Benjamin J. Li*
Wee Kim Wee School of
Communication and Information
Nanyang Technological University
31 Nanyang Link, Singapore 637718

Jeremy N. Bailenson
Department of Communication
Stanford University
450 Serra Mall, Building 110,
Stanford CA 94305, USA

Exploring the Influence of Haptic and Olfactory Cues of a Virtual Donut on Satiation and Eating Behavior

Abstract

Olfactory research in immersive virtual environments (IVEs) have often examined the addition of scent as part of the environment or atmosphere that act as experimental stimuli. There appears to be a lack of research on the influence of virtual foods in IVEs on human satiation. Studies based on situational cues or self-perception theory provide support for the hypothesis that touching and smelling a virtual food item may lead to increased consumption as a result of modeling expected behavior. On the other hand, studies grounded in embodied cognition suggest that satiation may take place as a result of mental simulation that resembles actual consumption behavior. In this preliminary study, we sought to explore the effects of haptic and olfactory cues through virtual food on human satiation and eating behavior. In our study, 101 participants took part in a 2 (touch: present vs absent) × 2 (scent: present vs absent) experiment where they interacted with a donut in an IVE. Findings showed that participants in the touch and scent present conditions ate significantly fewer donuts than those who were not exposed to these cues, and reported higher satiation as compared to their counterparts. However, findings were less clear with respect to participants who received both haptic and olfactory cues. As a whole, results provide preliminary support for satiation effects as a result of sensory simulation.

1 Introduction

Research on the associations between human behavior and immersive virtual environments (IVEs) has risen substantially in the past decade. While early studies explored the factors that influence our use of IVEs, recent work has focused on the influence of IVEs on human psychology and behavior after exposure (Ahn, Bailenson, & Park, 2014; Slater et al., 2013). Studies have shown that IVEs have the potential to affect prosocial behavior (Shriram, Oh, & Bailenson, 2017), environment consciousness (Ahn, Fox, Dale, & Avant, 2015), aid in phobia therapy (Emmelkamp, Bruynzeel, Drost, & van der Mast, 2001; Maltby, Kirsch, Mayers, & Allen, 2002), and empathy toward others (Li et al., 2017), among other behaviors.

Most of these studies examined the influence of visual and auditory cues present in IVEs that can result in behavioral changes. One area that has received

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*Correspondence to benjyli@ntu.edu.sg.

comparatively less attention is the simulation of touch and scent of virtual foods, and their subsequent effects on satiation. Hoffman, Hollander, Schroder, Rousseau, and Furness (1998) found that individuals who physically bit into a virtual chocolate bar found the experience more fun and realistic than those who simply imagined biting into it. In a recent study, Pallavicini et al. (2016) exposed obese individuals to food stimuli presented in one of three conditions: as real food, in pictures, or in augmented reality. Participants were free to examine the food stimuli without interacting with them. Results showed that participants perceived the augmented reality food stimuli to be as palatable as real food, and triggered similar arousal responses as determined through physiological measures.

Schroeder, Lohmann, Butz, and Plewnia (2016) measured participants' response times in grabbing food items in virtual reality. An infrared sensor tracked participants' dominant hand as they were tasked to either grasp or ward food (pizza, hamburger, pie, donut) or ball objects (baseball, volleyball, basketball, tennis ball). Results showed a behavioral bias in hand movements, where virtual food was collected faster than ball objects. Interestingly, the difference in speed correlated significantly with participants' body mass index and eating-related thoughts and attitudes. While these studies are novel in their own ways, the link between virtual foods and actual consumption has not been sufficiently explored.

