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Effects of physical, non-immersive virtual, and immersive virtual store environments on consumers' perceptions and purchase behavior

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ABSTRACT

The application of virtual reality in human activities has been rapidly growing during the last decade. Shopping for food is an important part of people's daily lives. As overnight delivery services of fresh produce, such as Amazon Fresh, are in their development stage, more studies on virtual stores for perishable products are needed, as the quality of fruits and vegetables (FaVs) cannot be easily assessed by consumers when virtual stores are used. This research examines the impact of a physical store, a non-immersive virtual store, and an immersive virtual store environment on consumers' perceptions and purchase behavior toward FaVs. Experimental between-subjects design (i.e., three groups), combined with a questionnaire survey (after-only design), was used to address the study objectives. The research found that consumers' perceptions of FaVs in both non-immersive and immersive virtual stores (VS) are similar to those in a physical store. By contrast, consumers buy more FaVs in both non-immersive and immersive VS compared to a physical store. The findings also indicate that consumers tend to rely more on extrinsic cues (i.e., FaVs' prices) in the immersive VS when evaluating FaVs on offer and less on intrinsic cues (e.g., FaVs' appearance) they use in the physical store. The results have important implications for practitioners and researchers with regard to the usefulness of virtual reality for better understanding of consumer behavior.

1. Introduction

The latest advances in the Virtual Reality (VR) technology have led to its growing adoption for different business purposes (see Berg & Vance, 2017 for a review). The total market size worldwide for virtual environments (particularly virtual and augmented reality) is expected to grow from 27 billion U.S. dollars in 2018 to 209.2 billion U.S. dollars in 2022 (Statista, 2018). VR is a useful technology for testing new products, by using virtual prototyping (VP) (Dahan & Hauser, 2002; Kim, Lee, Lehto, & Yun, 2011; Ottosson, 2002). VR facilitates users' interactive exploration of new products, and thus their better understanding of the features and benefits of the products presented (e.g., Backhaus et al., 2014). Hence, VR use can provide more reliable feedback or new ideas from users (Füller & Matzler, 2007). VR is also commonly used in different entertainment applications, such as gaming, 3D cinema, and feature films. What is more, VR is a new e-commerce platform (V-commerce; Martínez-Navarroa, Bigné, Guixeresc, Alcañizc, Torrecillac, 2019) (such as e-Bay's Shopticals and Alibaba's Buy+), which has a significant potential to change existing marketing practices and the way people shop. Among the retailers who are actively incorporating VR in their marketing activities are IKEA (e.g., a virtual visit to a kitchen before buying it), Tesco (e.g., virtual visits to different store layouts), Coca-Cola (e.g., a virtual visit to a company's factory), and Vuiton (e.g., virtual personalization of products).

During the last decade or so, virtual stores have been used by a number of studies in their attempt to better understand consumers' food choices. However, their review has identified the following issues. First, several of the studies use Desktop Virtual Reality (D-VR) (Bressoud, 2013; Pizzi, Scarpi, Pichierri, & Vannucci, 2019; Waterlander, Steenhuis, de Boer, Schuit, & Seidell, 2013, 2012; van Herpen, van den Broek, van Trijp, & Yu, 2016; Waterlander, Jiang, Steenhuis, & Mhurchu, 2015; Waterlander, Scarpa, Lentz, & Steenhuis, 2011). In this VR context, consumers could only navigate through the virtual store created through a personal computer screen and a keyboard. Recently, the Head

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Mounted Displays (HMD) have provided appealing visual stimuli to the users and improved their immersive experience (Farah, Ramadan, & Harb, 2019). Nowadays, affordable HMDs are equipped with high resolution displays. Few studies have made use of the HMD (Ledoux, Nguyen, Bakos-Block, & Bordnick, 2013; Martínez-Navarroa et al., 2019; Siegrist et al., 2019). However, to the best of our knowledge, no research has compared D-VR with HMD-VR in terms of consumers' behavior (i.e., products' perceptions and purchases).

Second, most of the existing studies have considered Fast Moving Consumer Goods (FMCG) (Waterlander, Steenhuis, de Boer, Schuit, & Seidell, 2012, 2013, 2015, 2011; Bressoud, 2013; Martínez-Navarroa et al., 2019; Pizzi et al., 2019; Siegrist et al., 2019; van Herpen et al., 2016), which are products placed in boxes that can be easily integrated and reproduced in a virtual world by using photos. Few studies have considered perishable products, such as fresh FaVs. Moreover, when some fresh FaVs were offered to consumers in a virtual store, this was done by using only the same photos of perfect FaVs, replicated several times (van Herpen et al., 2016; Waterlander et al., 2015). Thus, no variability in their appearance was integrated. However, recent research shows that moderately misshapen FaVs are perceived by consumers as better in terms of appearance and quality than heavily and slightly misshapen FaVs (Lombart et al., 2019). The study findings indicate that there is a minimum deformation threshold under which FaVs are not considered to be of good quality.

While these previous studies provide some valuable insights, they do not take full advantage of the latest VR developments (i.e., HMD-VR) to improve consumers' shopping experience. Moreover, fresh produce hardly features in these studies. However, fresh FaVs are one of the three "core" departments (together with dairy and meat) in the supermarket distribution sector. These "core" departments are a key pull factor in shoppers' choice of a supermarket or a hypermarket (Nielsen, 2016). Thus, further research is needed to address these issues.

VS could be a valuable tool for researchers and retailers to conduct studies with quickly perishable food products, such as fresh FaVs. By replacing real fresh products with virtual ones two important methodological issues can be better addressed: (a) replicating more easily existing consumer studies, and (b) better control of different aspects of food appearance (e.g., shape of FaVs) and evaluation of participants' shopping behavior. Indeed, the variability and perishability of fresh produce make it very difficult to replicate consumer studies with a large number of participants. Moreover, fresh products quickly deteriorate over time, and this can be further accelerated by the fact that study participants have to physically examine the products during experiments.

The goal of this research is to examine whether consumers' perceptions (i.e., perceived appearance, quality, price fairness, perceived healthiness, and perceived hedonism), attitude and purchase behavior (both intent and actual purchases) of FaVs are similar in a physical store, a Desktop Virtual Store (D-VS, called a non-immersive virtual store henceforth), and a HMD Virtual Store (HMD-VS, called an immersive virtual store henceforth), and to understand consumers' decision-making for FaVs' purchases across these three store environments.

The key contribution of the present study is in ascertaining the usefulness of VS as a market research tool, which can enable retail businesses to assess consumers' perceptions, attitudes and shopping behavior toward food products in general, and FaVs in particular. In addition, the study findings can raise food retailers' awareness about the transformative effect that VR could have on their businesses, as well as can help them make more informed decisions about possible integration of VR technologies for retaining their consumers by offering a seamless enhanced shopping experience between their physical and virtual stores. Furthermore, the study provides valuable insights as to the variations in the interactions between the constructs considered across the three shopping environments and links them to existing theoretical and empirical work.

The remainder of the article is organized as follows. First, a review of the use of VR in existing studies and the development of the research hypotheses are presented. Next, a discussion is provided on the experimental between-subjects design of the research (i.e., three groups (physical store, non-immersive virtual store, and immersive virtual store), which was accompanied by a questionnaire survey (after-only design). Lastly, the study results, contribution and research limitations are presented. Future research avenues are also identified.

