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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 &

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

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

"Insert Table 1 here" -> (Ullman, 2020)

Several studies have already validated VR for specific applications, including decision-making and purchase intension (Schnack et al., 2018; Siegrist et al., 2019), serving size in a food buffet (Persky et al., 2018; Ung et al., 2018), hedonic and emotional product assessments (Sinesio et al., 2019), food disgust (Ammann et al., 2020), food craving (Ledoux et al., 2013), stimulus-context congruence (Porcherot et al., 2018), visualization of complex product structure in the design phase (Crofton et al., 2019), and memorization tasks (Ouellet et al., 2018).

The technological solution most frequently used to manipulate an actual food product in a VR environment is cropping the virtual image to see the actual product in the surrounding VR space (see Sinesio et al., 2019; Ammann et al., 2020). Using a simulated virtual product in the VR environment (Ledoux et al., 2013; Persky et al., 2018; Ung et al., 2018) provides a frame for further additional applications such as cross-modal interactions, with the possibility of varying expectations from product appearance while-keeping the other sensory modalities (texture, flavor, etc.) constant. Narumi et al. (2011) added a virtual chocolate layer on a plain biscuit. However, their virtual product was embedded in a real environment, their approach used an 'augmented reality' which, unlike VR, does not allow any interactivity with the environment. Food product design is another practical application for presenting virtually simulated products in virtual environments. VR makes sample homogenization easy, either by hiding a brandname stamped on chocolates or biscuits, duplicating samples for visually heterogeneous products, or testing visual appreciation of products that do not yet exist.

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

This study was designed to explore the visual realism of a simulated food product in a full-VR environment. As we set out to explore the possibilities offered by a new technology, we started with the basic requirements. We compared the visual perception of food products assessed in real conditions (an actual product in natural environment) and in VR (virtual simulation of the same products presented in VR depicting the same environment). We used a set of cookies that display high visual complexity, and we investigated the degree of similarity between the actual and virtual food spaces in an exercise describing the appearance of the cookies. In order to explore how far a VR methodology can push the visual realism of a food product, we used the scanning method that currently gives the most realistic rendering possible, i.e. photogrammetry, on processed food products purpose-chosen to present visual complexity. Our first objective was to explore whether perceptions were distorted in VR by determining changes in the relative weight of the perceptual dimensions in the product space. The second objective was 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.

2. GENERAL MATERIAL

2.1. Participants

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

2.2. Food products

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

"Insert Fig.1 here"

2.3. Virtualization

2.3.1. Virtual cookies

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

Picturing

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

"Insert Table 2 here"

3D reconstruction

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**).

“Insert Fig.2 here”

Configuration in the virtual booth

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

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

“Insert Fig.3 here”

2.3.2. Environmental design

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

“Insert Fig.4 here”

2.4. Methods

To check changes in the relative weight of the perceptual dimensions in the product space, we performed a flash profiling study (study 1). Then, working from the compiled real and virtual descriptor lists generated in, we trained the remaining participants from study 1 to complete a conventional profile in order to assess whether these sensory dimensions are perceived similarly between real and virtual conditions (study 2). Half of the participants started with the virtual-product evaluation in each study, while the other half started with real-product evaluation. To ensure that all participants were equally familiarized with using the VR devices, before their first VR session they attended a 20-minute gaming session where no cookies or description tasks were involved, in order to teach them how to grab and move an object and check for absence of virtual reality sickness (‘cybersickness’).

Cookies were tested in individual sessions, and real cookies were handled with gloves and taken carefully by the edges to prevent causing any damage and maintain product integrity. For both studies and in both 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.

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

3.2. Results & Discussion

According to the vocabulary distribution in the 5 perceptual categories (**Fig. 5.**), the main difference across experimental conditions was the frequency of descriptors linked to brightness, with 12 words used for the real-condition description versus 1 word used for the virtual-condition description.

GPA showed a close rate of vocabulary consensus between participants in real and virtual conditions, and we validated the coherency of participants' answers based on the proximity of our two cookies taken from the same box (Pe1 and Pe2). On map 1–2 (**Fig. 6.**), when we align the orientation of both condition maps according to the common correlated descriptors, it shows similar product positions, which indicates that participants ranked products in a similar way between real and virtual conditions. Nevertheless, the products appeared to be slightly more discriminated in the real condition, as some cookies had a more distant position on axis 2 on the real condition map. This difference was mainly linked to brightness ("Bright"), shape ("Thick", "Curved", "Soufflé") and visual texture ("Cracked", "Bumpy") attributes, which were also linked to this axis. To better understand the origin of this small discrepancy, we went on to use conventional profiling to gain a quantitative assessment (**see study 2**).

In conclusion, despite some differences that were probably brightness-related, perceptions of the cookies were fairly similarly between the two experimental conditions. As only one brightness descriptor was cited in the virtual condition, it led us to posit that the two conditions may carry all the same dimensions but that these dimensions may not carry the same weight, and so differences among products are not identically perceived. We thus conducted study 2 to explore this second hypothesis.

“Insert Fig.5 here”

“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"

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

"Insert Table 3 here"

4.1.2. Data analysis

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

4.2. Results & Discussion

4.2.1. Descriptors use

Fig. 9 shows the number of descriptors that had significant product effect (p-value lower than 0.05) for each participant and in both conditions. Overall, the number of discriminant descriptors was similar across experimental conditions, which indicates that participants did not experience more difficulties rating intensity in the virtual condition than in the real condition.

"Insert Fig.9 here"

Fig. 10 shows the number of participants with a significant product effect (p-value lower than 0.05) for each descriptor and each experimental condition. Among the 40 descriptors, 33 discriminated cookies for a similar number of participants (± 2) across experimental conditions.

"Insert Fig.10 here"

For 7 descriptors ('heterogeneous shape of chocolate chips', 'chocolate chips inside the dough', 'raisin-like chocolate chips', 'many darker spots', 'chocolate chips with red-orangy hue', 'bright', and 'bright chocolate chips'), the difference in discriminant participants was larger by at least 3 participants. The biggest real–virtual differences were for the ‘bright’ and ‘bright chocolate chips’ descriptors, which had between-condition gaps of 9 and 12 participants, respectively.

To sum up, most of the descriptors appear to be just as useful for discriminating cookies in real conditions as in virtual conditions. For the descriptors ‘heterogeneous shape of chocolate chips’, ‘chocolate chips inside the dough’ and ‘raisin-like chocolate chips’, the cookies were better discriminated in the real conditions. These differences in visual texture descriptors could be explained by a different perception of the relief details. For the descriptors ‘many darker spots’ and ‘chocolate chips with red-orangy hue’, the cookies were better discriminated in the virtual condition, which could be explained by a better perception of color contrasts with virtual cookies. Finally, for the descriptors ‘bright’ and ‘bright chocolate chips’, the cookies were better discriminated in real conditions, which means that brightness is better perceived with real products and suggests that brightness is difficult to accurately reproduce in VR.

