtual sensory booths designed using Unity and presented via a first-version HTC Vive virtual reality headset. Flash profiling was used to determine changes in relative weight of the perceptual dimensions in the product space and compare descriptions of actual vs. virtual product appearance. Conventional profiling of both actual and virtual products then served to determine whether common sensory dimensions carry the same kind of weight in both real and virtual sensory spaces and show similar ranges of difference among products. The results showed that descriptions of virtual cookies were close to descriptions of the actual cookies. Brightness carried more weight in the perceptual space of actual products whereas color contrast carried more weight in the perceptual space of virtual products. However, this difference may have arisen from software-setting configurations that could be optimized for a better match. Taken together, the results of this study offer promising perspectives for the use of virtual products in sensory and consumers studies.

Keywords: virtual reality, virtual food, visual perception

1. INTRODUCTION

Contextual variables are now known to modulate food experience and behavior (Dacremont & Sester, 2019; Galiñanes Plaza et al., 2019 ; Meiselman, 2019), which has prompted sensory and consumer scientists to move away from laboratory experiments with high internal validity towards observational studies of spontaneous behavior that provide high external validity. For decades, sensory studies either carried high internal validity but low external validity (central location tests) or high external validity but low internal validity (home-user tests). Immersive setups have since been developed to secure both internal and external validity: experimental conditions were controlled to ensure all products are tested in a comparable way, and participants are immersed in an ecologically valid environment reproducing a consumption episode (Jaeger &

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62 36 Porcherot, 2017). As the level of immersion modulates product evaluations (Hathaway & Simons, 2017),
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64 37 increasing the realism of the environment should improve the reliability of sensory measurements. Virtual
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66 38 reality (VR) promises to meet this challenge.

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69 40 VR is more than electronic devices—it is a concept (Fuchs et al., 2006) designed to enable cognitive
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71 41 and sensorimotor activities in a numerically-built world that can be imaginary, symbolic, or a simulated reality.
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73 42 VR offers the possibility to leave the physical environment and enter a virtual-world experience that operates
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75 43 a different scale of time, location, or type of interactions with the environment. Compared to a physically
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77 44 recreated environment, a VR environment can be quickly modified to change context, for example to change
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79 45 from a kitchen to a public place to repeat the same odor assessment (Porcherot et al., 2018). Compared to a
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81 46 360° video (Andersen et al., 2019; Sinesio et al., 2019; Stelick et al., 2018), VR offers the further possibility of
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83 47 interacting with the environment (Table 1). However, sensory and consumer sciences have only recently
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85 48 started to investigate the use of VR, so whether and how new VR-enabled methodologies really can transform
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87 49 research practice remains to be explored (Jaeger & Porcherot, 2017).

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92 51 "Insert Table 1 here" -> (Ullman, 2020)
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101 53 Several studies have already validated VR for specific applications, including decision-making and
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103 54 purchase intention (Schnack et al., 2018; Siegrist et al., 2019), serving size in a food buffet (Persky et al., 2018;
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105 55 Ung et al., 2018), hedonic and emotional product assessments (Sinesio et al., 2019), food disgust (Ammann et
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107 56 al., 2020), food craving (Ledoux et al., 2013), stimulus-context congruence (Porcherot et al., 2018),
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109 57 visualization of complex product structure in the design phase (Crofton et al., 2019), and memorization tasks
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111 58 (Ouellet et al., 2018).

112 59
113 60 The technological solution most frequently used to manipulate an actual food product in a VR
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115 61 environment is cropping the virtual image to see the actual product in the surrounding VR space (see Sinesio
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117 62 et al., 2019; Ammann et al., 2020). Using a simulated virtual product in the VR environment (Ledoux et al.,
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119 63 2013; Persky et al., 2018; Ung et al., 2018) provides a frame for further additional applications such as cross-
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121 64 modal interactions, with the possibility of varying expectations from product appearance while-keeping the
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123 65 other sensory modalities (texture, flavor, etc.) constant. Narumi et al. (2011) added a virtual chocolate layer
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125 66 on a plain biscuit. However, their virtual product was embedded in a real environment, their approach used
126
127 67 an 'augmented reality' which, unlike VR, does not allow any interactivity with the environment. Food product
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129 68 design is another practical application for presenting virtually simulated products in virtual environments. VR
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131 69 makes sample homogenization easy, either by hiding a brandname stamped on chocolates or biscuits,

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121 70 duplicating samples for visually heterogeneous products, or testing visual appreciation of products that do not
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123 71 yet exist.

124 72
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126 73 There are promising applications surrounding the use of a virtual food product in a virtual
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128 74 environment. However, a prerequisite is to first ensure the accuracy of the visual product simulation. Many
129 75 aspects of behaviors in VR overlap with behaviors in real life (Fink et al., 2007; Persky et al., 2018; Ung et al.,
130
131 76 2018). However, for food products, consumer perceptions/choices could be very sensitive to the visual realism
132 77 of the food image depicted (Crofton et al., 2019). Ledoux et al. (2013) reported significantly less food craving
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134 78 induced in VR than in real-world conditions, and they went on to question the visual rendering of their VR
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136 79 system.

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138 81 This study was designed to explore the visual realism of a simulated food product in a full-VR
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140 82 environment. As we set out to explore the possibilities offered by a new technology, we started with the basic
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142 83 requirements. We compared the visual perception of food products assessed in real conditions (an actual
143 84 product in natural environment) and in VR (virtual simulation of the same products presented in VR depicting
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145 85 the same environment). We used a set of cookies that display high visual complexity, and we investigated the
146 86 degree of similarity between the actual and virtual food spaces in an exercise describing the appearance of
147
148 87 the cookies. In order to explore how far a VR methodology can push the visual realism of a food product, we
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150 88 used the scanning method that currently gives the most realistic rendering possible, i.e. photogrammetry, on
151 89 processed food products purpose-chosen to present visual complexity. Our first objective was to explore
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153 90 whether perceptions were distorted in VR by determining changes in the relative weight of the perceptual
154 91 dimensions in the product space. The second objective was to determine whether common sensory
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156 92 dimensions carry the same kind of weight in both real and virtual sensory spaces and show similar ranges of
157 93 difference among products.

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180 94 **2. GENERAL MATERIAL**
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184 96 **2.1. Participants**

185 97 We recruited 20 subjects (15 females and 5 males; mean age 37 years ± 11) from among the staff at
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187 98 AgroParisTech who were regular participants in sensory tests without being experts in the domain. The
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189 99 subjects chosen were regular cookies consumers who were available to participate in the study. Volunteers
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192 101 gave informed consent and received monetary compensation. All of them completed study 1, and 16 of them
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195 102 (11 females and 5 males) completed study 2.

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197 103 **2.2. Food products**

196 104 We selected a set of 10 cookies from a supermarket (**Fig. 1**) and took two cookies from the same batch
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198 105 (Pe1 and Pe2) for internal validation. To keep the exact same set of cookies during the whole study, we
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200 106 strengthened them with a universal colorless matt Luxens® varnish (batch number: 195529 121017).

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203 108 "Insert Fig.1 here"

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206 110 **2.3. Virtualization**

207 111 **2.3.1. Virtual cookies**

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209 112 After varnishing, the cookies were virtualized by photogrammetry. Photogrammetry is a method widely
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211 113 used in fields from topographic mapping, surveying, civil engineering and archaeology to urban, agricultural
212 114 and environmental planning. Since 2014, it has increasingly been used in game design as it can recreate real-
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214 115 word assets faster than with a non-photogrammetric method (at the same level of realism) and support the
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216 116 push for hyper-realistic textures. Furthermore, it does not require a large team of developers nor any
217 117 sophisticated equipment (Statham, 2018). Here we proceeded in three steps: picturing, virtual reconstruction,
218 118 and configuration of the virtual environment. This virtualization protocol is suitable for a rigid and relatively
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220 119 thin product with a geometric shape and an average size.

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223 121 **Picturing**

224 122 80 pictures per cookie were taken using a Canon EOS 750D® camera. To automate the process, the cookies
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226 123 were placed inside a ScanCube® (see **Table 2** for the parameters), giving 8 points of view, with 10 pictures for
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228 124 each, in 360°.

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128 **3D reconstruction**

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134 The pictures served to virtually reconstruct the cookies in 3D using Agisoft Photoscan® Software (version 1.2) and the reconstructions were exported to .fbx format supported by Unity 2017.2.0f3® software (**Fig. 2**).

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134 **Configuration in the virtual booth**

135 One by one, the reconstructed cookies were imported into virtual sensory booths in Unity 2017.2.0f3® .
136 First, virtual size was first adjusted to match real size, then the cookies were given physical attributes to enable
137 interaction with the user. To get convincing physical behavior, the cookies were implemented with the
138 following Unity object parameters: Rigidbody, Box collider, Mesh renderer, VRTK-InteractableObject, VRTK-
139 ChildOfControllerGrabAttach, and VRTK-InteractHaptics.

140 For testing, cookies were anonymized by a three-digit number presented virtually with a green bubble
141 (**Fig. 3**) in the virtual condition and on a cardboard tag attached with Blu-Tack (Patafix®) in the real condition.

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145 **2.3.2. Environmental design**

146 We wanted to keep a neutral environment to properly compare the products, and so they were assessed
147 in sensory booths. For the real condition, we used AgroParisTech sensory booths (at the Massy Center) (**Fig.**
148 **4A**). For the virtual condition, we used identically-copied virtual sensory booths designed with Unity®
149 2017.2.0f3 software (**Fig. 4B**), where each participant sat down, put on the HTC Vive® headset (first version),
150 and used the two controllers to interact with products inside the booth (the participant was implemented as
151 a first-person player in the virtual world).

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155 **2.4. Methods**

156 To check changes in the relative weight of the perceptual dimensions in the product space, we performed
157 a flash profiling study (study 1). Then, working from the compiled real and virtual descriptor lists generated in,
158 we trained the remaining participants from study 1 to complete a conventional profile in order to assess
159 whether these sensory dimensions are perceived similarly between real and virtual conditions (study 2). Half
160 of the participants started with the virtual-product evaluation in each study, while the other half started with
161 real-product evaluation. To ensure that all participants were equally familiarized with using the VR devices,

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162 before their first VR session they attended a 20-minute gaming session where no cookies or description tasks
163 were involved, in order to teach them how to grab and move an object and check for absence of virtual reality
164 sickness ('cybersickness').

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166 Cookies were tested in individual sessions, and real cookies were handled with gloves and taken carefully
167 by the edges to prevent causing any damage and maintain product integrity. For both studies and in both
168 conditions, all instructions and answers were given orally.

3. STUDY 1

To understand the distortion of visual product perception (determining changes in the relative weight of the perceptual dimensions in the product space), we used the flash profile method which initiates comprehension of the most important attributes of a product set while preserving inter-individual differences, as the participants use their own words and are not limited to a number of attributes (Dairou & Sieffermann, 2002). The flash profile technique has been applied to analyses of many different food-product categories including jams (Dairou & Sieffermann, 2002), dairy products (Delarue & Sieffermann, 2004), jellies (Blancher et al., 2007), wines and model wines (Fan et al., 2007; Liu et al., 2018, 2016), hot beverages (Moussaoui & Varela, 2010), lemon iced teas (Veinand et al., 2011), fish nuggets (Albert et al., 2011), liver pâté (Dehlholm et al., 2012), and even microbiological models (Gkatzionis et al., 2013). Here we conducted flash profiling with 20 participants to ensure better configuration plot stability (Liu et al., 2018).