2. Literature review

2.1. Overview

The VR technology aims at generating realistic images to stimulate a sense of a user's physical presence in a computer-simulated virtual environment. The VR equipment allows its users to observe and move around the artificial environment, as well as to interact with virtual objects (Brooks, 1999; Flavian, Ibanez-Sanchez, & Orus, 2019; Jason, 2016). The VR and the real environment are at the opposite ends of the Reality-Virtuality continuum, on which other types of combinations of virtuality and reality exist (e.g., augmented reality and augmented virtuality) (Milgram & Kishino, 1994).

With the help of VR, researchers can create automated virtual environments (AVEs), (Cowan & Ketron, 2019), such as virtual stores resembling the physical ones in terms of stores' environment and consumers' experiences. In a virtual store, consumers can walk around its virtual aisles, look at, pick up, and form an impression of its virtual products placed on its virtual shelves. They can thus evaluate them, make a choice among them, and finally decide to purchase them by putting them in a virtual basket. The consumers are immersed in this simulated store (see Slater, 2009 for more details on immersion), and the immersion they experience depends on the fidelity (e.g., the quality of the 3D graphics, the resolution of the screens used, and whether they wear a Head-Mounted Display or not) with which this virtual environment is created.

The virtual store (VS) can thus be a useful technology for conducting efficient and rigorous research in the field of consumer behavior (Pizzi et al., 2019; Siegrist et al., 2019), without the complexity or costs normally associated with undertaking such research in the real world (Waterlander et al., 2015). Virtual stores can facilitate experimental research on consumers' responses to manipulations of intrinsic (e.g., products' shape, Lombart et al., 2019) or extrinsic food product attributes (e.g., products' prices (Waterlander et al., 2013), promotions offered on these products (van Herpen et al., 2016), point-of-sale displays (Kim et al., 2014), and experience (e.g., relaxing vs. neutral, Van Kerrebroeck, Brengman, & Willems, 2017)). In addition, certain factors that influence consumer behavior (e.g., store layout, Krasonikolakis, Vrechopoulos, Pouloudi, & Dimitriadis, 2018) can be manipulated to a greater extent and with more flexibility in a VS compared to a physical one (Bressoud, 2013). Moreover, some factors that may modify consumer behavior in a physical store (e.g., the behavior of other shoppers) can be controlled in VS (van Herpen et al., 2016).

2.2. Consumers' perceptions and purchase behavior of FaVs

An obvious and crucial question in this area of research is whether consumer behavior in a VS and a physical store are similar and thus are comparable. The limited number of existing studies attempting to answer this question reports some contradictory findings.

The immersive VR technology has the capability to replicate several elements of the real shopping environment (e.g., store layout, point-of-sale displays, products, prices, promotions). An element that could not be replicated is the actual real-time assessment of the food products. When it comes to buying fresh produce, among the most important product attributes consumers use to evaluate FaVs in the physical store are freshness and labeled shelf-life date (Ragaert, Verbeke, Devlieghere, & Debevere, 2004). Ragaert et al. (2004) also report that these attributes are particularly important to consumers because of the nutrition and health benefits associated with them. Given the importance of FaVs' visual assessment before making a FaVs' purchase, as well as the fact that this assessment can only take place during a visit to a physical store, consumers are likely to have more favorable perceptions of FaVs' appearance and quality in a real than a VR supermarket environment.

This notion is partially supported by Bressoud (2013), in the context of fast moving consumer goods (FMCG). Specifically, the study reports that the affective component of attitude is more favorable when consumers are exposed to the real product in a physical store than when they just see a picture of it in VS. However, no differences are found with regard to the cognition and conation components of the study's attitudinal measure. A possible explanation for the latter findings could be the nature of the studied product (i.e., new adult cereal). Viewing the cereal pack in a real shop is not likely to provide a lot more information to the consumer than viewing the picture and reading the product information in a VS environment. What is more, given that the assessment of fidelity of FaVs in VS is affected by the presence of the sensory stimuli and user interaction (e.g., movement of head, body, hands for browsing and picking up products), the immersive experiences in VS can mitigate to some extent the lack of real-life interaction with the fresh produce. In the light of the above argumentation and limited evidence, the following null hypothesis is proposed:

H1. Consumers' perceptions of FaVs' appearance and quality will be similar in the non-immersive virtual, the immersive virtual, and the physical stores.

With regard to consumers' perceptions of price fairness, given that in real life the price levels are generally the same across different supermarket environments of a supermarket chain (e.g., off-line and on-line) (Cavallo, 2017; Wolk & Ebling, 2010), it is reasonable to expect that consumers' perception of price fairness will be the same in a real store and a VS. Hence, the following hypothesis is proposed:

H2. Consumers' perceptions of FaVs' price fairness will be similar in the real, virtual, and immersive VS.

As to the possible variations in the purchased quantities of FaVs, due to consumers' generally strong need for actual contact and visual (and also possibly haptic) assessment of the quality, appearance, and use-by date of the fresh produce, it may be reasonable to expect that they would prefer to buy FaVs in a real supermarket rather than a VS. These cognitive needs may also interact with the affective component of the "live" shopping experience in the real supermarket, thus increasing the likelihood of making more purchases in the real supermarket environment. In line with this logic, Waterlander et al. (2015) found that consumers bought less FaVs in the VS than in the physical shop. Another possible explanation for the findings related to the FaVs' product category could be that in the VS of the study the FaVs did not look like "real" ones, since the same photographs of perfect FaVs were replicated several times with no variability. A further explanation could be that participants' real purchasing behavior was measured only with the till receipts they collected (with the risk of some omissions) during their shopping trips to the supermarkets of their neighborhood, instead of visiting a physical store which mimics the VS used in the research.

An alternative line of reasoning is that in the VR shopping environments no real money is actually spent, and thus consumers do not have any budgetary constraints when making their purchases. As a result, consumers may be inclined to put more food products in their shopping basket than they actually do in real life purchase situations. This notion is supported by van Herpen et al. (2016), who compared consumers' purchasing behavior of food products in a physical store, pictures of a store (2D), and a VS. At odds with Waterlander et al. (2015), their results for the milk category showed that the shopping behavior in the VS was more similar to their behavior in the physical one than in the store depicted by pictures in terms of number of products selected and amount of money spent. Besides, the study participants bought more products and spent more money on FaVs in the VS and the pictorial condition than in the physical store. Similarly, Bressoud (2013) reports that consumers buy more FMCG products in a VS than in a real one, although the difference is not statistically significant. Lastly, Pizzi et al. (2019) found no significant differences in purchase volumes between a real store and a virtual store. Due to the lack of sufficient grounds, no specific effects of the different shopping environments on FaVs' purchase quantities are proposed below. Hence, the following null hypothesis is proposed:

H3. Consumers will buy similar quantities of FaVs in the non-immersive virtual, the immersive virtual, and the physical stores.

2.3. Consumers' decision-making for FaVs' purchases

Food choice is the outcome of different influences, such as product attributes (intrinsic and extrinsic), consumers (e.g., perceptions, beliefs, attitudes), and the consumption context (e.g., occasion) (Johansen, Næs, & Hersleth, 2011). The present research addresses the complexities in food choice by considering three product attributes (i.e., perceived quality, appearance, and price fairness of FaVs), the consumer (i.e., perceptions of FaVs' healthiness and hedonism, attitudes, behavioral intention and actual behavior), and the purchase context (i.e., three different shopping environments). Similar to Siegrist et al. (2019), complementary analysis was performed to understand better consumers' decision-making for FaVs' purchases across the three store environments. The Theory of Reasoned Action (TRA) served as a guide for the effect of attitude on behavioral intention and actual behavior (Ajzen, 1985; Fishbein & Ajzen, 1975) in a VS (non-immersive virtual as well as immersive virtual) context (Loureiro, Guerreiro, Eloy, Langaro, & Panchapakesan, 2019).