4.2.2. Product map comparison

The maps obtained by quadratic discriminant analysis showed that the two versions for a given cookie, in real and in virtual conditions, were always close. As they were not exactly at the same position, there were some small sensorial differences between the two. Either way, differences between cookies (in real or in virtual conditions) were stronger than the differences between real and virtual versions of the same product (**Fig. 11**). In the two conditions, the difference between cookie MV-Real *vs* MV-Virtual and all the other products was so magnified on axis 2 that it eclipsed any other differences among non-MV-group products, thus prompting us to also consider axis 3. Axis 2 was correlated to the attribute ‘different color of chocolate chips’, and the MV cookie was the only one with a blend of milk and dark chocolate chips, i.e. the only product that has chocolate chips with obvious heterogeneous color.

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

“Insert Fig.11 here”

“Insert Fig.12 here”

4.2.3. Interactions per descriptors

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

First, for 26 descriptors, cookie is the strongest effect (first 26 rows of **Table 4**). Among these 26, judge is the second strongest effect except for 'Different colors of chocolate chips' and 'Brown' where cookie x judge and condition x cookie, respectively, are the second strongest effects, but they only represent a tenth of the cookie effect.

Second, except for two descriptors ('more chocolate chips on the top than the bottom' and 'dough-chocolate balance'), all other descriptors had significant condition × cookie interactions, meaning that virtualization could have a different cookie-dependent impact on perception. However, the condition effect or one of its interactions with another effect only had a higher LogWorth than the cookie effect for three descriptors: 'Darker edge', 'Presence of nuts' and 'Bright chocolate chips'. The 'Bright' descriptor is almost close to these cases, as condition and cookie effects have LogWorth values of 82 and 129.8; respectively.

To illustrate the benefit of comparing effects based on LogWorth instead of p-values, let us consider 4 descriptors: 'Large diameter', 'Brown', 'Bright' and 'Bright chocolate chips'. For all 4 descriptors, the condition × cookie interaction had a p-value below 0.05. For the first two, the LogWorth of this interaction is very low compared to the LogWorth of the cookie effect. For the last two, the LogWorth of this interaction is comparable to the LogWorth of the cookie effect. The differences between these two cases can be seen on **Fig. 13**. For the first two (top of the **Fig.13**), the scores of the cookies are almost the same in the two conditions. For the last two (bottom), not only the scores but also the rankings of the cookies are different between real and virtual conditions. This supports the idea that the brightness is globally less perceptible in virtual conditions than in real conditions.

As the cookies can lose brightness, the color contrasts were amplified in the virtual condition for 4 descriptors as 'Different colors top to bottom' (**Fig. 14**).

"Insert Table 4 here"

"Insert Fig.13 here"

"Insert Fig.14 here"

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.

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

Descriptive analysis demands the very highest level of realism, which requires some improvement of the food product lighting configuration. Nevertheless, for hedonic studies, the impact of these realism differences may depend on the importance of each attribute for the product tested. Visual realism probably does not have the same impact in tests with different objectives, which may explain the differences reported in the literature comparing real against virtual conditions. Ung et al. (2018) and Siegrist et al. (2019) found good correlations in food behavior and decision-making between real and VR conditions, so we can assume that the visual realism level did not have any tangible impact on the quantity of food served from a food buffet or on the choice of cereals in a shop task. Brightness, for example, may have little importance for these tasks. Conversely, Ledoux et al. (2013) reported differences between real and virtual conditions in the induction of food craving, so the visual realism level may have a stronger influence when motivational mechanisms are involved. Deeper exploration is warranted to investigate the link between virtual food product realism and the reliability of the food behavior-related decision-making processes. Further research is planned to explore multi-criteria optimization of the product model as a route to increase the level of realism and reach the required threshold leading to the same behavioral decision.

6. CONCLUSION

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

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FIGURES TITLES – 'VALIDATION OF FOOD VISUAL ATTRIBUTE PERCEPTION IN VIRTUAL REALITY'

Fig. 1. Set of cookies set used for real–virtual comparison (presented here on the same scale). ***Mi***: *"Milka Choco Cookies"*. ***Al***: *"Allergo Cookies Pépites Chocolat"*. ***Co***: *"Cora Cookies Maxi Pépites de Chocolat"*. ***Ga***: *"Gayelord Hauser Diététicien Cookies Pépites de Chocolat"*. ***Lu1***: *"Lu Granola Gros Eclats de Chocolat"*. ***LuXM***: *"Lu Granola Cœur Extra Moelleux"*. ***BC***: *"The Biscuit Collection Chocolate Cookies"*. ***MV***: *"Matilde Vicenzi Premium Cookies with Double Chocolate Chunks"*. ***Pe1 & Pe2***: *"Pepperidge Farm Chocolate Chunk Milk Chocolate Cookies"*.

Fig. 2. Realism of a virtual cookie ("**Co**") after Agisoft Photoscan® 3D reconstruction.

Fig. 3. Examples of 3-digit code bubbles. Left: virtual bubble (virtual cookie **Pe1**). Right: real bubble (real cookie **Mi**).

Fig. 4. A) AgroParisTech sensory evaluation room (Massy Center). B) Virtual booths identically rebuilt with Unity 2017.2.0f3 software.

Fig. 5. Distribution of vocabulary used to rank the cookies.

Fig. 6. Generalized Procrustes analysis and correlated descriptors, map 1-2. Left: real condition. Right: virtual condition.

Fig. 7. Examples of 3D printed cookie models used to define the min–max scale limits.

Fig. 8. Left: real condition. Right: VR condition.

Fig. 9. Number of descriptors with a p-value lower than 0.05 for product effect per judge.

Fig. 10. Real–Virtual difference in number of judges with a p-value lower than 0.05 for the product effect per descriptors (a negative number means there are more judges discriminating products in the virtual condition, whereas a positive number means there are more judges discriminating products in the real condition).