3.1. Method

3.1.1. Procedure

The twenty participants were split into two groups of 10 with comparable female/male ratios (8/2 and 7/3). One group started by the virtual condition (S1 to S10) and the second group started by the real condition (S11 to S20).

In both conditions, participants individually took part in two sessions. In the first session, the whole set of cookies was presented all at once (according to a Williams Latin square design) and the participants generated any terms that would describe differences among products. All terms generated by the group were then compiled into an exhaustive list that was presented at the beginning of the second session. Participants were allowed to amend their initial list by adding or dropping terms. They then ranked the 10 cookies against each descriptor in their own final list.

An experimenter was present throughout the whole session, inside the next booth on the left of the participant, to give oral instructions to participants and collect their orally-reported rankings.

3.1.2. Data analysis

In total, the panelists used 254 descriptors to rank the real cookies and 265 to rank virtual cookies. Descriptors were grouped into five categories: geometry, color, visual texture, chunk distribution, and brightness. The number of descriptors per category was compared across experimental conditions.

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202 A generalized Procrustes analysis (GPA) was run on the ranking data to assess the consensus between
417 assessors' sensory maps, considering each descriptor from each panelist (Gower, 1975). The two conditions
418 203 were analyzed separately. On the variable coordinates from a principal component analysis (PCA) of this first
419 204 GPA, we ran an ascending hierarchical classification (AHC) to be used as a support for constructing meta-
420 205 descriptors for our final GPA analysis. Four independent analysts grouped descriptors based on semantic
421 206 meaning. If differences emerged, they tried to reach a consensus on the meta-descriptors. If no consensus
422 207 was found, the descriptor was dropped from subsequent analysis. The whole process was conducted in French,
423 208 and the meta-descriptors were then translated into English. Finally, we ran a GPA based on these meta-
424 209 descriptors to get an overall cookie space in both conditions. The real and virtual experimental conditions
425 210 were analyzed separately. Axes were captioned with the descriptors identified as consensual between
426 211 participants and correlated to the axis ($|\rho| > 0.6$).
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435 214 3.2. Results & Discussion

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437 215 According to the vocabulary distribution in the 5 perceptual categories (**Fig. 5.**), the main difference
438 216 across experimental conditions was the frequency of descriptors linked to brightness, with 12 words used for
439 the real-condition description versus 1 word used for the virtual-condition description.
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443 219 GPA showed a close rate of vocabulary consensus between participants in real and virtual conditions,
444 220 and we validated the coherency of participants' answers based on the proximity of our two cookies taken from
445 the same box (Pe1 and Pe2). On map 1-2 (**Fig. 6.**), when we align the orientation of both condition maps
446 221 according to the common correlated descriptors, it shows similar product positions, which indicates that
447 222 participants ranked products in a similar way between real and virtual conditions. Nevertheless, the products
448 223 appeared to be slightly more discriminated in the real condition, as some cookies had a more distant position
449 224 on axis 2 on the real condition map. This difference was mainly linked to brightness ("Bright"), shape ("Thick",
450 225 "Curved", "Soufflé") and visual texture ("Cracked", "Bumpy") attributes, which were also linked to this axis.
451 226 To better understand the origin of this small discrepancy, we went on to use conventional profiling to gain a
452 227 quantitative assessment (**see study 2**).
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459 229 In conclusion, despite some differences that were probably brightness-related, perceptions of the cookies
460 230 were fairly similarly between the two experimental conditions. As only one brightness descriptor was cited in
461 the virtual condition, it led us to posit that the two conditions may carry all the same dimensions but that
462 231 these dimensions may not carry the same weight, and so differences among products are not identically
463 232 perceived. We thus conducted study 2 to explore this second hypothesis.
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"Insert Fig.6 here"

4. STUDY 2

To obtain quantitative descriptive data and evaluate whether the differences among products were perceived equally in real and virtual conditions for each perceptive dimension, we led a conventional profiling study in both experimental conditions. The protocol was borrowed from the QDA[®] procedure described by Stone et al. (1974) and ISO standard EN 11035 (ISO 1994). In comparison with flash profiling, conventional profiling provides a quantitative measure of intensity differences in sensory attributes (Dehlholm et al., 2012; Liu et al., 2018). Following the advice given by Dairou & Sieffermann (2002), we used flash profiling as a preliminary phase of the conventional profiling to provide key attributes.

4.1. Method

4.1.1. Procedure

After study 1, we gathered together the real and virtual descriptor lists, and then 16 of the 20 participants (11 females and 5 males) followed three 1h45 training sessions (in sub-groups according to time availability):

- Session 1: Additional vocabulary generation, vocabulary definition and semantic grouping.
- Session 2: Ranking exercises with simple models, consensus on descriptors, and shortening of the attributes list.
- Session 3: Definition of the scale limits, with pictures and 3D-printed models (**Fig. 7**). Training on use of the scale with real cookies.

“Insert Fig.7 here”

The 3D-printed models were designed with the base of a real cookie dough scan, then the chocolate chips were artificially created. Sizes, shapes and distributions were adjusted for the dough and the fake chocolate chips to fit the scale limits of our set of cookies for the relevant attributes.

After the group sessions, the 16 panelists were trained in four individual sessions (two sessions with real products and two sessions with virtual products). Panelists assessed 3 new real cookies and 3 new virtual cookies that were all different from the final evaluation set. For all sessions and including final evaluation, all instructions and answers were given orally, and a scale memo was presented in the sensory booths (**Fig. 8.**).

“Insert Fig.8 here”

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271 For the final evaluation, participants assessed the same 10 cookies used for flash profiling, in triplicate
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273 for each condition. To alternate real with virtual, they were organized keeping the same two groups as
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274 during the flash profiling phase (without the participants who did not attend this study: S1, S4, S16 and
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275 S19). Cookies were rated on 40 descriptors (**Table 3**).

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276 "Insert Table 3 here"

602 603 604 278 **4.1.2. Data analysis**

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279 First, for each attribute, we ran individual one-way ANOVAs for product effect in each experimental
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280 condition separately in order to compare vocabulary use. Then, to see the global differences in product
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281 perceptions, we ran a quadratic discriminant analysis (QDA) with the assessment data (Hastie et al., 2008) on
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282 the two conditions together to compare the two product spaces, using the cookies as the qualitative variable.
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283 Finally, after checking the consensus on descriptors (with PCA/judges per attribute), we ran three-way
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284 ANOVAs (condition, cookie, judge) for each attribute to explain the variability of visual attributes by the effects
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285 of condition, product and judge, and their interactions.
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617 286 618 287 **4.2. Results & Discussion**

619 288 **4.2.1. Descriptors use**

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289 **Fig. 9** shows the number of descriptors that had significant product effect (p-value lower than 0.05) for
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290 each participant and in both conditions. Overall, the number of discriminant descriptors was similar across
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291 experimental conditions, which indicates that participants did not experience more difficulties rating intensity
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292 in the virtual condition than in the real condition.
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296 **Fig. 10** shows the number of participants with a significant product effect (p-value lower than 0.05) for
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297 each descriptor and each experimental condition. Among the 40 descriptors, 33 discriminated cookies for a
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298 similar number of participants (± 2) across experimental conditions.
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302 For 7 descriptors ('heterogeneous shape of chocolate chips', 'chocolate chips inside the dough', 'raisin-
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303 like chocolate chips', 'many darker spots', 'chocolate chips with red-orangy hue', 'bright', and 'bright chocolate
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304 chips'), the difference in discriminant participants was larger by at least 3 participants. The biggest real-virtual
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652 305 differences were for the 'bright' and 'bright chocolate chips' descriptors, which had between-condition gaps
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654 306 of 9 and 12 participants, respectively.

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657 308 To sum up, most of the descriptors appear to be just as useful for discriminating cookies in real conditions
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659 309 as in virtual conditions. For the descriptors 'heterogeneous shape of chocolate chips', 'chocolate chips inside
660 310 the dough' and 'raisin-like chocolate chips', the cookies were better discriminated in the real conditions. These
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662 311 differences in visual texture descriptors could be explained by a different perception of the relief details. For
663 312 the descriptors 'many darker spots' and 'chocolate chips with red-orangy hue', the cookies were better
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665 313 discriminated in the virtual condition, which could be explained by a better perception of color contrasts with
666 314 virtual cookies. Finally, for the descriptors 'bright' and 'bright chocolate chips', the cookies were better
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668 315 discriminated in real conditions, which means that brightness is better perceived with real products and
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670 316 suggests that brightness is difficult to accurately reproduce in VR.

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673 318 **4.2.2. Product map comparison**

674 319 The maps obtained by quadratic discriminant analysis showed that the two versions for a given cookie, in
675
676 320 real and in virtual conditions, were always close. As they were not exactly at the same position, there were
677 321 some small sensorial differences between the two. Either way, differences between cookies (in real or in
678
679 322 virtual conditions) were stronger than the differences between real and virtual versions of the same product
680
681 323 (**Fig. 11**). In the two conditions, the difference between cookie MV-Real vs MV-Virtual and all the other
682 324 products was so magnified on axis 2 that it eclipsed any other differences among non-MV-group products,
683
684 325 thus prompting us to also consider axis 3. Axis 2 was correlated to the attribute 'different color of chocolate
685 326 chips', and the MV cookie was the only one with a blend of milk and dark chocolate chips, i.e. the only product
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687 327 that has chocolate chips with obvious heterogeneous color.

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690 329 On axis 3 (**Fig. 12**), each cookie located to the same relative position in the two conditions.

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699 335 **4.2.3. Interactions per descriptors**

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701 336 As the p-values were quite low (mean 0.017, median 10^{-18}), we calculated the LogWorth $-\log(p\text{-value})$
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703 337 for each model effect. This transformation adjusts the p-values to give an appropriate scale. A value of 2 is
704 338 significant at the 0.01 level, a value of 3 at the 0.001 level, etc.