Research evidence indicates that product appearance (i.e., packaging of FMCG) (e.g., Marques da Rosa, Spence, & Miletto Tonetto, 2019), quality (e.g., Tudoran, Olsen, & Dopico, 2009), and price (e.g., Peterson, 1977) influence perceived healthiness of consumed foods (Howlett, Burton, Bates, & Huggins, 2009). For FaVs, these product attributes can signal freshness and nutritional properties. Therefore, FaVs' appearance, quality, and price are likely to have a positive effect on perceived healthiness. Hence, the following hypothesis is proposed:

H4. FaVs' perceived quality (a), appearance (b), and price fairness (c) will have a positive effect on perceived healthiness of consuming FaVs.

It has also been shown in the food sector that product appearance (e.g., Bruhn, 1995; Hurling & Shepherd, 2003; Wansink, 2004), quality (e.g., Konuk, 2019; Ryu, Lee, & Kim, 2012) and price (Konuk, 2019; Ryu & Han, 2010) have an impact on consumers' likes and dislikes, attitude, and satisfaction. The latter are constructs with both cognitive and affective components. Thus, FaVs' appearance, quality, and price may also affect perceived hedonism. In the literature on healthy food consumption, higher quality and price have been linked to more appealing flavors or better taste of food products (Hill & Lynchehaun, 2002). Flavors or taste have a strong bearing particularly on the affective component of attitude or consumers' preference (Bourn & Prescott, 2002). Hence, the following hypothesis is proposed:

H5. FaVs' perceived quality (a), appearance (b), and price fairness (c) will have a positive effect on perceived hedonic benefits of consuming FaVs.

Next, previous research indicates that consumers believe that healthy food products provide health benefits beyond what conventional products can offer (e.g., Baker, Thompson, Engelken, & Huntley, 2004; Zanoli & Naspetti, 2002). There is ample evidence suggesting that healthiness is one of the strongest predictors of food choice (e.g., Baudry et al., 2017; Johansen et al., 2011). Hence, the following hypothesis is proposed:

H6. FaVs' perceived healthiness will have a positive effect on consumers' attitude toward FaVs.

Lastly, products and brands can provide hedonic value by evoking feelings of enjoyment, pleasure, and well-being (Babin, Darden, & Griffin, 1994). In the context of food, taste (or hedonic preference) plays a key role—alongside health—in food choice (e.g., Baudry et al., 2017). What is more, perceived hedonism of healthy foods appears to be higher compared to conventional foods (e.g., McEachern & McClean, 2002; Tagbata & Sirieix, 2008), and the hedonic benefits derived from the consumption of healthy foods tend to determine consumers' purchase intention (Anisimova, 2016). Hence, the following hypothesis is raised:

H7. FaVs' perceived hedonism will have a positive effect on consumers' attitude toward FaVs.

The Theory of Reasoned Action (TRA) assumes that people's specific actions are largely guided by their beliefs, attitude and behavioral intention, which is, in turn, the immediate antecedent of actual behavior. Since the founding work of Fishbein and Ajzen (1975) and Ajzen (1985), significant and consistent positive relationships have indeed been found between consumers' attitude toward a product or a brand and their purchase intention and actual purchase behavior of this product or brand (Armitage & Conner, 2001; Fishbein & Ajzen, 2010). Hence, the following hypotheses are posited:

H8. Consumers' attitude toward FaVs will have a positive effect on behavioral intention to purchase FaVs.

H9. Consumers' behavioral intention to purchase FaVs will have a positive effect on actual purchases of FaVs.

The discussed above study hypotheses are presented in Fig. 1.

3. Method

3.1. Stimuli

The Virtual Store (VS) used in this research (see Picture 1) mimics the physical store of a store laboratory used for the purposes of the present research. Similar to the physical store, the VR supermarket had a cashier, four shelves filled in with non-perishable food products (e.g., rice, pasta) and a fresh produce stand filled in with eight families of FaVs: four fruits (i.e., oranges, bananas, pears (conference variety), and apples (Granny Smith), and four vegetables (i.e., potatoes, zucchinis, carrots, and tomatoes (round).

Variability in the FaVs appearance was integrated to look like "real" ones. The different types of FaVs were displayed in 18 baskets. The only information provided about the FaVs was their name and price per kilogram. Following van Herpen et al.'s (2016) advice, the same product assortment is offered to consumers in the physical store and the virtual store. Non-perishable food products were hand-modeled using products' real dimensions and were textured with high resolution pictures taken from the real products. The FaVs were semi-automatically generated (see Appendix 1, Picture 4).

The VS for this experiment was developed in two versions: an immersive VS and a non-immersive VS or 3D desktop VS. In the immersive and non-immersive stores, the virtual supermarket (approximately 96 m^2) and its content were identical (number of shelves, products, etc.), mimicking those of the physical store. The only difference between the two VS versions was related to how users saw and interacted with the VS.

Participants were immersed in the immersive VS with a VR Head-Mounted Display. For this experiment, an Oculus Rift DK2 was used. The HMD had a resolution of 960 $\times$ 1080 pixels per eye and a field-of-view (FOV) of approximately 80° horizontally and 100° vertically. The 3D scene was visualized stereoscopically, and the movement of participants' heads was tracked by a DK2 external infrared camera (see Picture 2). In order to navigate in the immersive VS and interact with the virtual products, participants used a controller (Xbox One controller). The navigation metaphor was identical to that classically seen in First-Person Shooter (FPS) games: participants could rotate using the left thumbstick and move forward/backward in the camera's direction using the right thumbstick. Note that since participants' head movements were tracked by the Oculus DK2, they could decide not to use the left thumbstick and use only their head to control the orientation of the camera. In order to avoid motion sickness, the rotation speed was adjusted empirically and the displacement speed was set to that of a normal walking space.

The interaction metaphor with the virtual FaVs was also implemented using the same controller. A small semi-transparent gray dot was always displayed at the center of the participants' view to serve as a selection target. The first object directly behind this dot became "active", meaning that the participants could interact with it. To exhibit that an object was active, we modified its display and made it blink. The participants could interact with the "active" object in multiple ways: they could select it, manipulate it (once selected), buy it (once selected), or put it back to its original place (once selected). These interactions were achieved by pressing different buttons on the controller. Once selected, the object was removed from its original position in the 3D scene and a bigger version of it was displayed at the center of the participant's view. The participant could then manipulate it by zooming in/out or rotating to inspect the product. If the participant decided to buy the product (by pressing a button on the controller), it disappeared and was added to a virtual basket. The participant could also decide to put it back on the shelf (by pressing another button). In that case the product went back to its original place in the virtual store. The virtual basket was simply a 2D Graphical User Interface (GUI) window listing all products currently in the basket, their individual price, as well as the total basket price. The latter was added to simplify the participants' task so that they always knew how much they spent.