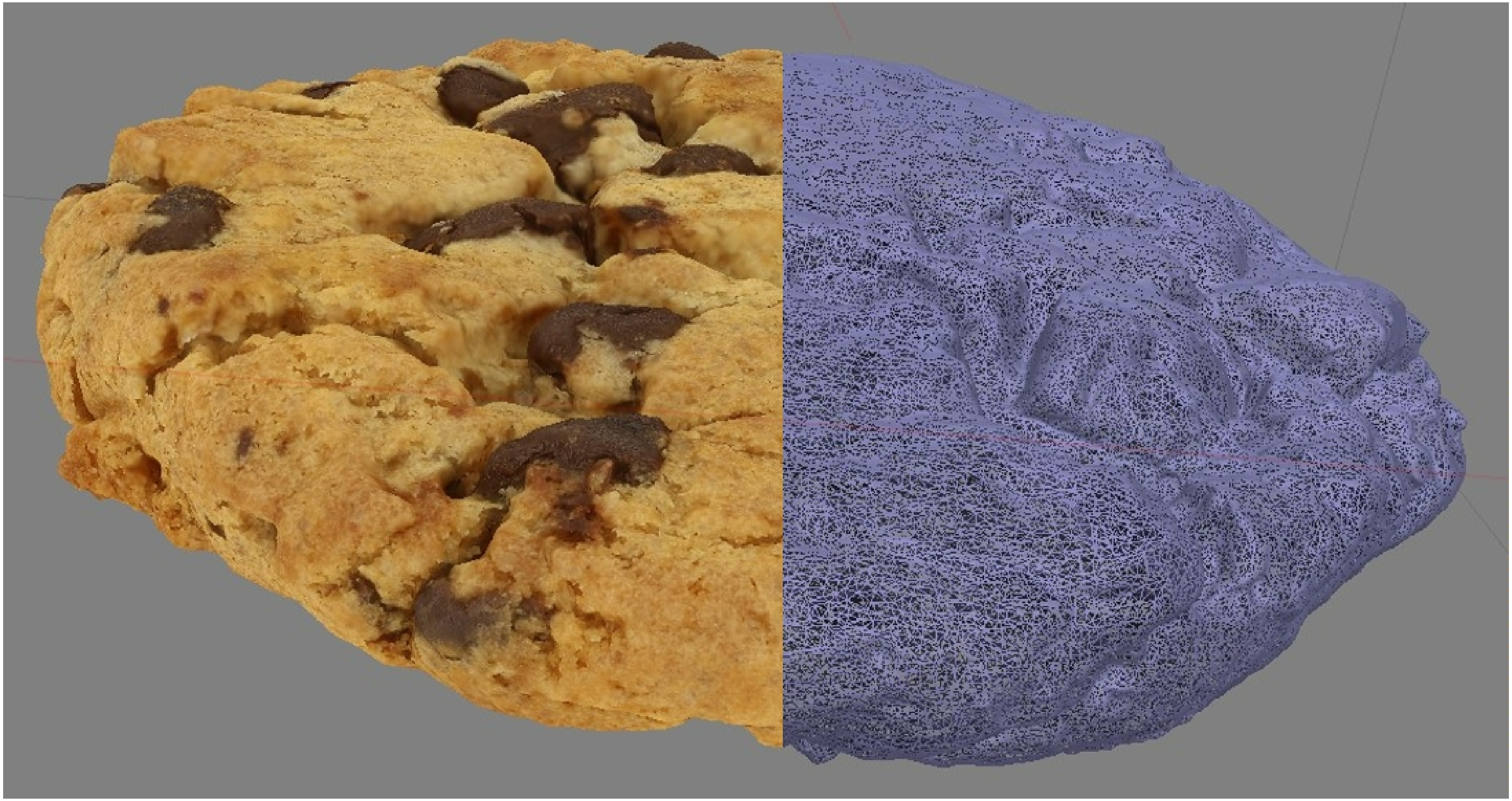
Fig. 11. Quadratic discriminant analysis, map 1-2. Left: Products position. Right: Descriptors correlation.

Fig. 12. Quadratic discriminant analysis, map 1-3. Left: Products position. Right: Descriptors correlation.

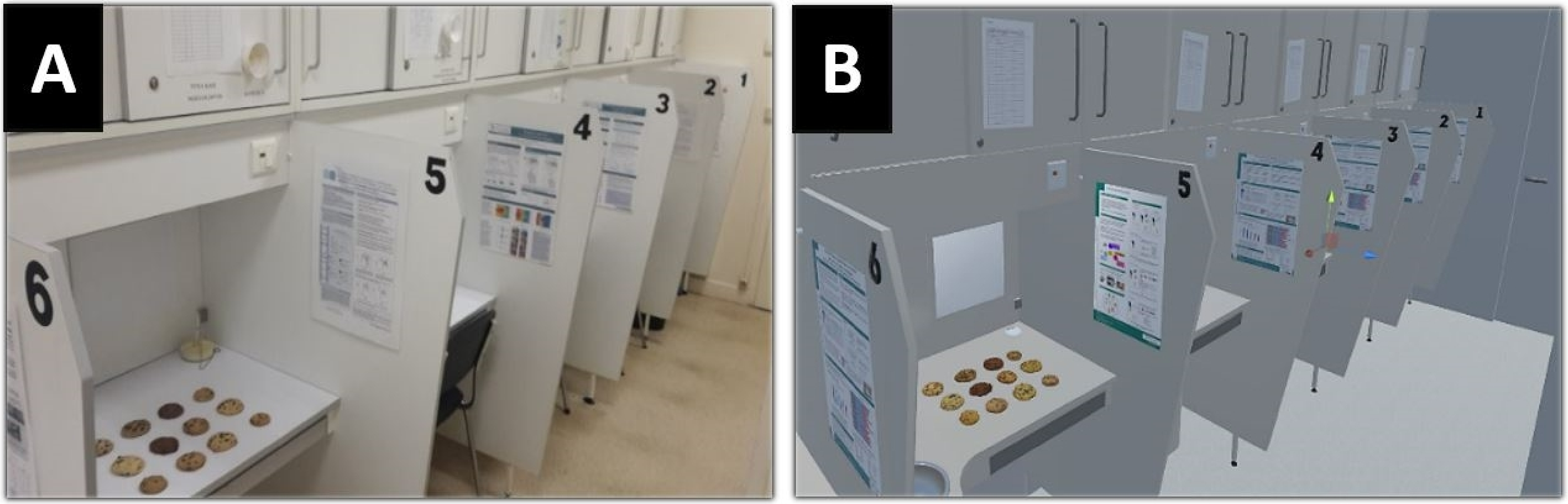
Fig. 13. Comparison of Condition × Cookie interactions. Top: Descriptors with low LogWorth value. Bottom: Descriptors with high LogWorth value.

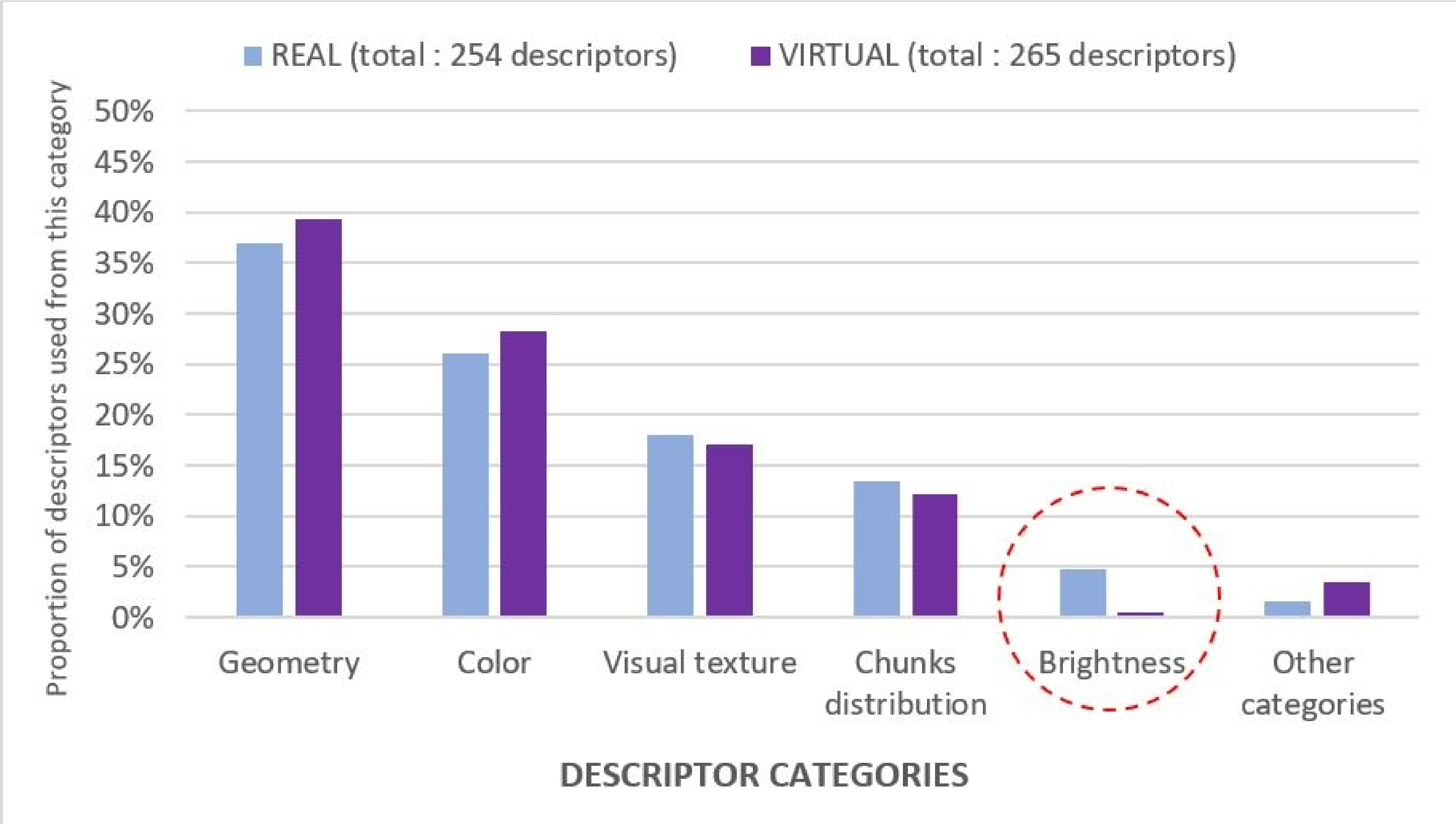
Fig. 14. Condition × Cookie interaction of the descriptor “Different colors top-vs-bottom”.