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713 340 First, for 26 descriptors, cookie is the strongest effect (first 26 rows of **Table 4**). Among these 26, judge
714 341 is the second strongest effect except for 'Different colors of chocolate chips' and 'Brown' where cookie x judge
715 342 and condition x cookie, respectively, are the second strongest effects, but they only represent a tenth of the
716 343 cookie effect.
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720 345 Second, except for two descriptors ('more chocolate chips on the top than the bottom' and 'dough-
721 346 chocolate balance'), all other descriptors had significant condition × cookie interactions, meaning that
722 347 virtualization could have a different cookie-dependent impact on perception. However, the condition effect
723 348 or one of its interactions with another effect only had a higher LogWorth than the cookie effect for three
724 349 descriptors: 'Darker edge', 'Presence of nuts' and 'Bright chocolate chips'. The 'Bright' descriptor is almost
725 350 close to these cases, as condition and cookie effects have LogWorth values of 82 and 129.8; respectively.
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729 351

730 352 To illustrate the benefit of comparing effects based on LogWorth instead of p-values, let us consider
731 353 4 descriptors: 'Large diameter', 'Brown', 'Bright' and 'Bright chocolate chips'. For all 4 descriptors, the
732 354 condition × cookie interaction had a p-value below 0.05. For the first two, the LogWorth of this interaction is
733 355 very low compared to the LogWorth of the cookie effect. For the last two, the LogWorth of this interaction is
734 356 comparable to the LogWorth of the cookie effect. The differences between these two cases can be seen on
735 357 **Fig. 13**. For the first two (top of the **Fig.13**), the scores of the cookies are almost the same in the two conditions.
736 358 For the last two (bottom), not only the scores but also the rankings of the cookies are different between real
737 359 and virtual conditions. This supports the idea that the brightness is globally less perceptible in virtual
738 360 conditions than in real conditions.
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742 362 As the cookies can lose brightness, the color contrasts were amplified in the virtual condition for 4
743 363 descriptors as 'Different colors top to bottom' (**Fig. 14**).
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747 365 "Insert Table 4 here"
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5. GENERAL DISCUSSION

From a qualitatively standpoint, this study showed close perceptions of the product set between real and virtual conditions, with similar descriptive patterns and closely-gathered products. Nevertheless, quantitative descriptive analysis highlighted different patterns of impact of brightness and color contrast. As we had chose our products for their visual complexity, these results should be applicable to products with the same attributes specifications, in other words products that can readily be scanned using the same protocol, i.e. rigid and relatively thin, with a geometric shape and an average size.

These results point to a possible application of VR in descriptive analysis for a specific food product category. In fact, if we focus on less-complex products, i.e. a mat, smooth and monochromatic product category like crisps, we could expect enough visual realism to move towards VR-enabled descriptive analysis.

Despite controlling a number of parameters for the camera images of the real product and the 3D reconstructions of the virtual product, some information appears to have been lost between these steps with the 2D projection of the cookie. However, the type of information lost here serves for the visual aspect of food products that we can now rebuild numerically. To improve VR perception for such 'complex' food product categories, the second strategy would be to use Unity's mesh configuration to change the way light interacts with the food product and thus modulate the way participants perceive it. For example, the normal map configuration can serve to embellish a model with surface details such as bumps, grooves and scratches that catch the light just as if they were represented by a real geometry. The smoothness configuration also makes it possible to control 'microsurface detail' or smoothness across a surface (Unity Technologies, 2019).

This study shows that photogrammetry enables enough realism to discriminate food products from the same product space in VR, but it requires a calibration phase to re-establish the lighting properties of the food products and check the perception of these numerical features by users. A virtual product that faithfully proxies the original product takes time but is entirely feasible. Another issue when using photogrammetry to achieve a realistic level of 3D reconstruction is that the process generates millions of dense polygon meshes that are particularly unsuitable for real-time rendering. In the video games field, environments are usually built from a mix of photogrammetric and non-photogrammetric assets to circumvent this problem (Statham, 2018). Likewise, in sensory evaluation applications, we could use photogrammetry only to design a realistic product, as the surrounding environment does not need the same high level of realism since the objective is to evoke consumption episodes rather than rebuild the identical place setting.

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829 403 We anticipate that VR could be used with sensory science upstream of advanced food processing and
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831 404 engineering steps (Kadri, 2007), where it could serve to change product parameters in a systematic way and
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833 405 test products that do not yet exist, at least on the appearance front. There are technologies that exist—like
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835 406 odor spatialization (Ischer et al., 2014; Porcherot et al., 2018), virtual flavors (Ranasinghe et al., 2019) and
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837 407 more—that can be mobilized to build a complete virtual product, but they remain fragmented. The hope is
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839 408 that as future developments emerge from other perceptions, we will one day have a fake product to put in
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841 409 the mouth.

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842 410 Descriptive analysis demands the very highest level of realism, which requires some improvement of the
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844 411 food product lighting configuration. Nevertheless, for hedonic studies, the impact of these realism differences
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846 412 may depend on the importance of each attribute for the product tested. Visual realism probably does not have
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848 413 the same impact in tests with different objectives, which may explain the differences reported in the literature
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850 414 comparing real against virtual conditions. Ung et al. (2018) and Siegrist et al. (2019) found good correlations
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852 415 in food behavior and decision-making between real and VR conditions, so we can assume that the visual
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854 416 realism level did not have any tangible impact on the quantity of food served from a food buffet or on the
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856 417 choice of cereals in a shop task. Brightness, for example, may have little importance for these tasks.
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858 418 Conversely, Ledoux et al. (2013) reported differences between real and virtual conditions in the induction of
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860 419 food craving, so the visual realism level may have a stronger influence when motivational mechanisms are
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862 420 involved. Deeper exploration is warranted to investigate the link between virtual food product realism and the
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864 421 reliability of the food behavior-related decision-making processes. Further research is planned to explore
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866 422 multi-criteria optimization of the product model as a route to increase the level of realism and reach the
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868 423 required threshold leading to the same behavioral decision.
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864 425
865 426 **6. CONCLUSION**

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867 427 This study paved the way towards using virtual food products in descriptive analysis. Today, VR is advanced
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869 428 enough to obtain good product realism, but it requires a configuration phase before product testing. The
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871 429 remaining issue is to understand the importance of realism level for non-descriptive tasks, such as decision
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873 430 tasks.

874
875 432 **7. ACKNOWLEDGMENTS**

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881 435 profile descriptors into meta-descriptors, Frederick Doulat for assistance with improving the cookie scanning
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883 436 protocol as part of a student project, and finally, all the cookie assessors for their participation.

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1
2 FIGURES TITLES – ‘VALIDATION OF FOOD VISUAL ATTRIBUTE PERCEPTION IN VIRTUAL REALITY’
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7 **Fig. 1.** Set of cookies set used for real–virtual comparison (presented here on the same scale).

8 **Mi:** “Milka Choco Cookies”. **Al:** “Allergo Cookies Pépites Chocolat”. **Co:** “Cora Cookies Maxi Pépites de Chocolat”. **Ga:**
9 “Gayelord Hauser Diététicien Cookies Pépites de Chocolat”. **Lu1:** “Lu Granola Gros Eclats de Chocolat”. **LuXM:** “Lu
10 Granola Cœur Extra Moelleux”. **BC:** “The Biscuit Collection Chocolate Cookies”. **MV:** “Matilde Vicenzi Premium
11 Cookies with Double Chocolate Chunks”. **Pe1 & Pe2:** “Pepperidge Farm Chocolate Chunk Milk Chocolate Cookies”.
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15 **Fig. 2.** Realism of a virtual cookie (“Co”) after Agisoft Photoscan® 3D reconstruction.
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18 **Fig. 3.** Examples of 3-digit code bubbles. Left: virtual bubble (virtual cookie **Pe1**). Right: real bubble (real cookie **Mi**).
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22 **Fig. 4.** A) AgroParisTech sensory evaluation room (Massy Center). B) Virtual booths identically rebuilt with Unity
23 2017.2.0f3 software.
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26 **Fig. 5.** Distribution of vocabulary used to rank the cookies.
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30 **Fig. 6.** Generalized Procrustes analysis and correlated descriptors, map 1-2. Left: real condition. Right: virtual
31 condition.
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34 **Fig. 7.** Examples of 3D printed cookie models used to define the min–max scale limits.
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38 **Fig. 8.** Left: real condition. Right: VR condition.
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41 **Fig. 9.** Number of descriptors with a p-value lower than 0.05 for product effect per judge.
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44 **Fig. 10.** Real–Virtual difference in number of judges with a p-value lower than 0.05 for the product effect per
45 descriptors (a negative number means there are more judges discriminating products in the virtual condition,
46 whereas a positive number means there are more judges discriminating products in the real condition).
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50 **Fig. 11.** Quadratic discriminant analysis, map 1-2. Left: Products position. Right: Descriptors correlation.
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53 **Fig. 12.** Quadratic discriminant analysis, map 1-3. Left: Products position. Right: Descriptors correlation.
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57 **Fig. 13.** Comparison of Condition × Cookie interactions. Top: Descriptors with low LogWorth value. Bottom:
58 Descriptors with high LogWorth value.
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Fig. 14. Condition × Cookie interaction of the descriptor “Different colors top-vs-bottom”.