As to the difference of the non-immersive VS with the immersive VS, the study participants visualized the store on a 17″ computer screen (see Picture 3) at a resolution of 1280 $\times$ 1024 pixels. To interact with the non-immersive VS, they used a keyboard and a mouse, just as they would do if they were playing a classical 3D computer game. The

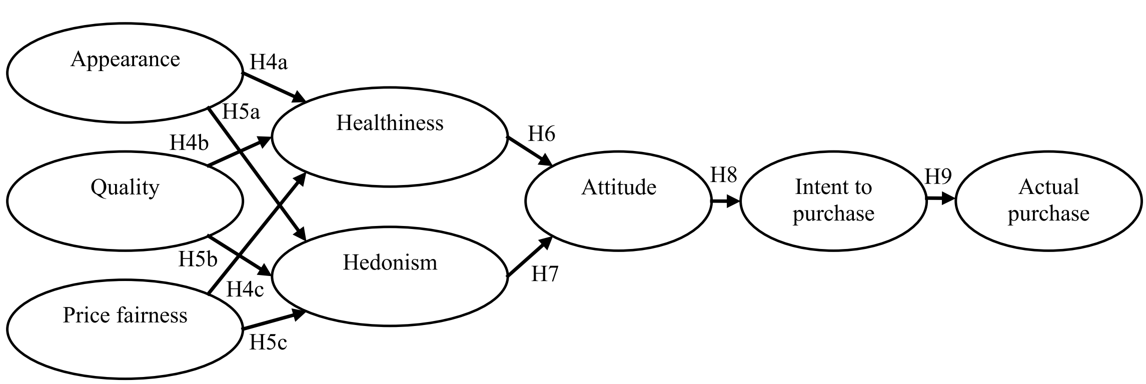


Fig. 1. Conceptual framework.

navigation and interaction metaphors were implemented to be as similar as possible to that of a classical 3D FPS game.

To navigate, participants could control the orientation of the camera with the mouse (by just moving it left/right) and they could move forward/backward in the camera's direction by pressing the up/down arrow on the keyboard. The left/right arrows could also be used to "strafe" (i.e., make a side step onto the left, respectively right, depending on the key they pressed).

To interact with the products, a comparable mechanism with that of the IVS was implemented. A similar semi-transparent gray dot was always displayed at the center of the view, which served as a target to activate the products. As in the IVS condition, once activated, a product blinked to let the participant know that s/he could interact with it. Again, similar to the immersive VS, the participant could select the product (by pressing a button on the mouse). Once selected, a bigger version of the product was displayed in the center of the participant's view, and the participant could rotate it (by moving the mouse left/right) or zoom in/out (by using the mouse wheel). Participants could buy a product by pressing a key on the keyboard (the product would then disappear from the 3D scene and go to the same virtual basket as in the immersive VS condition) or put it back in its original place in the 3D scene (by pressing another button).

3.2. Participants and research design

In this research, a convenience sample of 192 business school students (aged between 18 and 22 years) took part in the study experiment. This kind of homogeneous sample increases the internal validity of the research as the observed differences result only from the manipulation tested in the experiment and not from individuals' differences (Ashraf & Merunka, 2017). With regard to their previous experience with VR, 176 participants (91.7%) had no such experience, and 16 (8.3%) had some experience.

Using an experimental between-subjects design (Charness, Gneezy, & Kuhn, 2012), these students were randomly assigned either to the physical store (n = 64), the non-immersive virtual store (n = 68), or the immersive virtual store (n = 60). In the initial selection, the three samples comprised equal-sized groups. The small variation between the three groups reported above was due to cancellation of participation due to last-minute changes in students' schedules. It was thus impossible for them to attend the experiment at the time planned for its implementation. For the immersive virtual condition, a small number of participants withdraw during the experiment due to feeling unwell. If order disproportions in sample sizes in an experiment lower the overall power of tests, the variations have to be large to have an impact (Rusticus & Lovato, 2014).

According to Suh and Prophet (2018), the experimental method is the most frequently used (55.6%) by studies (n = 54) on immersive VR in different fields of research. In line with van Herpen et al. (2016), the participants in the different conditions were drawn from the same sample. In the existing experimental VR studies the sample size is predominantly small (according to Loureiro et al., 2019, around 100 participants in about 90% of the 150 studies on non-immersive and immersive VR reviewed in different fields of research, and with a mean of 48 participants (SD = 33.25) according to Lanier et al., 2019 in their review of 61 articles on immersive VR in different fields of research). They also predominantly use convenience samples comprising undergraduate or graduate students: according to Loureiro et al. (2019), about 80% of the 150 studies on non-immersive and immersive VR reviewed in different fields of research, and 65% according to Suh and Prophet (2018) in their review of the 54 studies using immersive VR, again in different research fields. Given the objectives of the present research and the fact that students are the dominant group among users of emerging technologies (Parboteeah, Valacich, & Wells, 2009), the sample size and composition of our experiment are deemed appropriate.

To validate the homogeneity of the groups formed, chi-square analysis and non-parametric ANOVA (Kruskal-Wallis test) were conducted. The three groups were homogeneous with regard to sex composition ($X^2 = 5.881$; $p = 0.053$) and age ($X^2 = 3.508$; $p = 0.173$). These three groups were also homogeneous with their level of food waste consciousness, measured with six items on a six-point Likert scale (see Lombart et al., 2019): construct reliability (CR) = 0.879, average variance explained (AVE) = 0.549, $X^2 = 0.011$; $p = 0.995$. Since consumers tend to have a higher propensity to choose suboptimal FaVs when they are conscious about food waste (de Hooge et al., 2017), this effect was also taken into consideration for each group ($M = 30.29$; $SD = 5.03$).

3.3. Procedure

First, the participants of the three subsamples were presented with the respective scenario of the experiment. The study participants had to buy at least two different types of fruits and at least two different types of vegetables of their liking in quantities that they considered suitable for four people. According to the experimental scenario, an amateur cook will come to their residence and deliver a dinner s/he will specially prepare for them and three of their friends in their workshop/kitchen. The content of the menu is kept a surprise and the cook is in charge of buying all the products s/he will use for this menu from her/his usual suppliers, except for the FaVs that the cook let the participant in the experiment decide about. In order for the participant to do the shopping, the cook gives them a budget of 20 euros that they can spend entirely or not. Thus, the participants in the different conditions received the same instructions and had budget restrictions to avoid spending more money than they would in reality (van Herpen et al., 2016). If a participant had a query regarding the scenario, s/he was encouraged to seek clarification from the researcher. This was done to avoid a situation wherein participants quickly select a product without spending sufficient time in the selection process (Siegrist et al., 2019). Consequently, as for shopping in real life, participants could take the time they wished to complete the scenario of the experiment (Waterlander et al., 2011).

After the participants read the scenario, in the physical store, they took a basket and shopped as they would do in a real point of sale, moved through the store and, if they wished, physically handled the products and read the POS information with the names of the FaVs and their prices. In the non-immersive and immersive VS, as the VR technology is rather new, a training session was held to explain to the study participants how to interact with the VR supermarket in terms of navigation, selection, manipulation and purchase of the FaVs by using either the screen and the keyboard in front of them (in the Desktop Virtual Reality or non-immersive virtual store) or the Oculus Rft DK2 HMD and the Xbox One controller (in the HMD Virtual Reality or immersive virtual store). If a participant had a query regarding the use of the VS equipment, as before, s/he was encouraged to seek clarification from the researcher. At any time during their virtual shopping, if they wished, the participants could access the content of their virtual shopping basket by pressing a button on the controller (the one used for purchasing when an object is selected). Similar to the physical store, each product had its name (e.g., carrot, apple) and price displayed, as well as the total value of the whole shopping basket.

Lastly, once the experiment was completed in the physical, non-immersive and immersive stores, the participants paid at the (virtual) cashier, where the total number of FaVs purchased and the amount of money spent on FaVs were recorded. Immediately after that the participants filled in the study questionnaire.