Mi
Al
Co
Ga
Lu1
LuXM
BC
MV
Pe1
Pe2

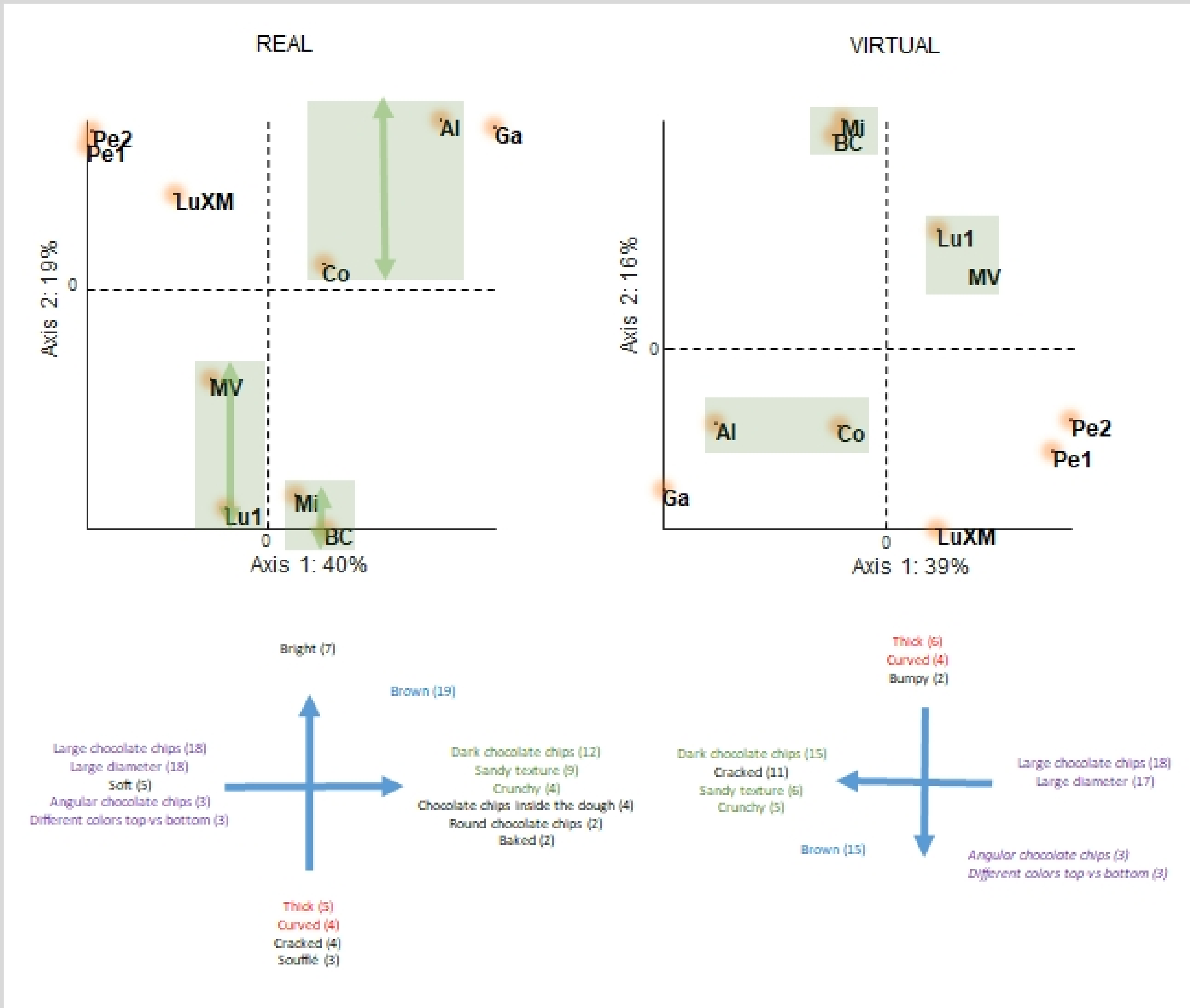



893
521


A
6
5
4
3
2
1
B
6
5
4
3
2
1



REAL (total : 254 descriptors)
VIRTUAL (total : 265 descriptors)
Proportion of descriptors used from this category
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Geometry
Color
Visual texture
Chunks distribution
Brightness
Other categories
DESCRIPTOR CATEGORIES


REAL
VIRTUAL
Pe2
Pe1
LuXM
Al
Ga
Co
MV
Lu1
Mi
BC
0
Axis 2: 19%
Axis 1: 40%
Axis 2: 16%
Axis 1: 39%
Bright (7)
Brown (19)
Large chocolate chips (18)
Large diameter (18)
Soft (5)
Angular chocolate chips (3)
Different colors top vs bottom (3)
Dark chocolate chips (12)
Sandy texture (9)
Crunchy (4)
Chocolate chips inside the dough (4)
Round chocolate chips (2)
Baked (2)
Thick (5)
Curved (4)
Cracked (4)
Soufflé (3)
Thick (6)
Curved (4)
Bumpy (2)
Dark chocolate chips (15)
Cracked (11)
Sandy texture (6)
Crunchy (5)
Large chocolate chips (18)
Large diameter (17)
Brown (15)
Angular chocolate chips (3)
Different colors top vs bottom (3)