When one tastes food, the perception of flavor and palatability is not simply a result of receptors on the tongue sending signals to the brain. The tasting process is essentially a multisensory experience (Spence & Piqueras-Fiszman, 2014). Consider a piece of steak. The smell of the freshly grilled meat, together with the sizzling sounds it produces as it is laid on a dinner plate, engages the senses. As you slice through the crispy brown crust, the rich juice slowly seeps out, revealing the perfectly grilled tender insides. Each of the five senses is engaged to prepare the body for the gustatory experience. Of these five senses, olfactory cues have been estimated to contribute to as much as 80 to 90% of flavor perception (Roach, 2013; Stuckey, 2012). In one study, participants held an odorless and tasteless sugar solution in their mouths and were given a bottle of benzaldehyde (a chemical compound with a distinct almond odor) to smell. Compared to those who did not have any solution present in the mouths, participants holding the sugar solution in their mouths perceived the almond smell to be more intense (Dalton, Doolittle, Nagata, & Breslin, 2000). A study by Djordjevic, Zatorre, and Jones-Gotman (2004) showed similar results. Participants who smelled strawberry odor rated a sugar solution as sweeter, while those who smelled soy sauce rated a salt solution as saltier. These studies show the influence that olfactory cues have on our perception of taste.

Our sense of touch tends to influence our judgment of the texture, quality, and freshness of food (Spence & Piqueras-Fiszman, 2014). We ascertain whether a piece of chicken breast is overcooked or grilled just right by poking at it with a fork and feeling its firmness. We often check whether a fruit is ripe by holding it in our hand and pressing it. Interestingly, the tactile cues we feel when holding a food item can influence its perceived texture in our mouths. Blindfolded participants were asked to rate the taste of a pretzel while holding onto the other end of it. Unbeknownst to them, the pretzels were either half-fresh/half-stale (incongruent condition) or fully fresh/stale (congruent condition). Participants who held a fresh end of a pretzel but bit into the stale end of it (the incongruent condition) rated the pretzel as significantly fresher and crispier to taste, suggesting that the tactile cues provided by holding onto the fresh end of the pretzel resulted in a change in the perceived texture of the pretzel in the mouth (Barnett-Cowan, 2010).

The sense of touch can be a compelling factor in a virtual experience. Hoffman et al. (1998) examined the influence of tactile feedback in virtual environments on how realistic participants perceived the experience to be. Participants who grabbed a real-world plate in their hands but saw a virtual representation of it through a head-mounted display (HMD) perceived the plate to be heavier and more likely to obey gravity than those who saw the plate only in virtual reality. Virtual reality exposure therapy that employed tactile cues in the form of a furry toy spider were found to assist individuals in overcoming arachnophobia (Carlin, Hoffman, & Weghorst, 1997; Garcia-Palacios, Hoffman, Carlin, Furness, &

Botella, 2002). Participants who cut down a tree using a force-feedback haptic joystick consumed less paper than those who read print descriptions of tree cutting (Ahn et al., 2014). To our knowledge, there has been little empirical effort in examining the sense of touch with regard to food in virtual environments.

There are two main reasons for the current study: First, olfactory research in IVEs have often examined the addition of scent as part of the environment or atmosphere that act as experimental stimuli. For example, Serrano, Baños, and Botella (2016) included lavender scent as part of an IVE treatment to induce relaxation among participants. Bordnick et al. (2008) incorporated scents of alcoholic drinks like whiskey, gin, and brandy as additional stimuli in bar and kitchen IVEs to test alcoholics' reactions to these environments. Gerardi, Rothbaum, Ressler, Heekin, and Rizzo (2008) delivered scents of burning rubber, diesel fuel, and weapons fire as part of a war-torn city IVE as potential therapy for post-traumatic stress disorder. In our understanding, scent as a construct on its own has not been examined empirically in IVEs. Second, there is a lack of research on the influence of virtual foods in IVEs on human satiation. While researchers have begun to explore the intersection of virtual and augmented reality with foods (see Spence, Okajima, Cheok, Petit, & Michel, 2016), work in this area has focused on changing the visual texture and lighting of foods in virtual reality (Okajima, Ueda, & Spence, 2013) and manipulating the perceived taste of foods by modifying how it looks, smells, and is presented in virtual and augmented reality (Narumi, Ban, Kajinami, Tanikawa, & Hirose, 2012; Narumi, Nishizaka, Kajinami, Tanikawa, & Hirose, 2011; Sakurai, Narumi, Ban, Tanikawa, & Hirose, 2013).