3.4. Measures

Consumers' perceptions of FaVs' appearance and quality were measured with six and five items, respectively, drawn from Aurier and Siriex (2009). Consumers' perceptions of FaVs' price fairness were measured with two items from Bolton, Keh, and Alba (2010). FaVs' perceived healthiness and hedonism were measured with two and three items, respectively, from Bauer, Heinrich, and Schäfer (2013). Consumers' attitude was measured with four items from Lombart and Louis (2012). The multi-item measures used in this study are presented in Table 1. Lastly, purchase intention was captured with a single-item measure.

3.5. Statistical analysis

In this research, we used partial least squares structural equation modelling (PLS-SEM) with a bootstrap procedure with 5000 replications (Tenenhaus, Esposito Vinzi, Chatelin, & Lauro, 2005). We used PLS-SEM, referred to as variance-based, instead of covariance-based structural equation modelling (CB-SEM), for four main reasons provided by Hair, Sarstedt, Ringle, and Mena (2012) in their meta-analysis on the use of PLS-SEM in management research, as well as by Hair, Sarstedt, Hopkins, and Kuppelwieser (2014) in their review of PLS-SEM use in business research. These reasons are as follows: (a) it does not require the variables to follow a multivariate normal distribution (computed coefficient Mardia > |3| in this research); (b) it works well with small samples (around 60 for the different subsamples considered in this research); (c) it works well with models comprising a large number of latent variables (an average number of 7.94 in the management field and 8 in this research); (d) it allows the unrestricted use of single-items (for the purchase intention of FaVs in this research).

4. Results

4.1. Psychometrics properties of the measures

CFA confirmed the expected one-dimensional factor structures of the study constructs (see Table 1). Multi-group analyses and permutation tests were conducted to establish measurement invariance across the three subgroups (see Chin & Dibbern, 2010). These additional analyses revealed partial invariance of the measures used for the three subgroups studied. Of the 66 differences tested, four were significant at the 0.05 level. All factor loadings were above 0.5 and statistically significant at the 0.01 level. Jöreskog's rhô coefficients (Jöreskog, 1971) were estimated to establish construct reliability (CR). Finally, measures' convergent and discriminant validity was ascertained using Fornell and Larcker's (1981) approach. These analyses confirmed the reliability and validity of the measures used in the present research (see also Table 2).

4.2. Comparisons of consumers' perceptions and purchase behavior across the physical, non-immersive virtual, and immersive virtual store

Kruskal-Wallis analysis of variance was performed to test the study hypotheses. This is a rank-based nonparametric test that is used to determine if there are statistically significant differences between two or more groups of an independent variable on a continuous dependent variable. The test replaces all scores with their rank numbers, so that higher scores get higher rank numbers. If the grouping variable does not affect the ratings, then the mean ranks should be roughly equal and this should be confirmed by a chi-square test. The mean ranks within each group or relative ranks, as well as the results of the chi-square tests, are presented in Table 3.

The tests performed indicated no significant differences among the three stores with regard to consumers' perceptions of the FaVs (perceived appearance, perceived quality, perceived price fairness, perceived healthiness, perceived hedonism, attitude, and purchase intention). Consequently, consistent with H1 and H2, consumers' perceptions of FaVs' appearance, quality, and price fairness were similar in the real, virtual, and immersive VS. As to H3, the null hypothesis of no difference in FaVs' quantities purchased across the three store environments was not supported: consumers bought more FaVs in the two VS (i.e., non-immersive and immersive) compared to the physical store.

4.3. Consumers' decision-making for FaVs' purchases

Our SEM analysis indicates (see Table 4 and Figs. 2–4) that in the physical (Path Coefficient (PC) = 0.599, $p < 0.01$) and non-immersive virtual (PC = 0.776, $p < 0.01$) stores, consumers tend to rely on the perceived quality of the FaVs to infer about their *healthiness*. In the immersive VS, consumers tend to rely on the perceived quality (PC = 0.670, $p < 0.01$) of the FaVs to infer about their *healthiness* but also on their perceived price fairness (PC = 0.215, $p < 0.05$). Consequently, H4b

Table 1
Results of CFA.

Constructs	Items	Physical store (n = 64)		Non-immersive VS (n = 68)		Immersive VS (n = 60)	
		PC	*t*	PC	*t*	PC	*t*
Appearance	The color of the FaVs Vs gives me the impression of high-quality products	0.871	19.259***	0.754	15.984***	0.785	12.760***
	The size of the FaVs gives me the impression of high-quality products	0.845	16.996***	0.784	12.405***	0.745	8.297***
	The shape of the FaVs gives me the impression of high-quality products	0.841	19.588***	0.803	13.895***	0.703	10.249***
	The apparent texture of the FaVs gives me the impression of high-quality products	0.780	17.724***	0.804	16.242***	0.803	13.182***
	The apparent freshness of the FaVs gives me the impression of high-quality products	0.732	13.289***	0.755	16.426***	0.671	8.517***
	The external appearance of the FaVs gives me the impression of high-quality products	0.863	20.740***	0.899	13.067***	0.873	12.656***
Quality	I will be satisfied by the taste of the FaVs	0.880	16.073***	0.831	18.150***	0.822	11.751***
	I will be satisfied by the nutritional quality of the FaVs	0.879	18.317***	0.806	12.477***	0.804	15.427***
	I will be satisfied by the sanitary quality of the FaVs	0.816	19.178***	0.861	16.769***	0.579	4.526***
	I will be satisfied by the environmental impact of the production of the FaVs	0.655	8.169***	0.789	16.047***	0.699	9.929***
	I will be satisfied by their global quality	0.853	15.850***	0.875	18.177***	0.895	12.028***
Price fairness	Prices of the FaVs are fair	0.926	24.353***	0.951	68.127***	0.905	19.366***
	Prices of the FaVs are appropriate	0.926	24.353***	0.951	68.127***	0.905	19.366***
Healthiness	Eating these FaVs could help me to improve my health	0.953	61.657***	0.937	41.257***	0.946	55.695***
	Consuming these FaVs would allow me to live a healthy life	0.953	61.657***	0.937	41.257***	0.946	55.695***
Hedonism	By consuming these FaVs, I could take care of myself	0.877	17.017***	0.897	17.722***	0.871	21.479***
	By consuming these FaVs, I could strengthen my personal well-being	0.899	16.867***	0.794	18.360***	0.894	17.389***
	For me, consuming these FaVs would be a pleasure	0.808	18.955***	0.819	18.268***	0.857	21.233***
Attitude	I find this offer of FaVs interesting	0.877	33.356***	0.843	17.518***	0.835	17.197***
	I appreciate this offer of FaVs	0.928	29.087***	0.915	16.265***	0.942	24.244***
	I could recommend to my friends or relatives to buy the FaVs of this store	0.900	28.826***	0.781	16.602***	0.869	20.797***
	Overall, I have a favorable attitude towards the offer of FaVs of this store	0.891	35.918***	0.838	16.327***	0.926	23.201***

Notes: PC = Path coefficient and ***/** Coefficient significant. Student's *t*-test values higher than |2.575| indicate parameters significant at the 1% level and n.s. stand for non-significant coefficient.

Table 2
CR, convergent and discriminant validity.