Heterogeneous size of chocolate chips

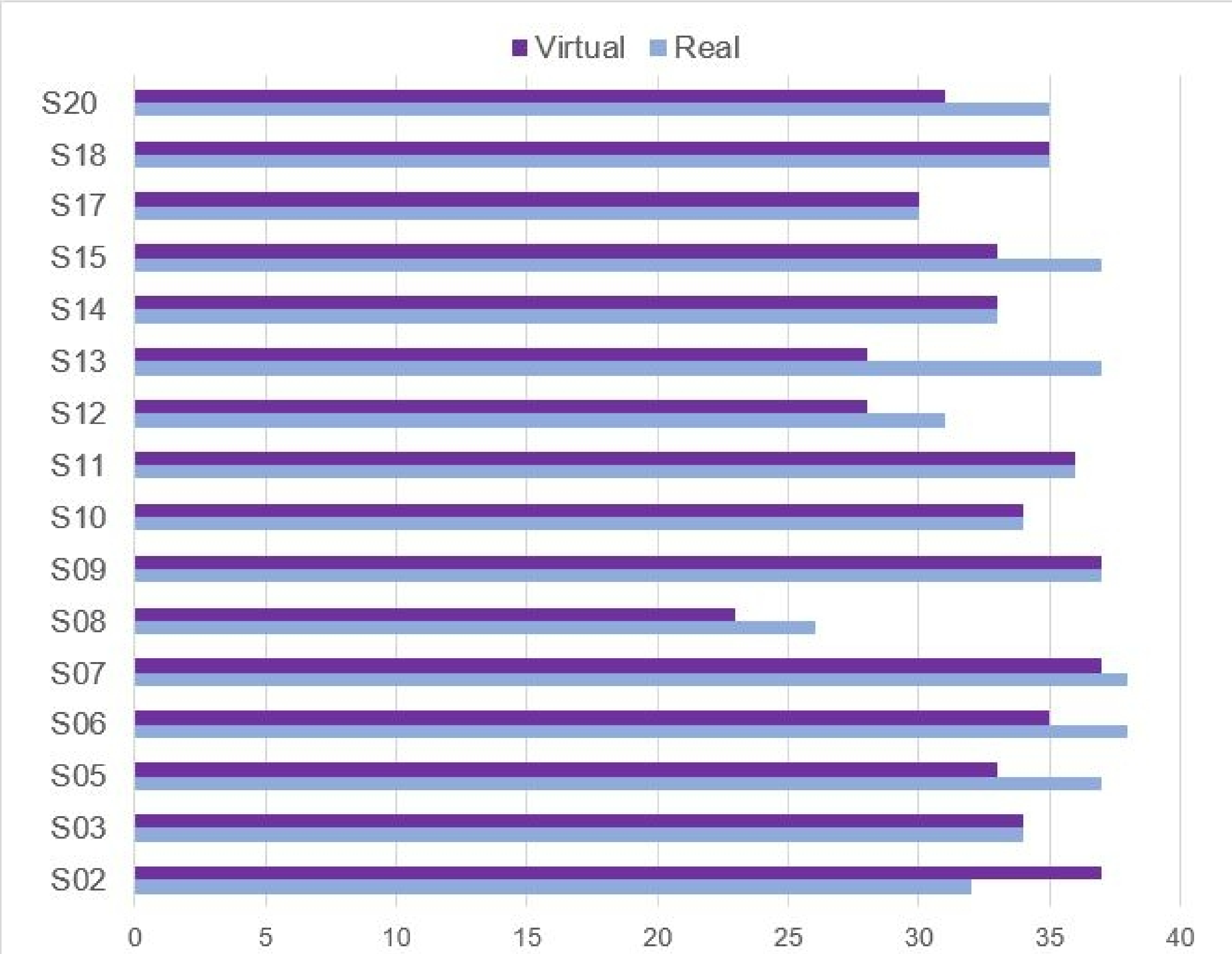
(-) (+)

Curved

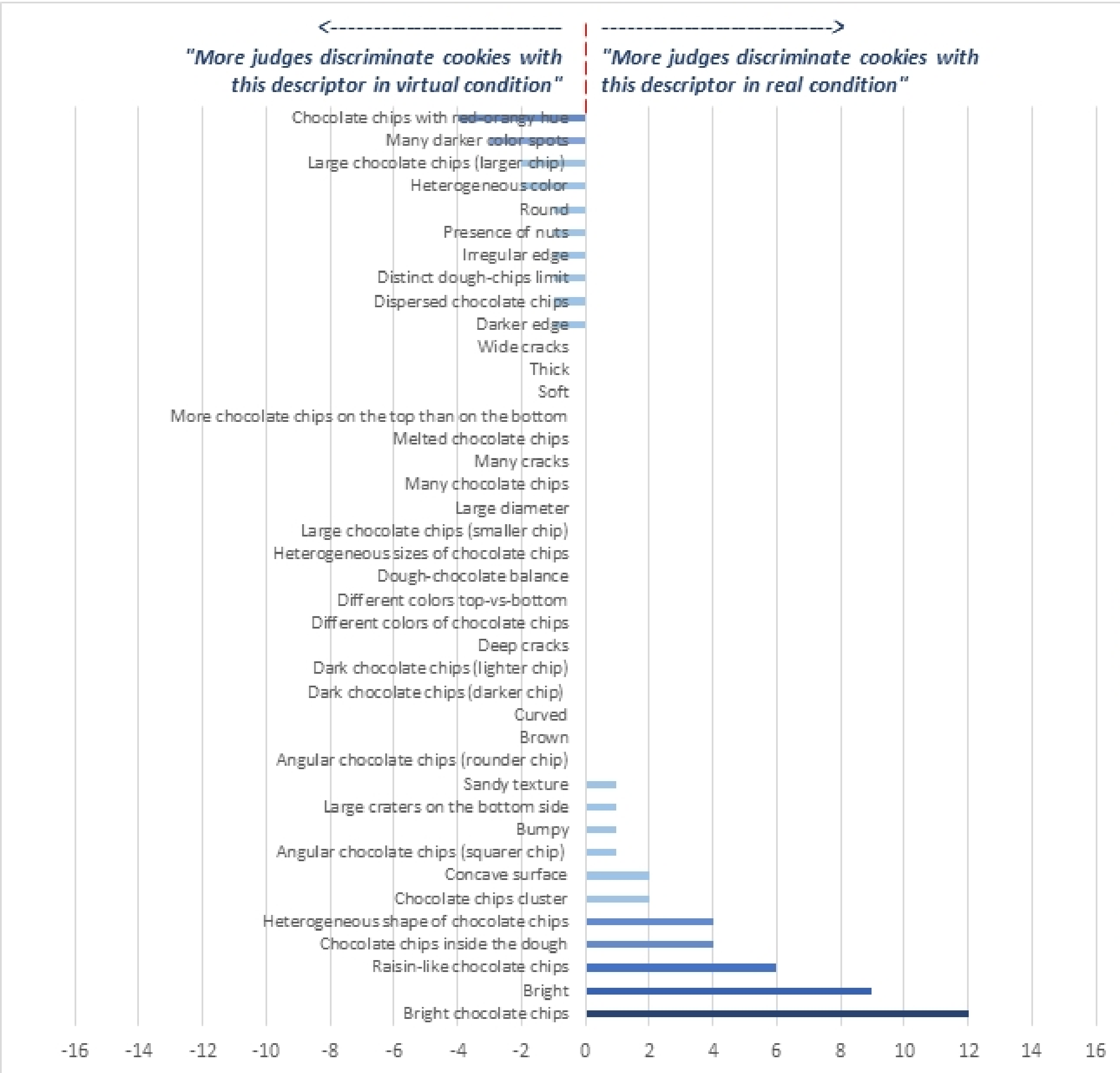
(-) (+)