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Mi



Al



Co



Ga



Lu1



LuXM



BC



MV

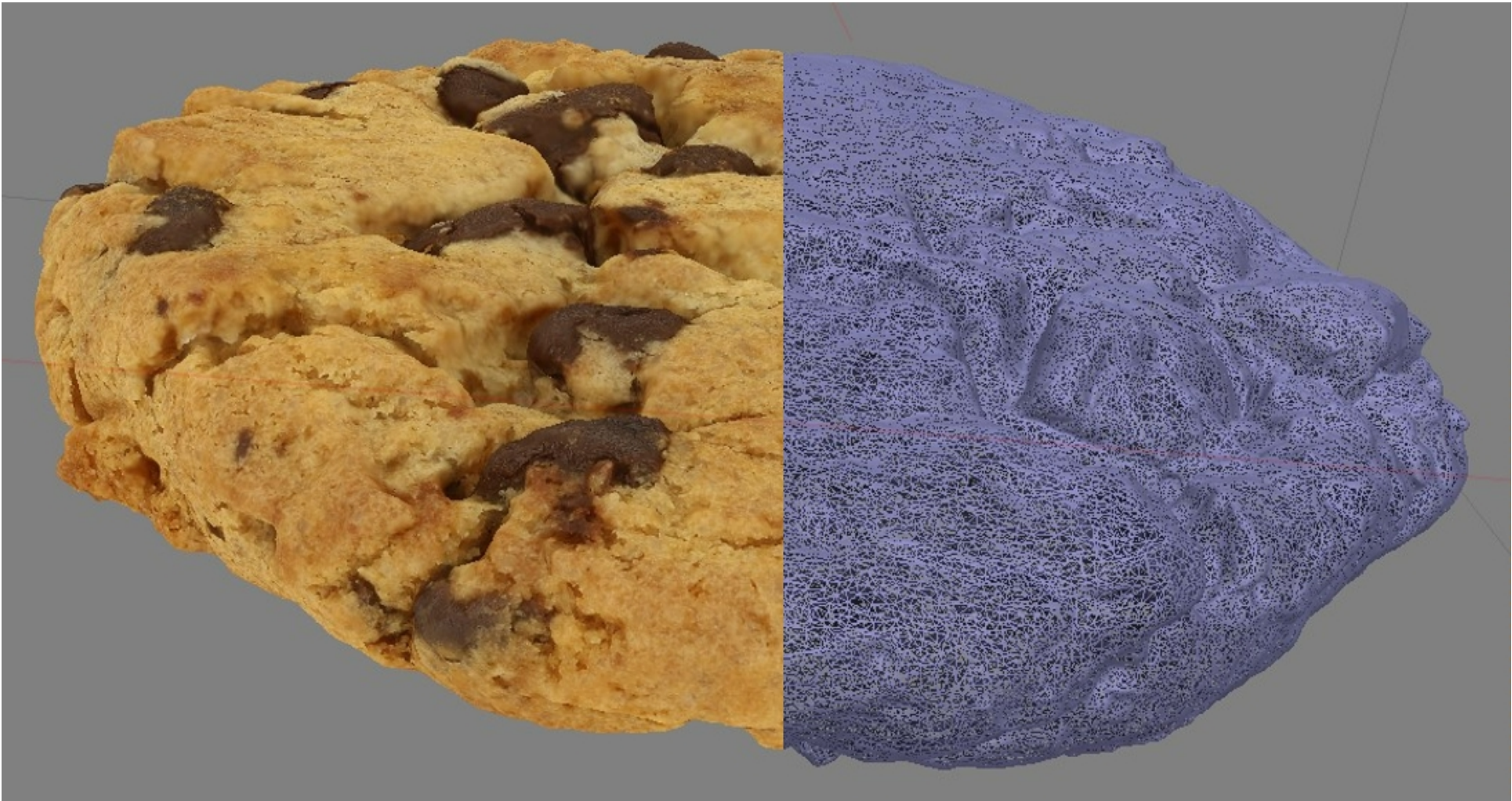


Pe1



Pe2

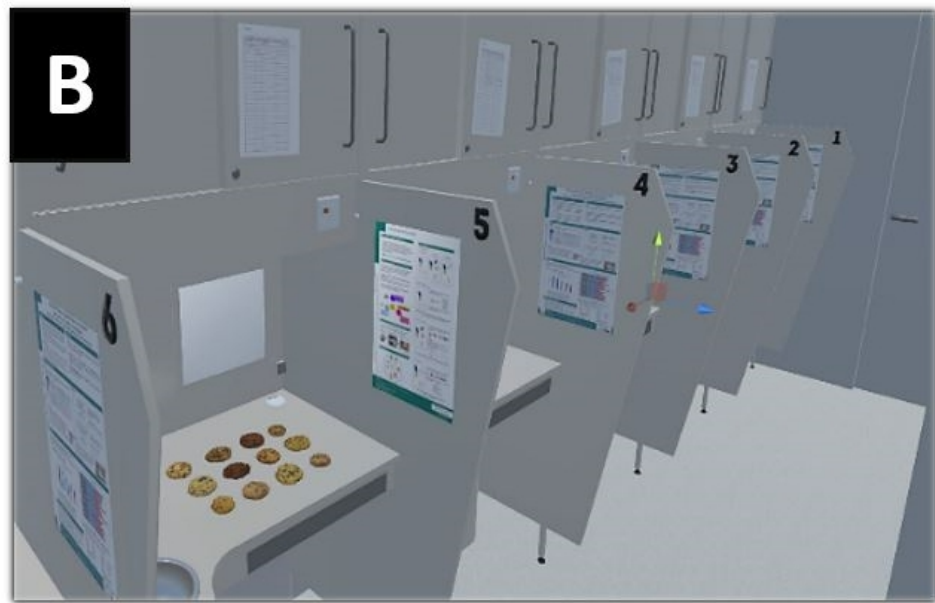
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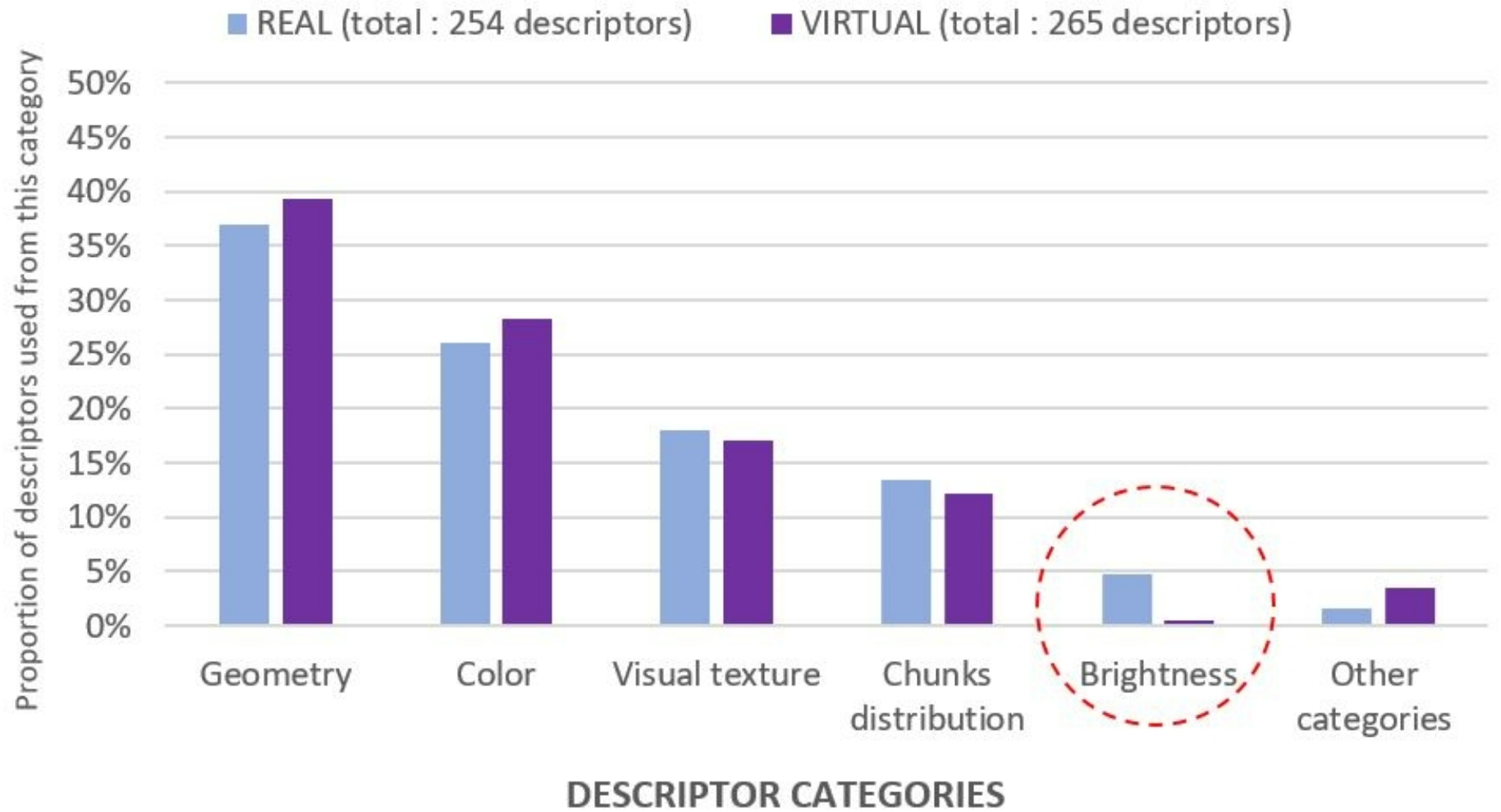


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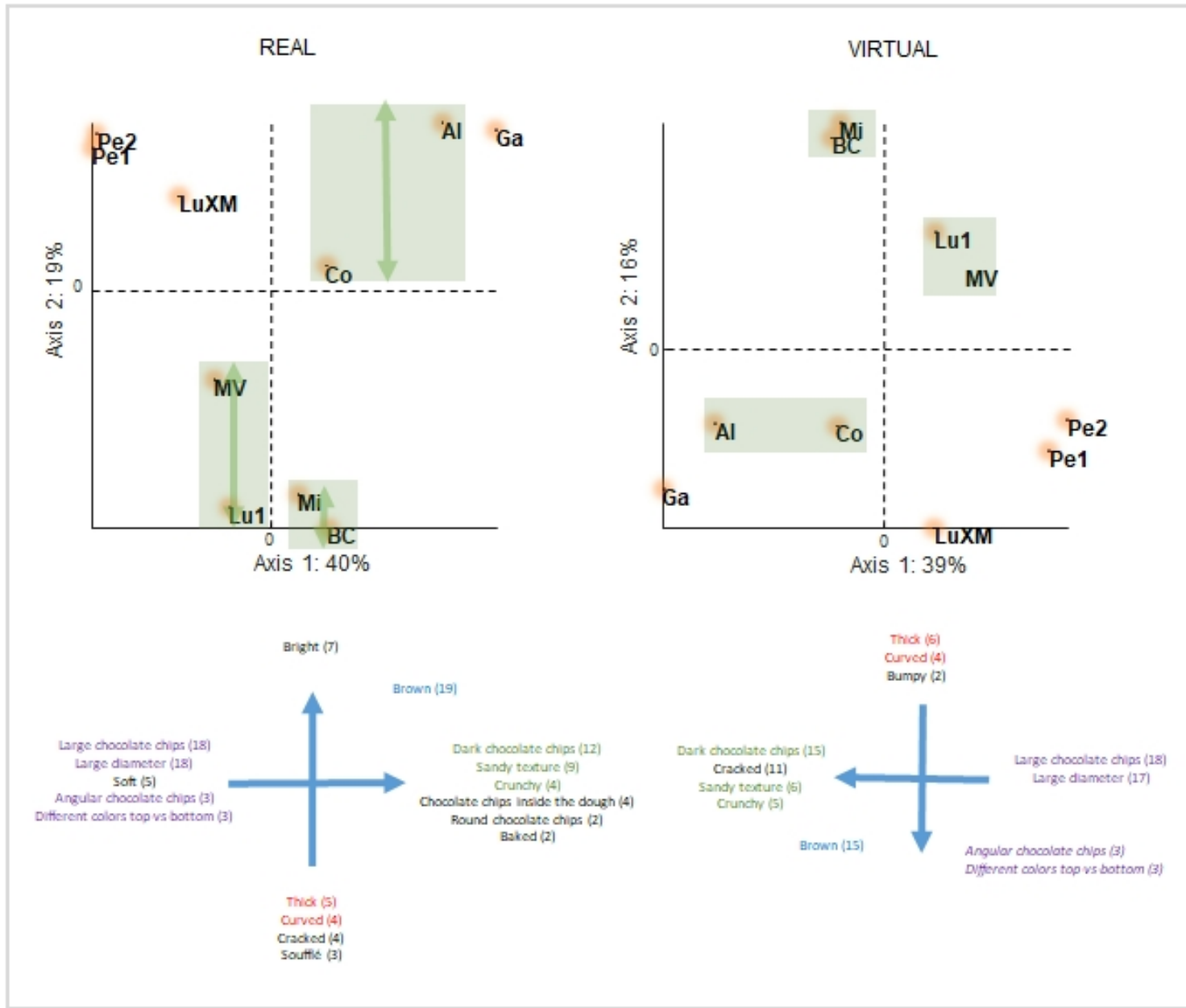
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Heterogeneous size of chocolate chips