Conditions	Constructs	CR	1.	2.	3.	4.	5.	6.
Physical store (1; n = 64)	1. Appearance	0.926	0.678					
	2. Quality	0.911	0.607	0.674				
	3. Price Fairness	0.924	0.168	0.140	0.858			
	4. Healthiness	0.952	0.244	0.438	0.174	0.909		
	5. Hedonism	0.897	0.357	0.447	0.251	0.692	0.743	
	6. Attitude	0.944	0.552	0.421	0.227	0.214	0.341	0.809
Non-immersive virtual store (2; n = 68)	1. Appearance	0.915	0.642					
	2. Quality	0.919	0.379	0.694				
	3. Price Fairness	0.950	0.068	0.056	0.905			
	4. Healthiness	0.935	0.157	0.526	0.068	0.879		
	5. Hedonism	0.876	0.271	0.442	0.060	0.652	0.702	
	6. Attitude	0.909	0.239	0.310	0.193	0.287	0.356	0.715
Immersive virtual store (3; n = 60)	1. Appearance	0.894	0.587					
	2. Quality	0.875	0.402	0.589				
	3. Price Fairness	0.901	0.197	0.257	0.819			
	4. Healthiness	0.944	0.209	0.449	0.184	0.894		
	5. Hedonism	0.907	0.411	0.475	0.316	0.683	0.764	
	6. Attitude	0.941	0.533	0.424	0.247	0.177	0.282	0.799

Notes: CR=Composite reliability and the convergent validities (ρ_{vc}) are shown on the diagonal and the square of the correlations (R_{ij}^2) appear below the diagonal.

Table 3
Consumers' perceptions and behavior: Relative ranks.

Conditions	Physical store (1; n = 64)	Non-immersive virtual store (2; n = 68)	Immersive virtual store (3; n = 60)	1–2 X^2 (p-value)	1–3 X^2 (p-value)	2–3 X^2 (p-value)
Appearance	65.25	67.68	63.61	0.133 (0.715)	0.111 (0.739)	0.001 (0.973)
Quality	68.94	64.21	59.62	0.507 (0.477)	0.751 (0.386)	0.072 (0.789)
Price fairness	60.65	72.01	62.48	2.980 (0.084)	0.000 (0.994)	3.001 (0.083)
Perceived healthiness	68.31	64.79	61.11	0.287 (0.592)	0.179 (0.672)	0.000 (0.998)
Perceived hedonism	65.69	67.26	65.33	0.057 (0.812)	0.729 (0.393)	0.568 (0.451)
Attitude	68.8	64.34	60.28	0.450 (0.502)	0.448 (0.503)	0.000 (0.985)
Intent to purchase	68.55	64.57	59.50	0.376 (0.540)	0.849 (0.357)	0.337 (0.562)
Number of products purchased	52.06	80.09	76.98	17.798 (0.000)	18.955 (0.000)	0.088 (0.767)

Table 4
Results of the structural equations models.

	Physical store (1; n = 64)			Non-immersive virtual store (2; n = 68)			Immersive virtual store (3; n = 60)			Results (*p*-value) of tests of differences between the two parameters (PC)		
	PC	*t*	R^2	*PC*	*t*	R^2	*PC*	*t*	R^2	(1) vs (2)	(1) vs (3)	(2) vs (3)
Appearance → Healthiness	0.049	n.s.	0.481	−0.097	n.s.	0.562	−0.103	n.s.	0.486	0.475	0.329	0.974
Quality → Healthiness	0.599	4.532***		0.776	7.243***		0.670	4.520***		0.738	0.583	0.185
Price fairness → Healthiness	0.109	n.s.		0.108	n.s.		0.215	2.115**		0.997	0.528	0.403
Appearance → Hedonism	0.321	2.910***	0.621	0.159	n.s.	0.501	0.135	n.s.	0.551	0.328	0.896	0.302
Quality → Hedonism	0.377	3.340***		0.567	4.959***		0.484	3.493***		0.187	0.556	0.639
Price fairness → Hedonism	0.239	2.466**		0.093	n.s.		0.268	2.828***		0.203	0.257	0.840
Healthiness → Attitude	0.107	n.s.	0.365	0.130	n.s.	0.379	0.265	n.s.	0.328	0.606	0.153	0.362
Hedonism → Attitude	0.690	3.784***		0.505	2.978***		0.789	3.551***		0.449	0.738	0.313
Attitude → Intent to purchase	0.831	11.741***	0.690	0.821	11.677***	0.674	0.791	9.841***	0.625	0.867	0.600	0.697
Intent to purchase → Actual purchase	0.103	n.s.	0.041	0.016	n.s.	0.000	0.065	n.s.	0.004	0.251	0.795	0.460
External GoF	0.992			0.991			0.991					
Internal GoF	0.923			0.947			0.898					

Notes: PC = Path coefficient and ***/** Coefficient significant. Student's *t*-test values higher than |2.575/1.96| indicate parameters significant at the 1%/5% level and n.s. stand for non-significant coefficient.

(related to FaVs quality) is confirmed for the three conditions and H4c (related to FaVs price fairness) only for the immersive VS. By contrast, H4a (related to FaVs appearance) is not supported for the three conditions.

In the immersive VS, the perceived quality (PC = 0.484, $p < 0.01$) of the FaVs and their perceived price fairness (PC = 0.268, $p < 0.01$) are

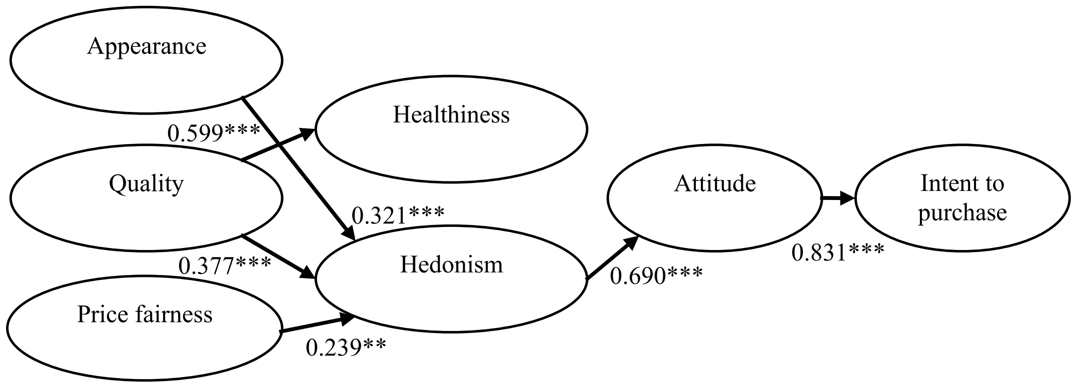


Fig. 2. Physical store (n = 68).

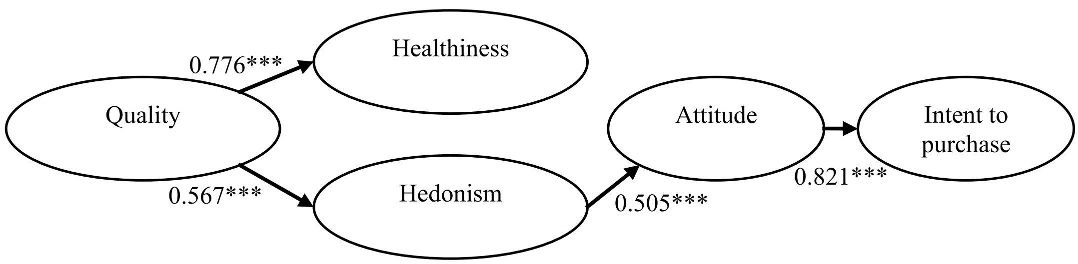


Fig. 3. Non-immersive virtual store (n = 68).