Thick

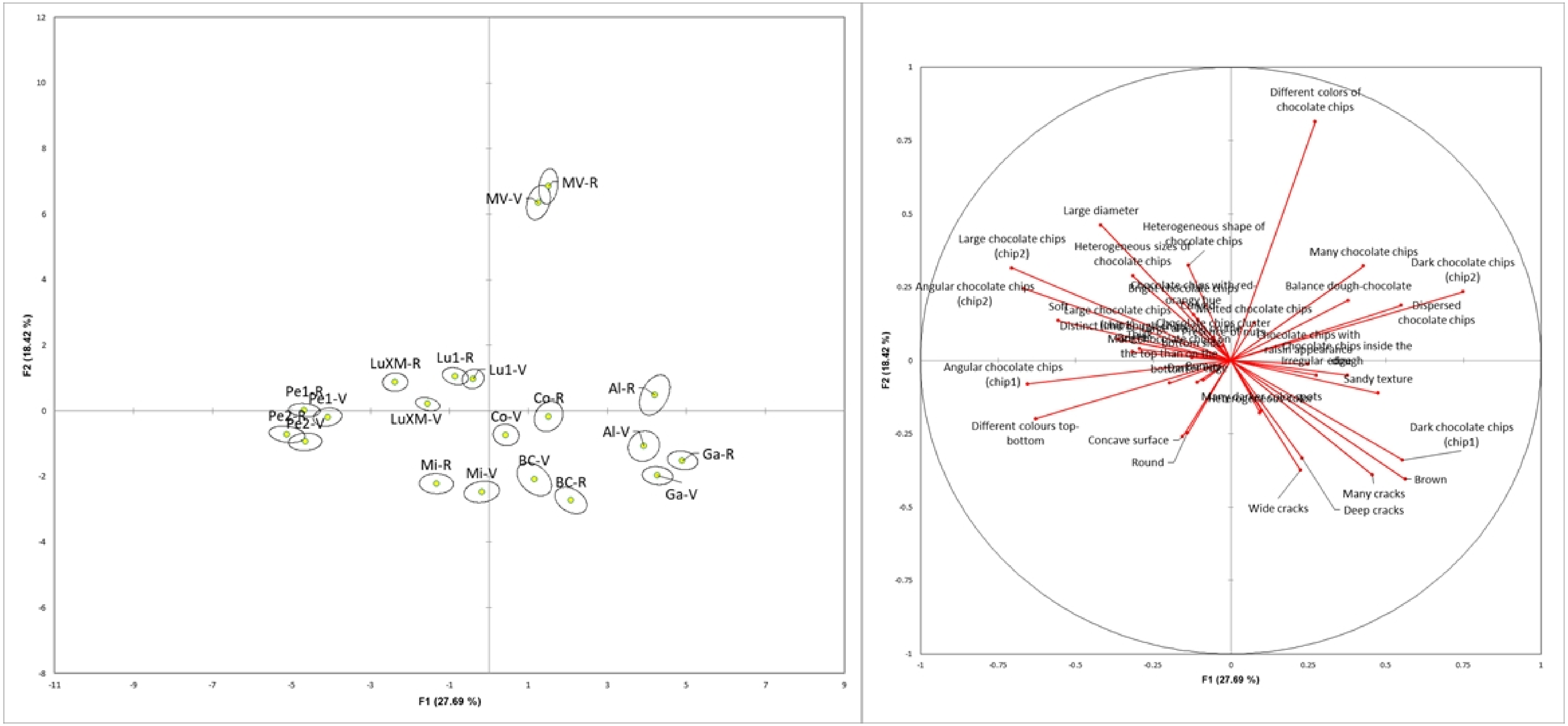
(-) (+)



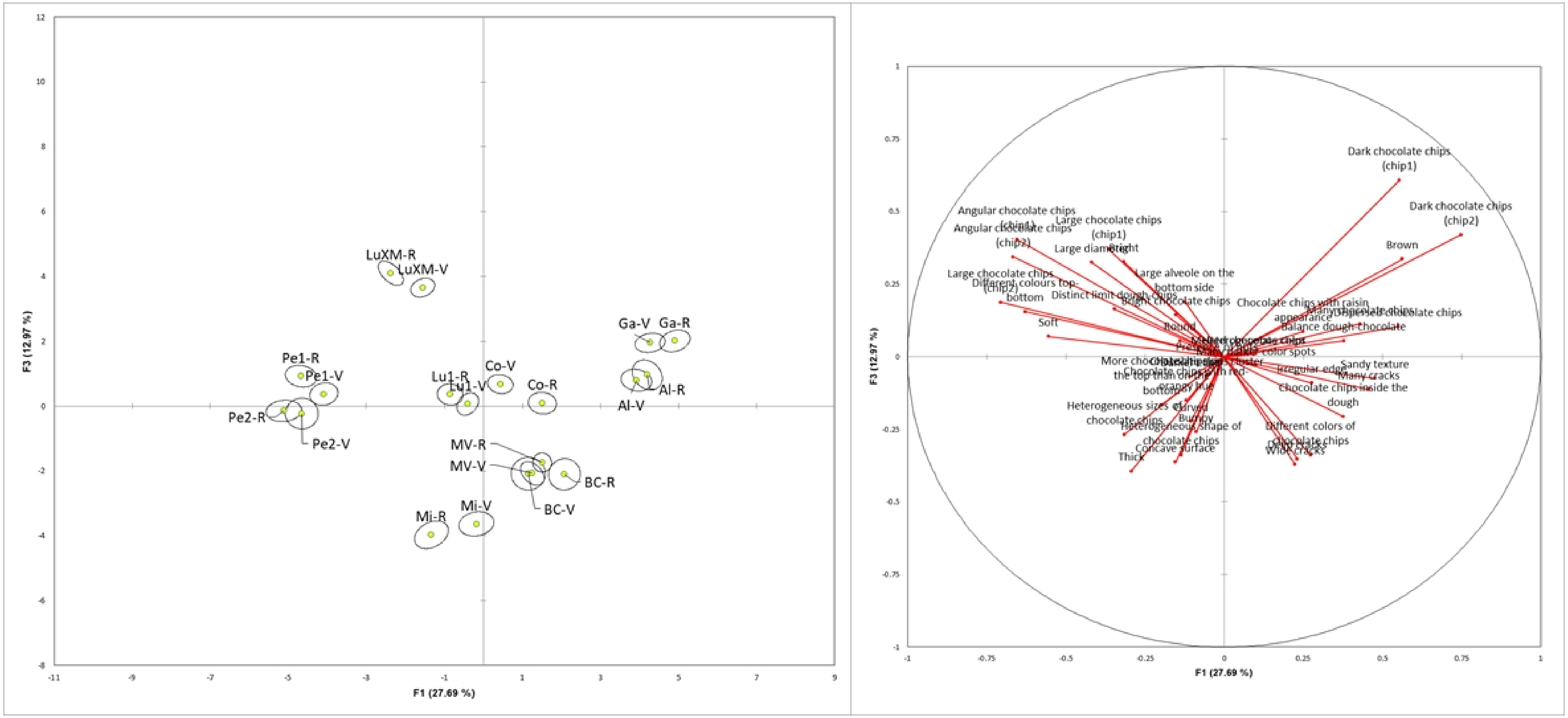
Virtual
Real
S20
S18
S17
S15
S14
S13
S12
S11
S10
S09
S08
S07
S06
S05
S03
S02
0
5
10
15
20
25
30
35
40