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Curved

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Thick

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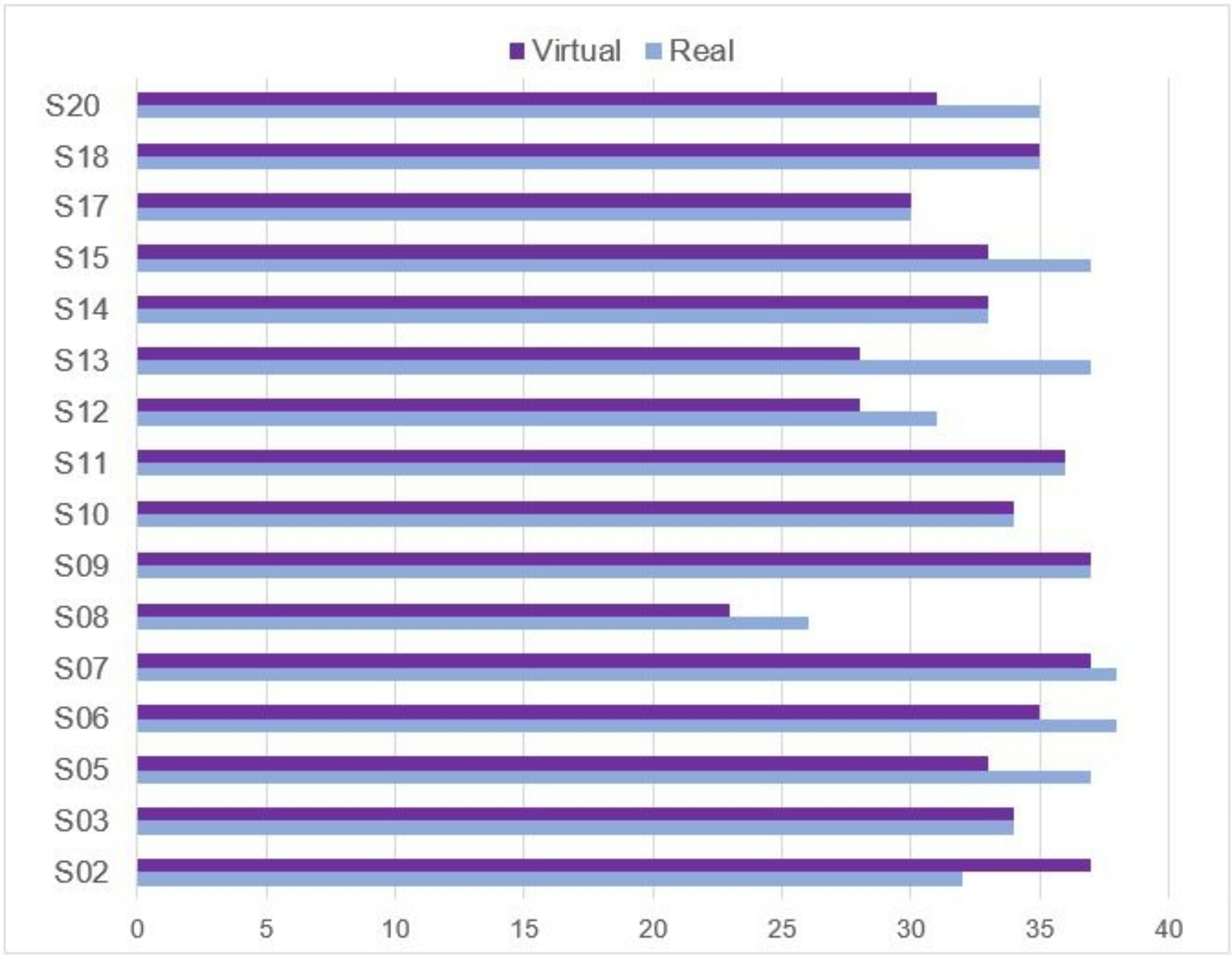
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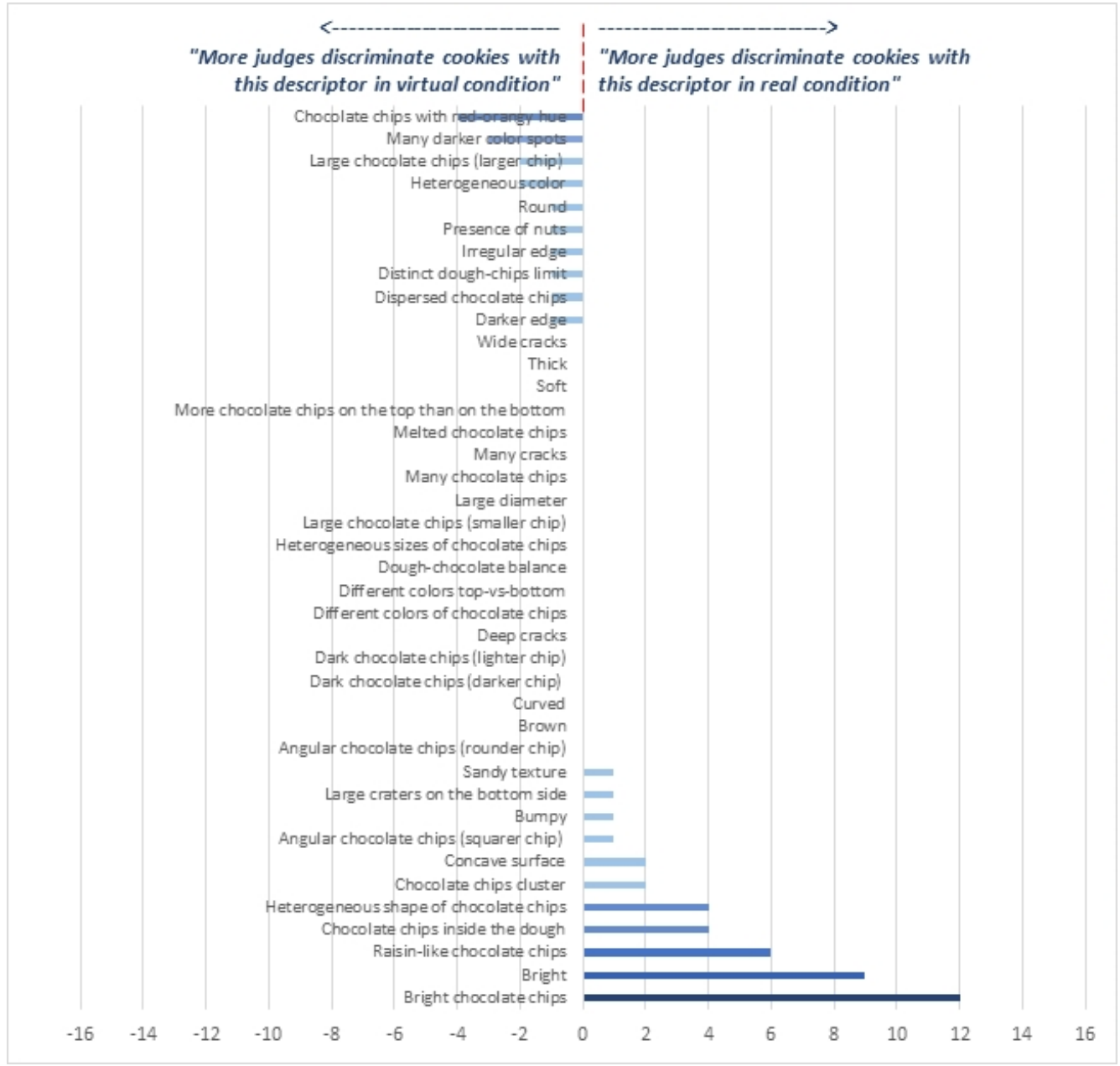
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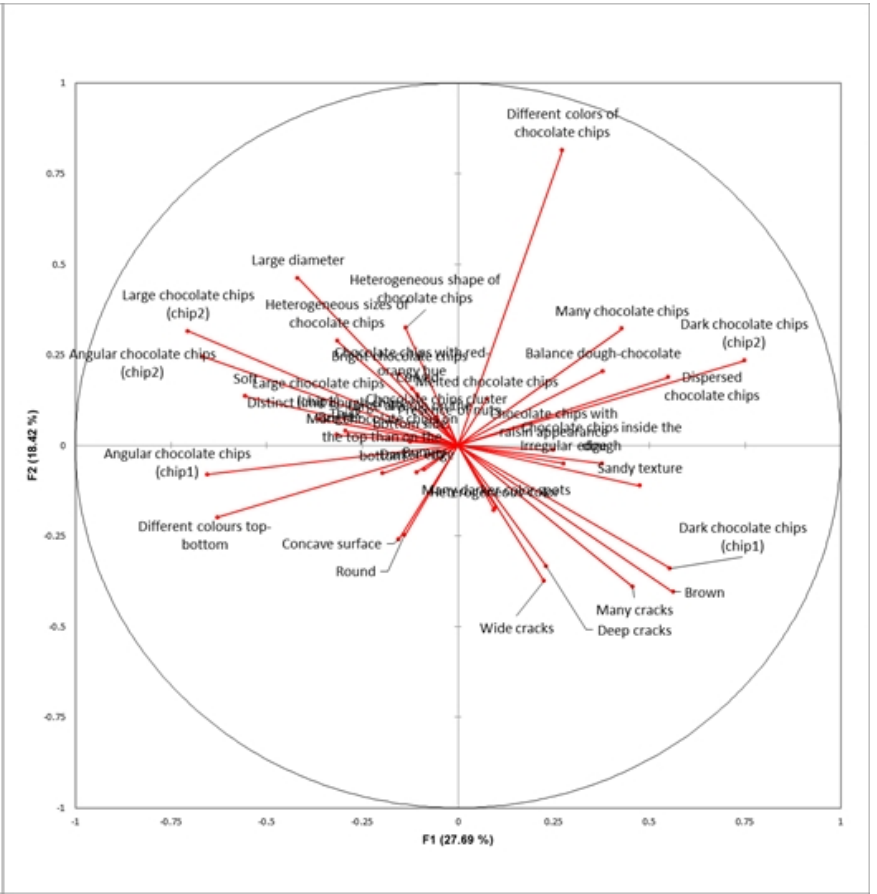
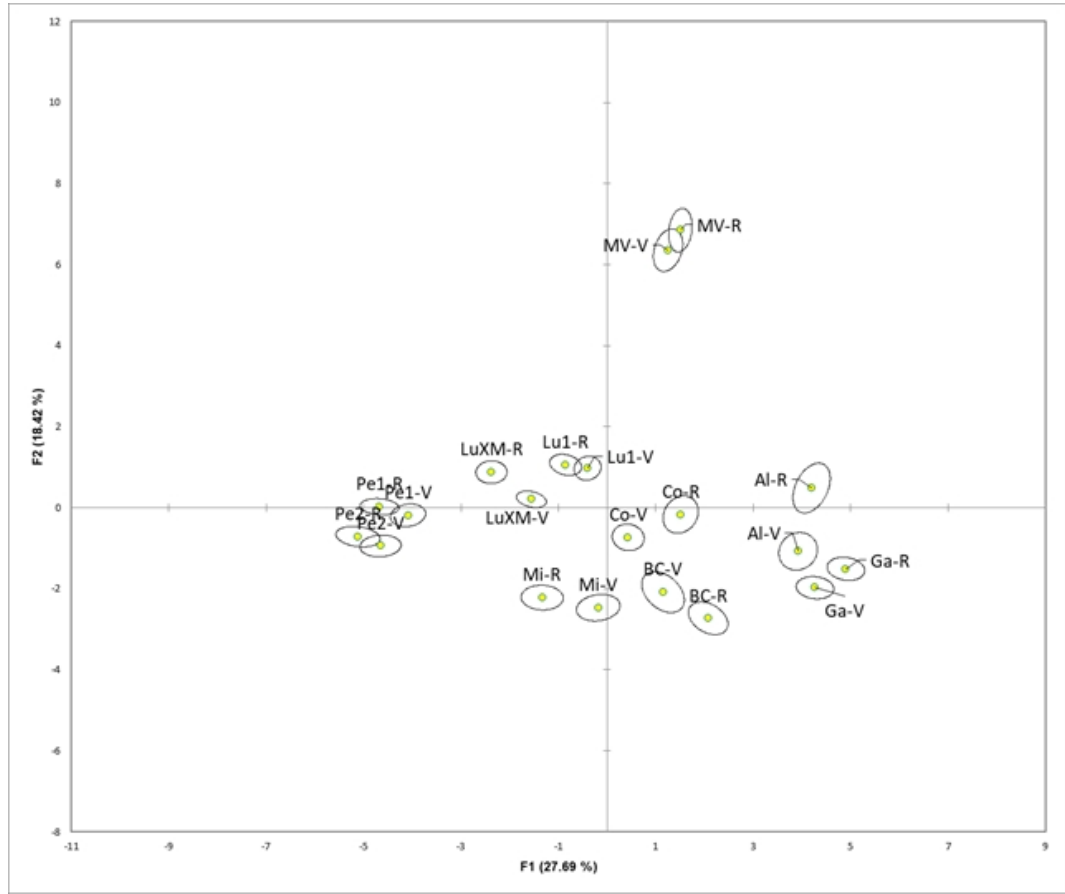
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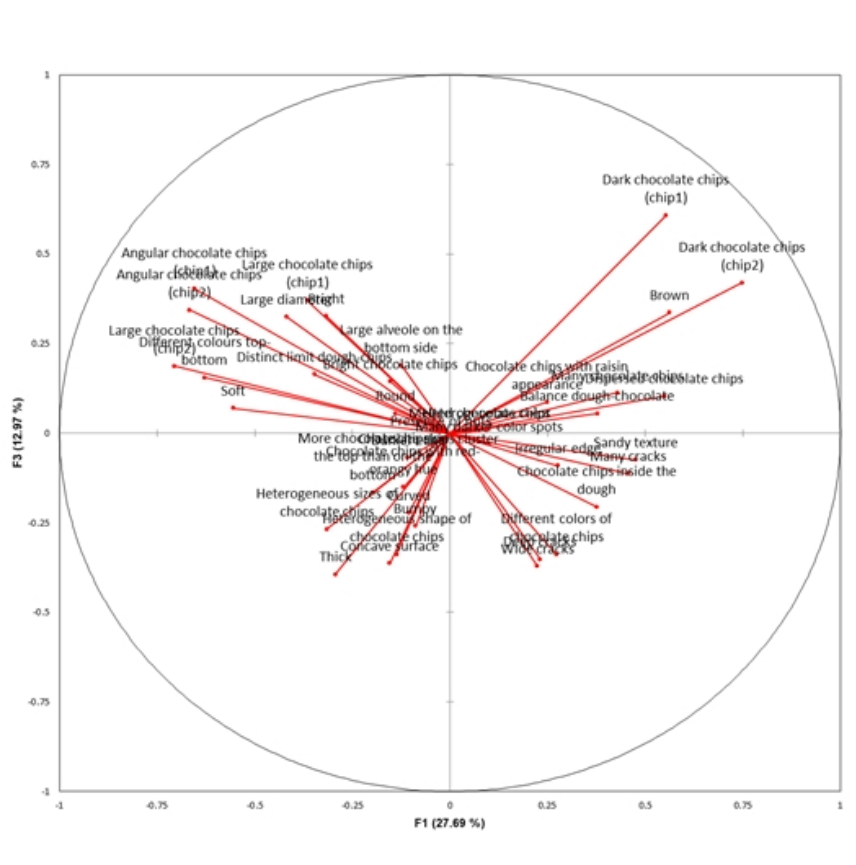