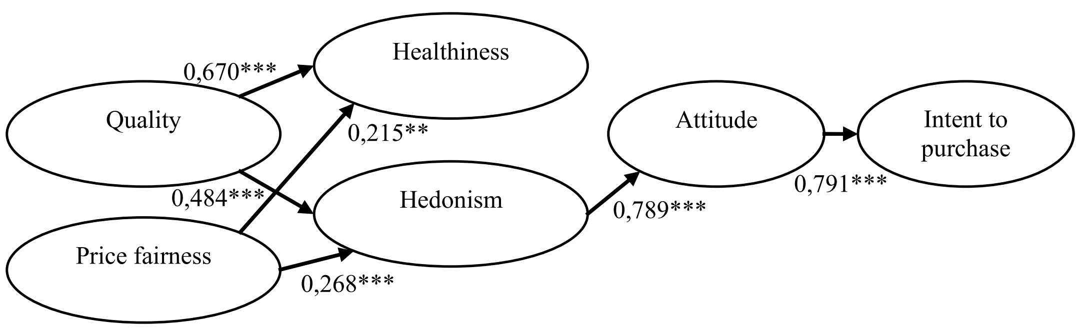
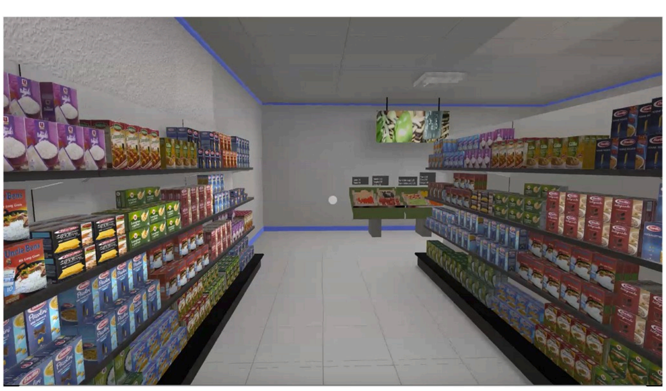


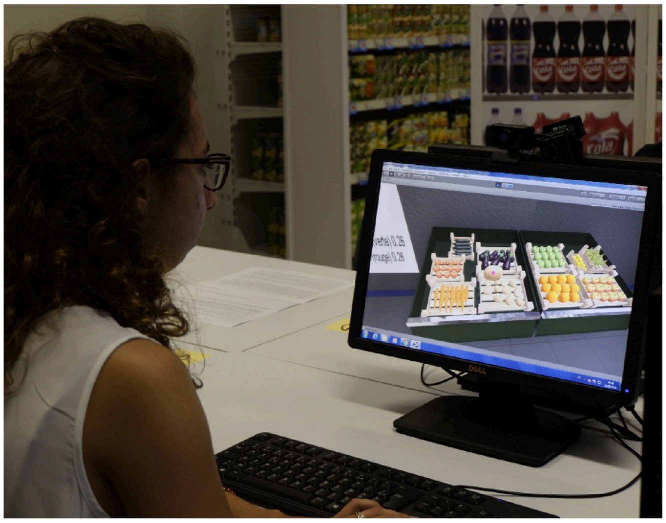
Fig. 4. Immersive virtual store (n = 60).



Picture 1. The virtual store.

Picture 2. The immersive virtual store condition.

also used by consumers to infer the *hedonic* benefit they can derive from consuming these products. In the non-immersive VS, they only use FaVs' perceived quality (PC = 0.567, $p < 0.01$) to infer their *hedonic* value. By contrast, in the physical store consumers use the perceived quality (PC = 0.377, $p < 0.01$) of the FaVs and their perceived price fairness (PC = 0.239, $p < 0.05$), as well as their perceived appearance (PC = 0.321, $p < 0.01$), to infer the *hedonic* benefit they can derive from the consumption



Picture 3. The non-immersive virtual store condition.

of these products. Consequently, H5b (related to FaVs quality) is supported for the three conditions, H5c (related to FaVs price fairness) for the physical and immersive virtual stores, and H5a (related to FaVs appearance) only for the physical store.

The SEM results also indicate that consumers' attitude towards the FaVs is based, in the three stores studied (physical (PC = 0.690, $p < 0.01$), non-immersive virtual (PC = 0.505, $p < 0.01$), and immersive virtual (PC = 0.789, $p < 0.01$)) on the perceived *hedonism* linked to the consumption of these products, as posited by H7. By contrast, FaVs' perceived healthiness does not have an effect on consumers' attitude toward FaVs, as posited by H6.

Lastly, consistent with H8, SEM indicates that consumers' *attitude* toward FaVs is a predictor of their BI in the three stores studied (physical (PC = 0.831, $p < 0.01$), non-immersive virtual (PC = 0.821, $p < 0.01$), and immersive virtual (PC = 0.791, $p < 0.01$)). However, a gap between BI and actual FaVs' purchases consistently emerged in the three store environments. Specifically, the relationship between *consumers' intention to purchase FaVs* and *actual purchases* of these products, posited by H9, is not significant.

5. Discussion

This study explored the effects of real, non-immersive virtual, and immersive virtual store environments on shoppers' perceptions of appearance, quality, and price fairness of FaVs. It also examined the effects of perceived healthiness, perceived hedonism, and attitude on BI and actual purchases of FaVs in the three different supermarkets. Consistent with prior expectation, this research found that consumers' perceptions of appearance and quality of FaVs in a VS (virtual and immersive virtual) were similar to their perceptions in a physical store. The realistic representations of the FaVs in the VR environment which, accompanied by users' visual and haptic interaction and immersive experience in the VR supermarket, might have tricked human senses, thus making consumers to believe that what they see is what they would get. Or consumers may just instinctively assume that food provided in those virtual stores is of good quality as that in real stores. According to Mazursky and Vinitzky (2005) and Kim and Krishnan (2015), consumers do not buy products online if there is a high degree of uncertainty about subjective product quality; however, this effect appears to be limited to expensive products, even when consumers have accumulated much online shopping experience. Another possible explanation is that the study participants' awareness of the experimental environment could have reduced the importance they might place on freshness/quality of the food. In addition, the limitation of the immersive VR supermarket due to the lack of real contact with the FaVs could be offset, at least to some extent, by certain benefits that the immersive VR store offers, such as real time product information, and easy selection. Given the fact that nowadays consumers in general have significant experience with online shopping, the additional benefits offered by the immersive VR shopping environment may be perceived as interesting and appealing. What is more, during their interaction with the VS, consumers may also satisfy their curiosity as to the nature of this novel shopping environment and the shopping experience, which is consciously or unconsciously compared with the one in the physical store.

As to consumers' perceptions of price fairness, consistent with the argumentation for H2, no differences were found across the three supermarket environments. Also, consumers bought more FaVs in the VS (virtual and immersive virtual) compared to the physical one, which is in line with van Herpen et al.'s (2016) findings. This finding also provides support to the argumentation that in the VR shopping environment, where no real money is involved, consumers are likely to increase their purchase rate.

With regard to the consumers' decision-making process when evaluating and selecting FaVs in the three supermarket environments, FaVs' quality (an intrinsic cue) was linked positively to both healthiness, which is consistent with Tudoran et al. (2009), and hedonism, which is in line with Ryu et al. (2012) and Konuk (2019). Besides, perceived appearance (also an intrinsic cue) was not associated with the healthiness benefit of FaVs in the three shopping environments. Hence, FaVs' appearance does not seem to provide informational cues about the possible health effects of consuming fresh produce. Furthermore, consistent with the postulated effect of attitude on BI within the TRA (see Fishbein & Ajzen, 2010), this study found that attitude had a significant positive effect on BI across the three store environments. Interestingly, the same gap between BI and actual purchase was identified in the three store conditions. This gap is in line with the findings of several studies in physical food shopping environments (for review, see Armitage & Conner, 2001). Given the health-related consequences of consuming FaVs, it may be the case that the reported BI is more of an aspiration rather than as an actual behavioral outcome (see Alwitt & Pitts, 1996). What is more, when actually choosing their food, consumers have to consider competing and often contradictory needs (see Lockie, Lyons, Lawrence, & Mummery, 2002). Hence, their actual food purchases are likely to reflect the uncertainties created by these competing demands, and perhaps also some situational factors that can intervene and weaken this relationship. Apparently, this gap is not influenced by the environment in which the shopping takes place.