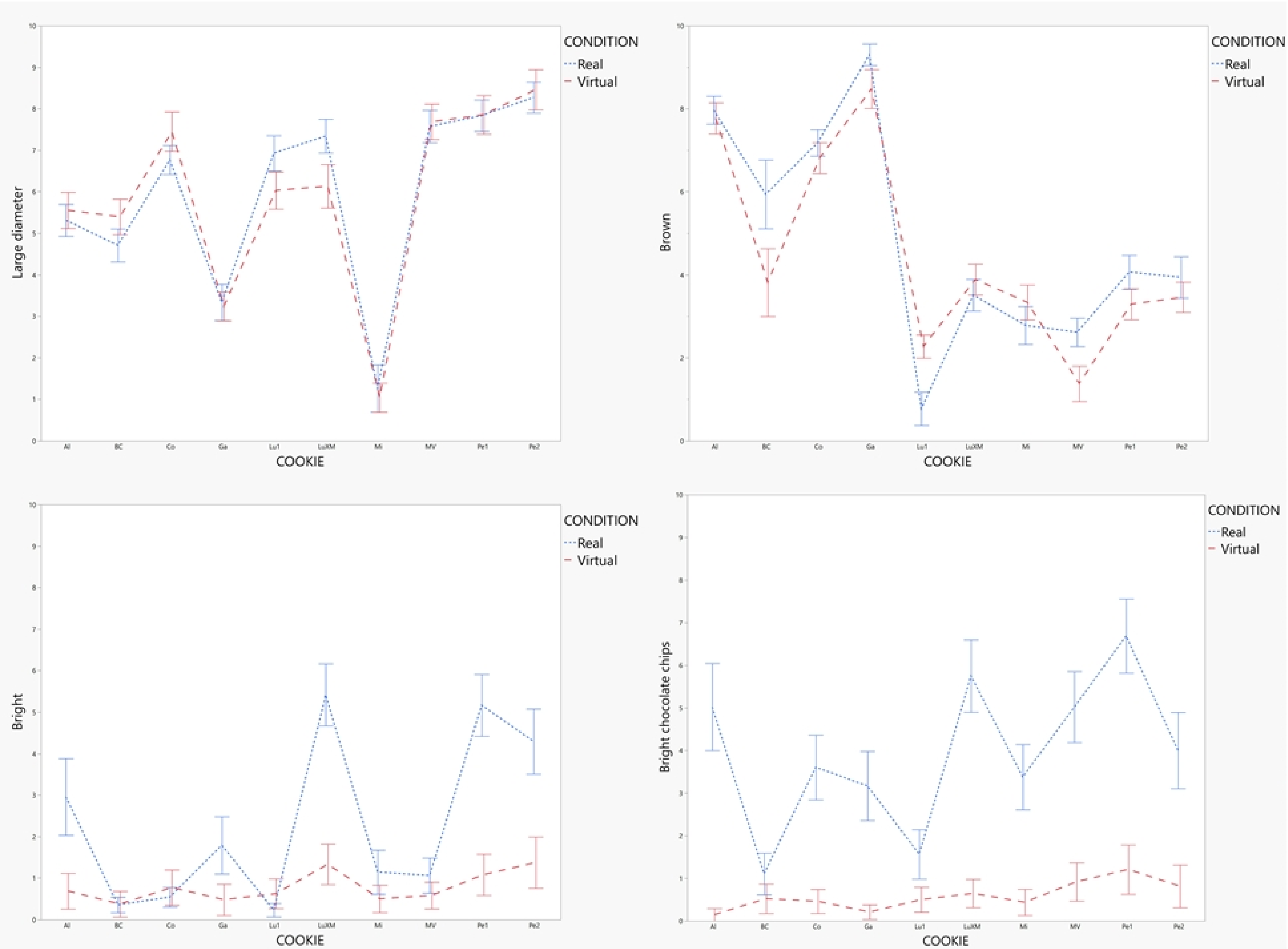
<-----------------------
"More judges discriminate cookies with this descriptor in virtual condition"
----------------------->
"More judges discriminate cookies with this descriptor in real condition"
Chocolate chips with red-orangy hue
Many darker color spots
Large chocolate chips (larger chip)
Heterogeneous color
Round
Presence of nuts
Irregular edge
Distinct dough-chips limit
Dispersed chocolate chips
Darker edge
Wide cracks
Thick
Soft
More chocolate chips on the top than on the bottom
Melted chocolate chips
Many cracks
Many chocolate chips
Large diameter
Large chocolate chips (smaller chip)
Heterogeneous sizes of chocolate chips
Dough-chocolate balance
Different colors top-vs-bottom
Different colors of chocolate chips
Deep cracks
Dark chocolate chips (lighter chip)
Dark chocolate chips (darker chip)
Curved
Brown
Angular chocolate chips (rounder chip)
Sandy texture
Large craters on the bottom side
Bumpy
Angular chocolate chips (squarer chip)
Concave surface
Chocolate chips cluster
Heterogeneous shape of chocolate chips
Chocolate chips inside the dough
Raisin-like chocolate chips
Bright
Bright chocolate chips
-16
-14
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14
16