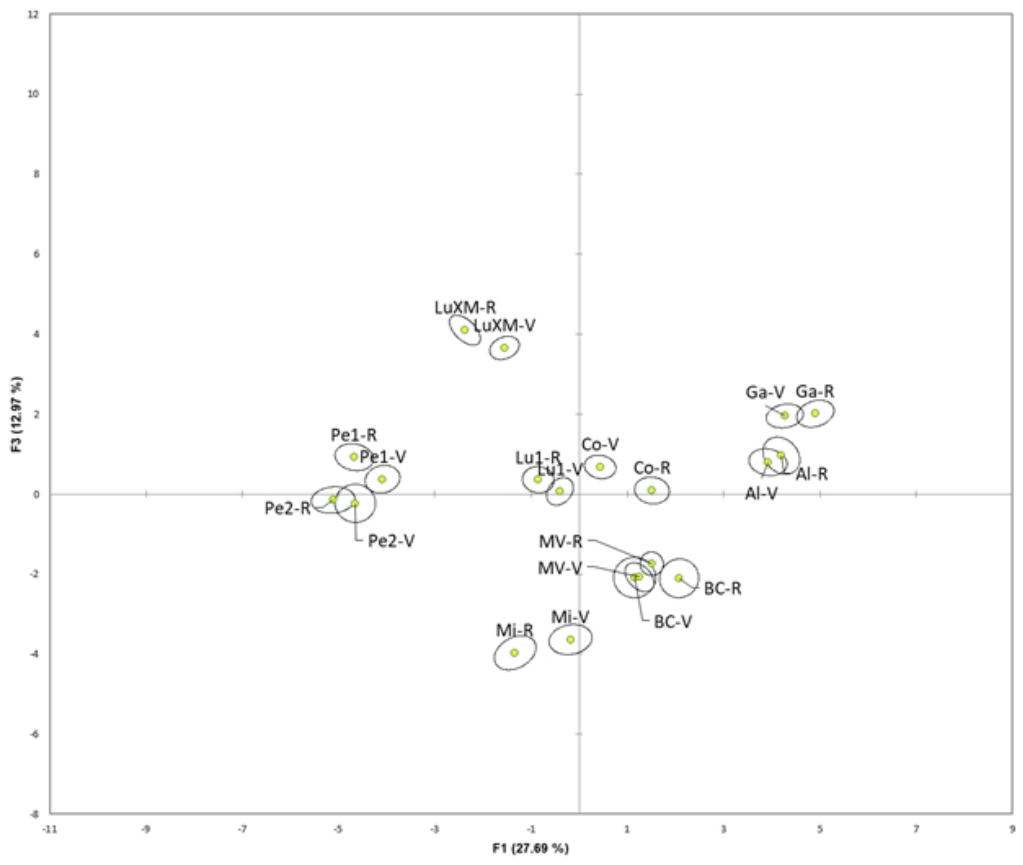
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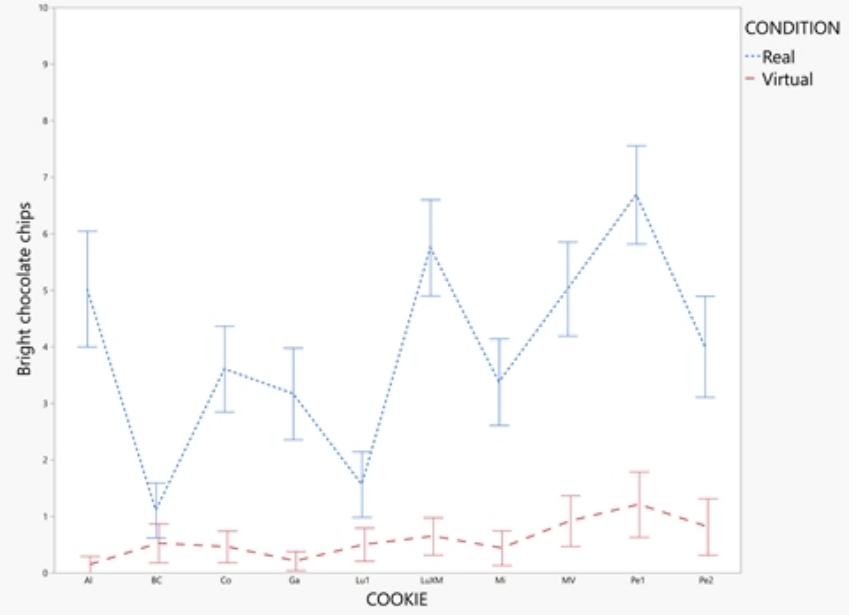
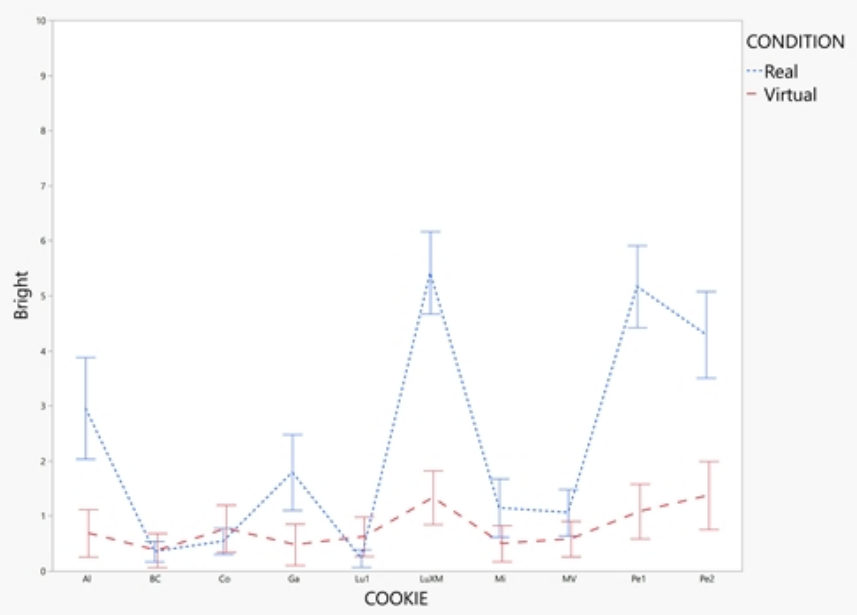
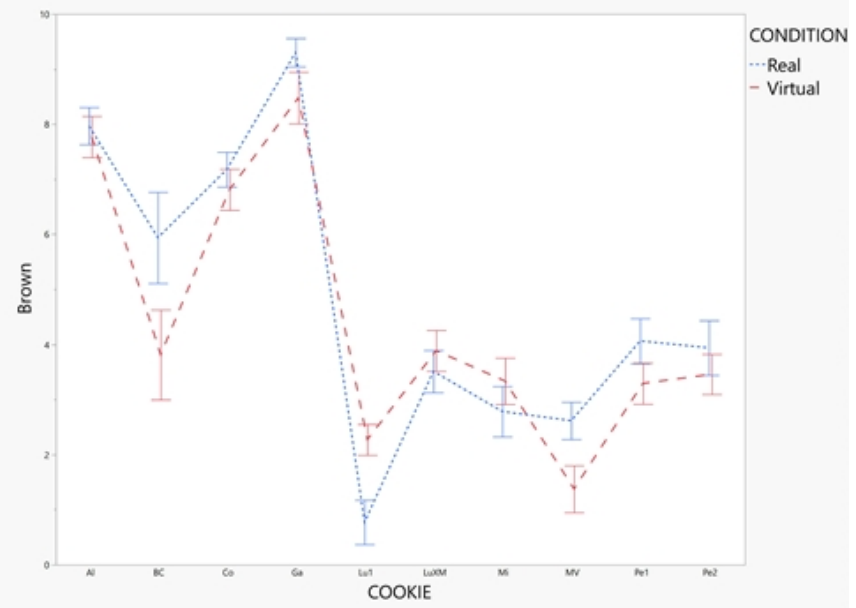
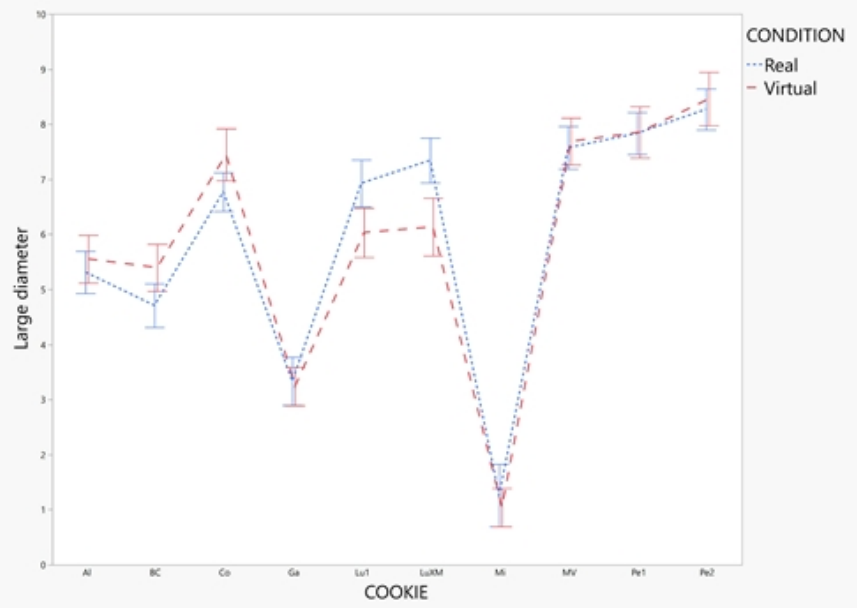
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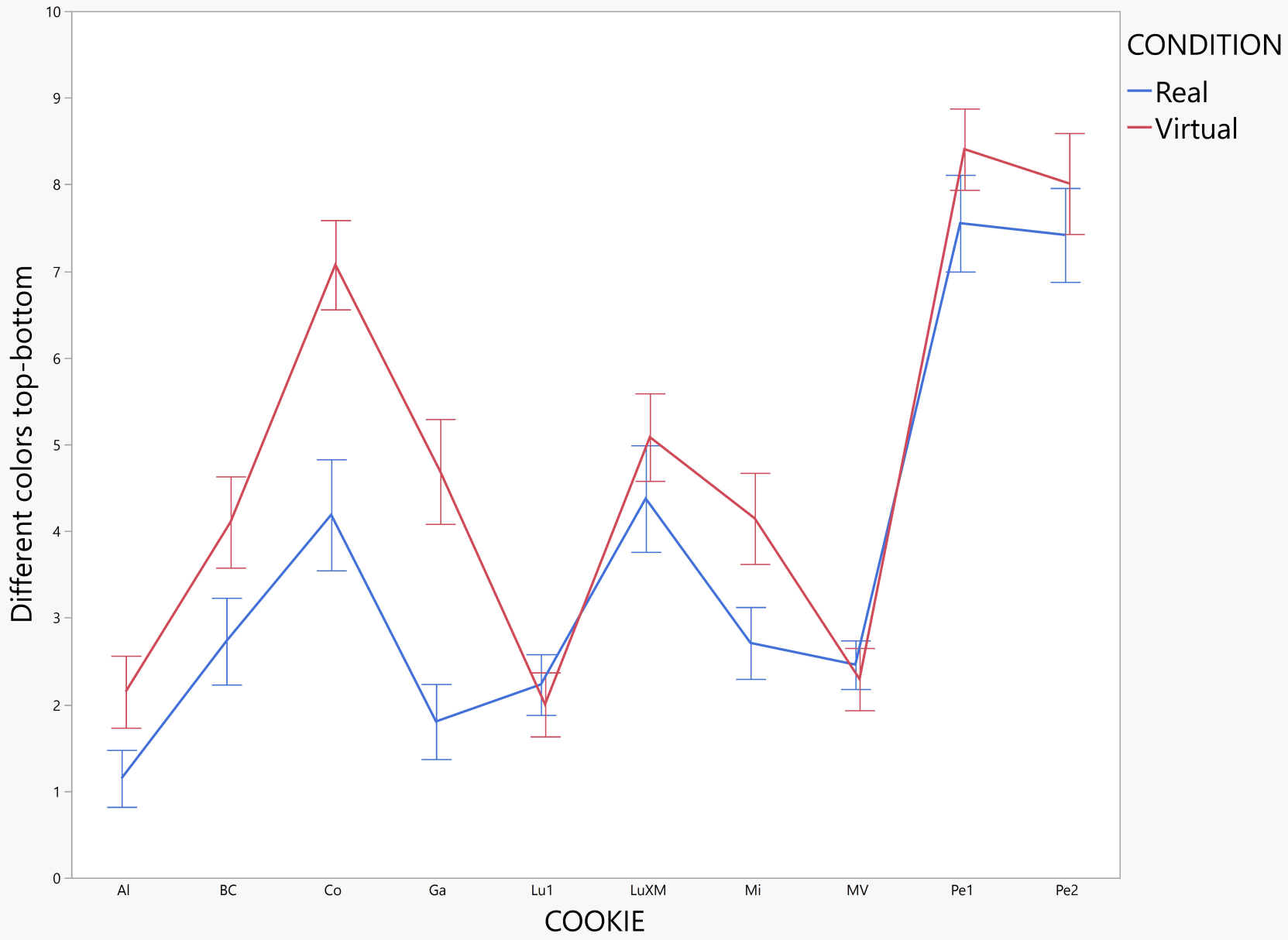
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TABLES – ‘VALIDATION OF FOOD VISUAL ATTRIBUTE PERCEPTION IN VIRTUAL REALITY’