Some differences across the studied store environments were also found. Our findings indicate that consumers rely on extrinsic cues (i.e., FaVs' prices) in the immersive virtual store when evaluating the healthiness of FaVs, which is not the case for the physical and the non-immersive VS. Also, the link between appearance and hedonism was significant only in the physical supermarket. This finding supports our argument about the importance of visually assessing FaVs in a physical store environment. What is more, the non-significant effect of perceived healthiness of FaVs on attitudes and the significant positive effect of hedonism on attitudes in the three shopping environments suggest that for FaVs the hedonic aspect of their consumption may be more important than their cognitive appraisal. This last result is in line with Anisimova's (2016) findings. Finally, the positive effect of price fairness on hedonism was significant for the physical and immersive VR supermarkets. The direction of this effect was the same for the non-immersive virtual store; however, it was not significant. These findings highlight the importance of price fairness (an extrinsic product attribute) in consumer decision-making, as also shown by previous research (Konuk, 2019; Ryu & Han, 2010). It also points out that consumers are likely to develop stronger believes about the hedonic benefits from consuming FaVs on the basis of their price levels. Indeed, evidence suggests that consumers perceive higher-priced organic foods to have a better taste than conventionally produced ones (e.g., Davies, Titterington, &

Cochrane, 1995; Xie, Wang, Yang, Wang, & Zhang, 2015).

It is noteworthy that as not being part of the physical products, extrinsic attributes can be changed easily without modifying the physical properties of the products (Akdeniz, Calantone, & Voorhees, 2013; Richardson, Dick, & Jain, 1994). Our findings indicate that the extrinsic (intrinsic) cues are easier (more difficult) to be evaluated in an immersive VS compared to a physical one. Hence, they provide support to Martínez-Navarroa et al.'s (2019) argument that a VS is more effective in generating cognitive responses.

Our findings have important implications for practitioners and researchers. They demonstrate that as a new research tool VR can be successfully used to simulate a store environment (Cowan & Ketron, 2019). VR also allows the administration of various experiments that would not be possible in the real world (Siegrist et al., 2019; Waterlander et al., 2015). In a VS, consumers' food (FMGC and FaVs) choices could be studied in a controlled environment. One could examine, for example, how food advertising and point-of-sale activities, point-of-sale displays or promotions could influence different behavioral outcomes. In addition, the effects of additional extrinsic (e.g., prices, promotions, point-of-sale displays) and intrinsic (e.g., products' shape, color, texture) product attributes could be examined. Our findings also indicate that VR could be of great value for studying "fresh" food products (e.g., dairy, fruits and vegetables, meat, fish), for which in-store studies prove close to impossible to be conducted with large numbers of participants due to rapid deterioration of real fresh products. After an experiment is run with a few participants, products that have deteriorated will need to be replaced with new ones, and as a result not all participants will experience the same experimental conditions.

Some future improvements needed in the VR setup are worth mentioning. For instance, if the VR setup could better model the movement of placing products in a shopping cart or allow consumers carrying a basket or pushing a (virtual) shopping cart, participants may be better able to track their purchases. Improvements are also needed to enable control devices to better resemble realistic actions, such as physically inspecting the products and sensing their textures through touch. In the same vein, the simulated social aspect of the shopping environment could be improved (Hudson, Matson-Barkat, Pallamin, & Jegou, 2019). Further research could consider the VS as another channel to sell products to consumers (i.e., V-commerce, Martínez-Navarroa et al., 2019), as well as to study the benefits that VS (virtual and immersive) could offer to consumers in terms of improved browsing, real time product information, easy selection, and personalization of market offers.

Lastly, the study limitations are worth mentioning. To start with, convenience sampling was used, and only young people participated in this research. Additional validation studies of VS could use larger more representative samples. Next, this study was focused on FaVs. Further research could consider other fresh produce (e.g., meat, fish, bread and bakery). Lastly, the present study used a between-subject design. If a within-subject design (one participant in all stores) instead of a between-subject design (one participant in only one store) were used, the study's participants could have noticed the differences among the three stores studied in a direct fashion. The effect of this joint experience on consumers' responses to the different store environments is worth exploring.

CRediT authorship contribution statement

Cindy Lombart: Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Elena Millan:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Jean-Marie Normand:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Adrien Verhulst:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Blandine Labbé-Pinlon:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Guillaume Moreau:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing.

Appendix 1. The semi-automatic generation process

Our semi-automatic generation process is based on a modified generalized cylinder technique (Agin & Binford, 1976). A set of 3D objects is procedurally generated using two manually generated user inputs:

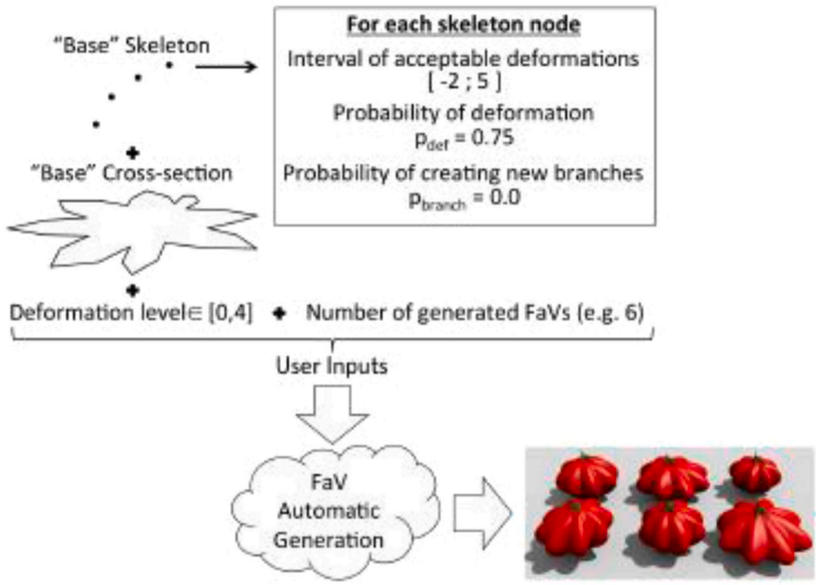
- base 3D skeleton
- base 2D cross-section

of the targeted FaV family (e.g. a cross-section of an apple, orange, …).

In order to generate a set of 3D FaVs, both the base 3D skeleton and the base 2D cross-section undergo automated randomized variations in their overall shape. The range of variations automatically applied depends on the required level of deformity for the FaVs.

Once the randomized skeletons are generated, the base 2D cross-section is swept along each of branches of each skeleton to generate rough 3D models. Finally, a smoothing algorithm (a Catmull-Clark subdivision method (Catmull & Clark, 1978) followed by a Laplacian smoothing operator (Taubin, 1995)) is applied to obtain the set of final automatically generated 3D models.

The virtual 3D FaVs are manually chosen from this set of automatically generated models in order to discard the less realistic ones.



Picture 4. Automated generation process from a "base" 3D skeleton and a "basic" cross-section of a beefsteak tomato.

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