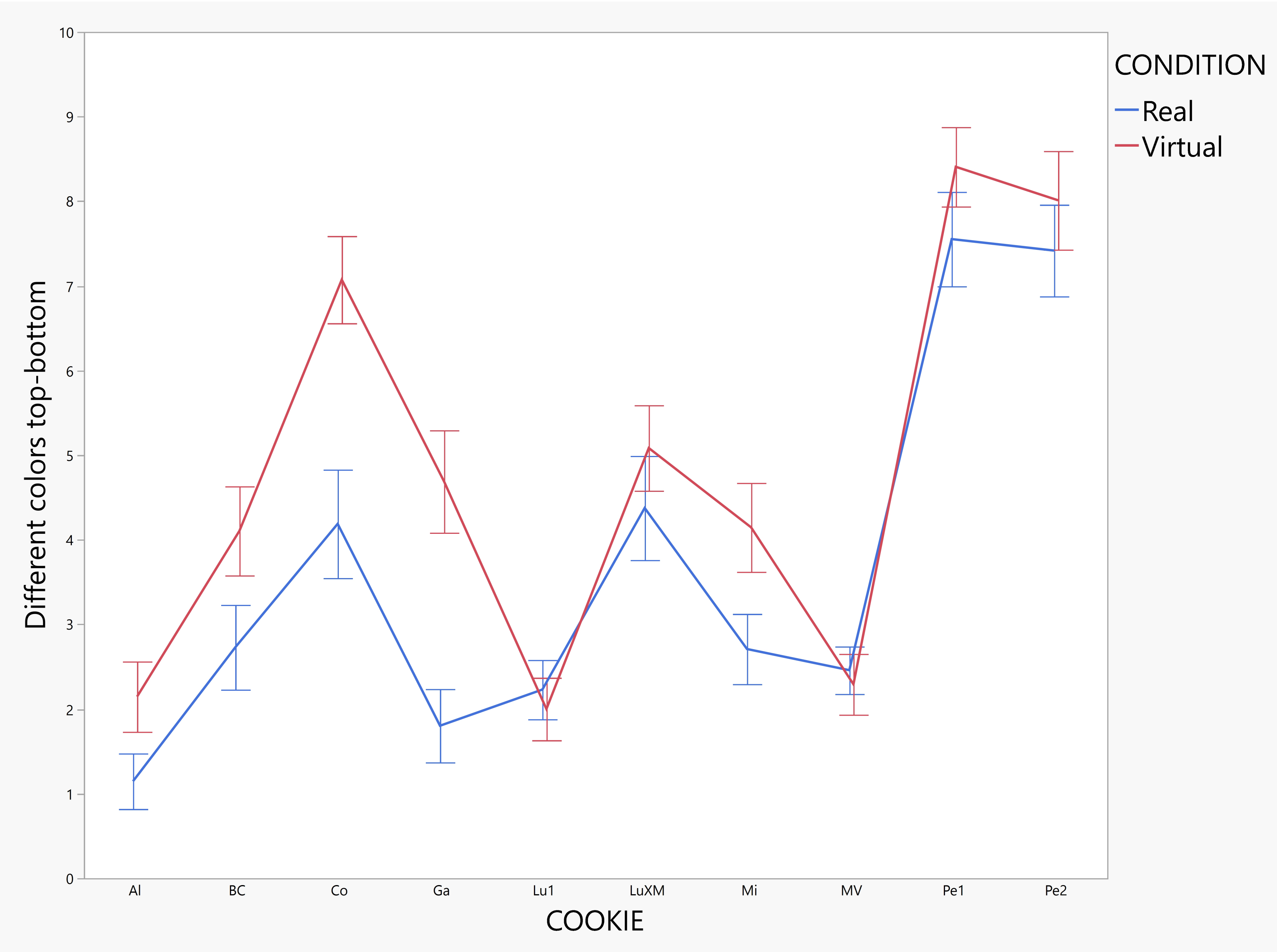
F1 (27.69 %)
F2 (18.42 %)
MV-R
MV-V
LuXM-R
LuXM-V
Lu1-R
Lu1-V
Pe1-R
Pe1-V
Pe2-R
Pe2-V
Co-R
Co-V
Al-R
Al-V
Ga-R
Ga-V
Mi-R
Mi-V
BC-V
BC-R
Different colors of chocolate chips
Large diameter
Heterogeneous shape of chocolate chips
Large chocolate chips (chip2)
Heterogeneous sizes of chocolate chips
Many chocolate chips
Dark chocolate chips (chip2)
Angular chocolate chips (chip2)
Balance dough-chocolate
Dispersed chocolate chips
Melted chocolate chips
Soft
Large chocolate chips
Chocolate chips with raisin appearance
Chocolate chips inside the dough
Irregular edge
Angular chocolate chips (chip1)
Sandy texture
Different colours top-bottom
Concave surface
Round
Dark chocolate chips (chip1)
Brown
Many cracks
Deep cracks
Wide cracks



LuXM-R
LuXM-V
Ga-V
Ga-R
Pe1-R
Pe1-V
Lu1-R
Lu1-V
Co-V
Co-R
Al-R
Al-V
Pe2-R
Pe2-V
MV-R
MV-V
BC-R
BC-V
Mi-V
Mi-R
F3 (12.97 %)
F1 (27.69 %)
Dark chocolate chips (chip1)
Dark chocolate chips (chip2)
Brown
Angular chocolate chips (chip1)
Angular chocolate chips (chip2)
Large chocolate chips (chip1)
Large chocolate chips (chip2)
Large alveole on the bottom side
Soft
Chocolate chips with raisin appearance
Balance dough-chocolate
Sandy texture
Many cracks
Chocolate chips inside the dough
Irregular edge
Heterogeneous sizes of chocolate chips
Heterogeneous shape of chocolate chips
Different colors of chocolate chips
Concave surface
Thick
Wide cracks
Bumpy



Large diameter
CONDITION
Real
Virtual
COOKIE
Brown
CONDITION
Real
Virtual
COOKIE
Bright
CONDITION
Real
Virtual
COOKIE
Bright chocolate chips
CONDITION
Real
Virtual
COOKIE


CONDITION
Real
Virtual
Different colors top-bottom
COOKIE
Al
BC
Co
Ga
Lu1
LuXM
Mi
MV
Pe1
Pe2
0
1
2
3
4
5
6
7
8
9
10

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

Irregular edge	Rough dough around the cookie edge
Large diameter	Perceived diameter of the cookie dough when positioned in the center of the sensory booth table
Thick	Thickness of the dough in the middle of the cookie
Curved	Thicker dough in the middle of the cookie than at the edge
Concave surface	Dough sagging in the middle
Bumpy	Irregular thickness forming bumps on cookie dough surface
Many cracks	Perceived amount of cracks in the dough
Deep cracks	Average depth of cracks in the dough
Wide cracks	Average width of cracks in the dough
Sandy texture	Sandy texture on the dough surface
Large craters on the bottom side	Size of the small holes in dough on the bottom side of the cookie
Soft	Looks (visually) easy to break in half without effort
Bright chocolate chips	Intensity of light reflection on the chocolate chips when the cookie is moved under the light
Different colors of chocolate chips	Chocolate chips with obvious contrasting color
Dark chocolate chips (darker chip)	Color intensity of darker chocolate chips
Dark chocolate chips (lighter chip)	Color intensity of lighter chocolate chips
Chocolate chips with red-orangy hue	Red-orange color reflection on the chocolate chips
Raisin-like chocolate chips	Crumpled aspect of the chocolate chips
Heterogeneous sizes of chocolate chips	Chocolate chips with obvious gap between smaller and larger chips
Large chocolate chips (larger chip)	Perceived size of the larger chocolate chips
Large chocolate chips (smaller chip)	Perceived size of the smaller chocolate chips
Heterogeneous shape of chocolate chips	Chocolate chips with various shapes
Angular chocolate chips (squarer chip)	Angularness of the squarer chips
Angular chocolate chips (rounder chip)	Angularness of the rounder chips
Melted chocolate chips	Chocolate chips with a shape that looks like they have melted
Many chocolate chips	Perceived amount of chocolate chips
Chocolate chips cluster	Chocolate chips clustered in small groups
Dispersed chocolate chips	No area without chocolate chips
Chocolate chips inside the dough	Chocolate chips covered with dough (visible by transparency)
Dough-chocolate balance	Equal amount of dough and chocolate
Distinct dough-chips limit	Clear line between the cookie dough and the chocolate chips
More chocolate chips on the top than on the bottom	Unequal distribution of the chocolate chips between the top and the bottom side of the cookie
Presence of nuts	Presence of roughness suggesting that the cookie contains nut chunks

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 * JUDGE			COOKIE * JUDGE			CONDITION * COOKIE * JUDGE		
	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		
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

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