Table 1. Virtual reality vs. 360° Video (Ullman, 2020)

	VIRTUAL REALITY	360° VIDEO
PHOTOGRAPHY	Digital Environment	Live Action
MOBILITY	Immersive world that you can walk around in (as long as you are not “tethered” or “connected to a computer	360 degree view from camera perspective, but limited to filmmaker’s camera movements
VIDEO TIMELINE	Video can progress through a series of events or experience can be simply an existing world to be explored by the user	Video progresses on a timeline created by the filmmaker’s camera movements
PLATFORMS	Full experience requires a VR headset (can be “tethered” or mobile)	Available on 360 compatible players including YouTube (desktop and mobile)
STORY	Filmmaker does not control physical location of the viewer in the built environment (as long as you are not tethered) and as such must capture attention and also motivate user to travel in the direction of the events of the story	Filmmaker controls physical location of the camera, but must capture attention of viewer to direct the story

Table 2. ScanCube® parameters

SCANCUBE® CONFIGURATION	
Camera zoom lens	135 (manual configuration of the Canon EOS 750D)
Aperture	13 (1/3)
Shutter speed	1/8
Lighting	Controlled (intensity: 30%)
Focus	Unlocked
Ratio	Free
L	6000 pixels
H	4000 pixels
Cropping	OFF
Center with laser	Used to position the cookie in the middle of the ScanCube
Animation 360°	10 photos in 360°
Pause between photos	10 seconds

Table 3. Descriptors list

DESCRIPTORS	DEFINITIONS
<i>Bright</i>	Intensity of light reflection on the dough when the cookie is moved under the light
<i>Brown</i>	Dark color of the dough
<i>Heterogeneous color</i>	Global heterogeneity of the perceived dough color
<i>Many darker color spots</i>	Heterogeneous dough color with many darker spots visible
<i>Darker edge</i>	Heterogeneous dough color with a darker edge than center
<i>Different colors top-vs-bottom</i>	Gap in dough color intensity between the top and bottom side
<i>Round</i>	Overall round shape of the cookie

60	<i>Irregular edge</i>	Rough dough around the cookie edge
61	<i>Large diameter</i>	Perceived diameter of the cookie dough when positioned in the
62		center of the sensory booth table
63		
64	<i>Thick</i>	Thickness of the dough in the middle of the cookie
65	<i>Curved</i>	Thicker dough in the middle of the cookie than at the edge
66	<i>Concave surface</i>	Dough sagging in the middle
67		
68	<i>Bumpy</i>	Irregular thickness forming bumps on cookie dough surface
69		
70	<i>Many cracks</i>	Perceived amount of cracks in the dough
71	<i>Deep cracks</i>	Average depth of cracks in the dough
72		
73	<i>Wide cracks</i>	Average width of cracks in the dough
74	<i>Sandy texture</i>	Sandy texture on the dough surface
75	<i>Large craters on the bottom side</i>	Size of the small holes in dough on the bottom side of the cookie
76		
77	<i>Soft</i>	Looks (visually) easy to break in half without effort
78	<i>Bright chocolate chips</i>	Intensity of light reflection on the chocolate chips when the cookie is
79		moved under the light
80		
81	<i>Different colors of chocolate chips</i>	Chocolate chips with obvious contrasting color
82		
83	<i>Dark chocolate chips (darker chip)</i>	Color intensity of darker chocolate chips
84	<i>Dark chocolate chips (lighter chip)</i>	Color intensity of lighter chocolate chips
85		
86	<i>Chocolate chips with red-orangy hue</i>	Red-orange color reflection on the chocolate chips
87	<i>Raisin-like chocolate chips</i>	Crumpled aspect of the chocolate chips
88		
89	<i>Heterogeneous sizes of chocolate chips</i>	Chocolate chips with obvious gap between smaller and larger chips
90	<i>Large chocolate chips (larger chip)</i>	Perceived size of the larger chocolate chips
91	<i>Large chocolate chips (smaller chip)</i>	Perceived size of the smaller chocolate chips
92		
93	<i>Heterogeneous shape of chocolate chips</i>	Chocolate chips with various shapes
94	<i>Angular chocolate chips (squarer chip)</i>	Angularness of the squarer chips
95	<i>Angular chocolate chips (rounder chip)</i>	Angularness of the rounder chips
96		
97	<i>Melted chocolate chips</i>	Chocolate chips with a shape that looks like they have melted
98		
99	<i>Many chocolate chips</i>	Perceived amount of chocolate chips
100	<i>Chocolate chips cluster</i>	Chocolate chips clustered in small groups
101	<i>Dispersed chocolate chips</i>	No area without chocolate chips
102		
103	<i>Chocolate chips inside the dough</i>	Chocolate chips covered with dough (visible by transparency)
104	<i>Dough-chocolate balance</i>	Equal amount of dough and chocolate
105		
106	<i>Distinct dough-chips limit</i>	Clear line between the cookie dough and the chocolate chips
107	<i>More chocolate chips on the top than on</i>	Unequal distribution of the chocolate chips between the top and the
108	<i>the bottom</i>	bottom side of the cookie
109		
110	<i>Presence of nuts</i>	Presence of roughness suggesting that the cookie contains nut chunks
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Table 4. F values and P values for all effects of conventional profile evaluations (d.f. model = 319; d.f. residual = 640; d.f. total = 959).

	CONDITION			COOKIE			JUDGE			CONDITION *			COOKIE *			CONDITION *			COOKIE *			CONDITION *		
	F	Prob>F	LogWorth	F	Prob>F	LogWorth	F	Prob>F	LogWorth	F	Prob>F	LogWorth	F	Prob>F	LogWorth	F	Prob>F	LogWorth	F	Prob>F	LogWorth	F	Prob>F	LogWorth
d.f.	1			9			15			9			15			135			135			135		
Different colors of chocolate chips	1.30	0.25	0.6	564.06	0.00	296.8	7.18	0.00	14.0	12.04	0.00	16.9	2.96	0.00	3.9	3.38	0.00	24.1	1.90	0.00	6.8			
Brown	17.28	0.00	4.4	337.18	0.00	260.3	8.01	0.00	16.3	13.76	0.00	19.9	2.48	0.00	2.9	2.47	0.00	13.8						
Large chocolate chips (chip2)	51.59	0.00	11.7	416.80	0.00	260.2	12.46	0.00	26.7	4.71	0.00	5.4	4.48	0.00	7.4	2.35	0.00	11.8	1.38	0.01	2.2			
Wide cracks	3.55	0.06	1.2	394.51	0.00	253.7	41.72	0.00	83.7	3.70	0.00	3.8	3.96	0.00	6.2	3.82	0.00	29.5	2.11	0.00	9.1			
Thick	75.03	0.00	16.4	342.42	0.00	237.2	99.05	0.00	154.8	6.54	0.00	8.2	8.86	0.00	18.1	5.09	0.00	44.5	1.25	0.04	1.4			
Many cracks	0.41	0.52	0.3	327.76	0.00	232.2	85.51	0.00	141.0	12.85	0.00	18.2	5.90	0.00	10.8	6.24	0.00	57.2	1.77	0.00	5.5			
Different colours top-bottom	202.03	0.00	39.3	315.90	0.00	228.0	23.74	0.00	51.3	18.15	0.00	26.3	7.06	0.00	13.7	2.88	0.00	18.1	1.79	0.00	5.8			
Many chocolate chips	26.39	0.00	6.4	306.63	0.00	224.7	65.52	0.00	117.7	4.70	0.00	5.3	3.88	0.00	6.0	3.72	0.00	28.3	1.59	0.00	3.9			
Deep cracks	6.56	0.01	2.0	284.11	0.00	216.2	61.37	0.00	112.3	12.86	0.00	18.2	3.72	0.00	5.6	3.95	0.00	31.1	1.37	0.01	2.2			
Soft	16.19	0.00	4.2	268.19	0.00	209.8	139.27	0.00	189.3	3.58	0.00	3.6	5.64	0.00	10.2	11.83	0.00	107.8	2.08	0.00	8.7			
Dark chocolate chips (chip1)	14.63	0.00	3.8	656.85	0.00	199.0	14.16	0.00	30.7	14.01	0.00	20.0	2.90	0.00	3.7	3.78	0.00	29.0	2.03	0.00	8.3			
Dark chocolate chips (chip2)	8.44	0.00	2.4	635.33	0.00	199.0	19.39	0.00	42.3	14.43	0.00	20.6	3.51	0.00	5.1	3.16	0.00	21.5	1.73	0.00	5.2			
Large diameter	0.68	0.41	0.4	576.51	0.00	199.0	64.35	0.00	124.2	10.52	0.00	14.7	5.30	0.00	9.5	4.43	0.00	39.3						
Angular chocolate chips (chip1)	35.02	0.00	8.3	241.88	0.00	198.6	11.94	0.00	25.5	5.26	0.00	6.2	6.25	0.00	11.7	3.09	0.00	20.7	2.19	0.00	10.0			
Angular chocolate chips (chip2)	12.03	0.00	3.3	240.63	0.00	198.1	17.14	0.00	37.4	6.35	0.00	7.9	2.02	0.01	1.9	2.82	0.00	17.4	1.73	0.00	5.2			
Heterogeneous sizes of chocolate chips	14.15	0.00	3.7	222.80	0.00	189.9	17.66	0.00	38.5	3.34	0.00	3.3	4.34	0.00	7.0	3.37	0.00	24.1	1.44	0.00	2.7			
Round	0.34	0.56	0.3	201.52	0.00	179.5	47.32	0.00	92.5	5.79	0.00	7.0	5.35	0.00	9.5	4.34	0.00	35.8	1.85	0.00	6.4			
Dispersed chocolate chips	7.41	0.01	2.2	167.79	0.00	174.6	40.59	0.00	86.3	1.91	0.05	1.3	3.54	0.00	5.2	4.20	0.00	36.4						
More chocolate chips on the top than on the bottom	0.96	0.33	0.5	161.96	0.00	171.5	10.52	0.00	22.6				2.70	0.00	3.3	2.28	0.00	11.5						
Large chocolate chips (chip1)	1.74	0.19	0.7	173.39	0.00	164.3	21.89	0.00	47.5	2.34	0.01	1.9	1.99	0.01	1.8	1.68	0.00	4.7	1.81	0.00	6.0			
Sandy texture	14.88	0.00	3.9	153.04	0.00	152.4	61.84	0.00	112.9	3.52	0.00	3.5	26.10	0.00	56.0	5.79	0.00	52.3	2.80	0.00	17.1			
Heterogeneous shape of chocolate chips	3.04	0.08	1.1	146.58	0.00	148.4	20.78	0.00	45.2	3.81	0.00	4.0	3.36	0.00	4.8	3.25	0.00	22.6	1.44	0.00	2.7			
Bright	503.36	0.00	82.0	119.23	0.00	129.8	46.16	0.00	90.7	64.98	0.00	83.6	34.25	0.00	71.1	3.63	0.00	27.2	3.23	0.00	22.4			
Concave surface	4.34	0.04	1.4	100.90	0.00	115.8	56.20	0.00	105.3	4.82	0.00	5.5	2.85	0.00	3.6	7.07	0.00	65.8	1.39	0.01	2.3			
Irregular edge	8.45	0.00	2.4	90.12	0.00	113.5	24.93	0.00	55.8	2.11	0.03	1.6	2.17	0.01	2.2	2.68	0.00	16.5						
Chocolate chips inside the dough	0.46	0.50	0.3	81.08	0.00	99.0	32.50	0.00	68.0	9.27	0.00	12.6	5.06	0.00	8.8	2.58	0.00	14.5	1.40	0.00	2.3			

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Balance dough-chocolate	2.43	0.12	0.9	206.62	0.00	182.1	143.89	0.00	192.7	1.81	0.06	1.2	3.38	0.00	4.8	4.92	0.00	42.6	1.24	0.05	1.3
Melted chocolate chips	80.49	0.00	17.5	31.91	0.00	45.6	93.37	0.00	149.2	3.57	0.00	3.6	9.76	0.00	20.3	4.09	0.00	32.7	1.66	0.00	4.5
Bumpy	1.52	0.22	0.7	89.93	0.00	106.8	89.42	0.00	145.1	3.35	0.00	3.3	6.05	0.00	11.2	6.29	0.00	57.7	2.03	0.00	8.3
Curved	1.35	0.25	0.6	72.39	0.00	90.9	85.80	0.00	141.3	4.76	0.00	5.4	11.96	0.00	25.5	8.06	0.00	75.5	2.17	0.00	9.8
Many darker color spots	122.14	0.00	25.4	59.12	0.00	77.6	61.02	0.00	111.9	4.68	0.00	5.3	9.34	0.00	19.3	5.97	0.00	54.3	1.64	0.00	4.4
Large alveole on the bottom side	62.65	0.00	14.1	31.99	0.00	47.1	54.31	0.00	109.2	12.46	0.00	17.9	7.52	0.00	15.1	2.10	0.00	9.4			
Distinct limit dough-chips	57.26	0.00	12.9	80.60	0.00	98.6	58.63	0.00	108.7	7.53	0.00	9.8	44.25	0.00	87.7	3.19	0.00	21.9	1.32	0.02	1.8
Heterogeneous color	143.86	0.00	29.3	37.15	0.00	52.3	37.69	0.00	77.1	5.26	0.00	6.2	8.26	0.00	16.6	5.07	0.00	44.3	1.44	0.00	2.7
Chocolate chips with red-orangy hue	175.15	0.00	34.8	52.71	0.00	70.7	168.98	0.00	210.2	8.84	0.00	11.9	22.24	0.00	48.3	11.42	0.00	104.7	3.47	0.00	25.3
Chocolate chips cluster	0.09	0.77	0.1	44.22	0.00	60.9	74.32	0.00	128.4	3.62	0.00	3.7	2.00	0.01	1.9	9.52	0.00	88.9	1.50	0.00	3.1
Darker edge	324.19	0.00	58.2	23.26	0.00	33.7	37.00	0.00	75.9	9.72	0.00	13.3	16.35	0.00	35.6	2.86	0.00	17.9	1.43	0.00	2.6
Presence of nuts	29.43	0.00	7.1	2.85	0.00	2.6	23.49	0.00	50.8	2.11	0.03	1.6	12.78	0.00	27.5	2.60	0.00	14.7	1.82	0.00	6.1
Chocolate chips with raisin appearance	30.85	0.00	7.4	38.92	0.00	54.5	47.61	0.00	92.9	8.41	0.00	11.2	5.73	0.00	10.4	11.84	0.00	107.9	3.13	0.00	21.1
Bright chocolate chips	1958.95	0.00	196.2	65.94	0.00	84.6	57.78	0.00	107.5	46.30	0.00	63.4	58.98	0.00	109.1	3.02	0.00	19.8	2.56	0.00	14.3

Gouton : Conceptualization, Methodology, Formal analysis, Visualization, Writing - Original Draft

Dacremont : Conceptualization, Methodology, Writing - Review & Editing

Trystram : Conceptualization, Methodology

Blumenthal : Conceptualization, Methodology, Formal analysis, Visualization, Writing - Review & Editing