In spite of the unique studies done in this field, one question remains unanswered: Do virtual foods make people want to eat more, or do they cause individuals to feel more satiated? The answer could be useful for researchers using virtual reality in assessing and treating weight disorders. IVEs have been used as part of therapy for patients suffering from issues such as obesity and binge eating disorders (Perpiñá, Botella, & Baños, 2003; Riva et al., 2000). Understanding the influence of virtual foods on satiation and eating behavior might provide support for the increased interest and use of IVEs in this area, or allow researchers to tweak their therapeutic tools accordingly. As such, in this study, we sought to explore the effects of haptic and olfactory cues through virtual food on human satiation and attitudes.

1.1 The Relevance of Immersive Virtual Environments

There is evidence that individuals have the tendency to model behavior when they are primed to do so in IVEs (Blascovich & Bailenson, 2011). Peña, Hancock, and Merola (2009) found that participants who used avatars dressed in black displayed higher aggressive intentions and attitudes and reported less group cohesion than participants who used avatars dressed in white. The authors attributed this to the participants being primed to think or act because of the situational cues (in their case, the symbolic associations of colors) they were exposed to. The cues related to the memories that the individual possesses results in him or her acting in behaviors consistent with the associations, all this without him being aware of it (Bargh, Chen, & Burrows, 1996).

Yee and Bailenson (2009) proposed that IVEs influence behavioral changes through self-perception theory, where people infer their expected thoughts and behaviors by observing themselves from a third-person point of view (Bem, 1972). This happens in IVEs through embodiment, where individuals take on the bodies of their virtual graphical representations. Findings from their study showed that participants who were embodied in an IVE displayed greater behavioral change compared to those who did not take on digital embodiment. Other studies provided evidence for the influence of digital embodiment. Participants who saw embodied versions of themselves exercising in an IVE demonstrated more voluntary exercise behavior compared to those who were not exposed to digital self-embodiment (Fox & Bailenson, 2009). Individuals assigned to embodied avatars whose faces were identical to their real selves reported greater anxiety in speeches made to a virtual audience, as compared to those in a dissimilar avatar condition (Aymerich-Franch, Kizilcec, & Bailenson, 2014). Regardless of situational cues or self-perception being the driving force, findings from these studies provide support for the priming effects of embodiment in IVEs. It is plausible that when an individual is exposed to a food item in an IVE, situational cues such as feeling the touch and texture of the food item, or the familiar smell of it, may trigger the desire to consume the food item. Seeing their embodied hand hold the food item may also lead to greater self-perception and increased desire for consumption.

On the other hand, studies have shown that imagined consumption may lead to satiation. Individuals who repeatedly imagined consuming M&Ms demonstrated a significant decrease in subsequent consumption of M&Ms (Morewedge, Huh, & Vosgerau, 2010). Even just showing pictures of food has a similar effect, with repeated evaluations of foods decreasing subsequent enjoyment of the corresponding food items (Larson, Redden, & Elder, 2014). These studies suggest that satiation can result from processes outside of conscious awareness. One explanation for this is via the embodied cognition framework (Barsalou, 2008). According to this approach, our cognitive activity is caused by the bodily states, situated actions, and mental simulations that we generate. Processing of sensory perceptions has been shown to activate neural constructs in corresponding regions of the brain (Herholz, Halpern, & Zatorre, 2012; Zatorre & Halpern, 2005). González et al. (2006) demonstrated that the primary olfactory cortex is activated when individuals are asked to read words linked to strong smells such as "garlic" and "cinnamon." Seeing pictures of food has been linked to activations in the taste and gustatory cortices (Rolls, 2005; Simmons, Martin, & Barsalou, 2005). Barsalou (1999) suggests that in the absence of actual experience, the mental simulations that influence these activations are possible because perceptual symbols of these experiences that have been stored in memory are accessed. Following this line of thought, past experiences of consuming a food item, such as a donut, can create perceptual symbols of various sensory modalities, such as its touch, taste, and scent, and store them in memory. When one imagines or sees a picture of a donut, one accesses the symbols that are linked to the touch, taste, and scent of the donut, and uses them to simulate the experience of eating the donut. Larson et al. (2014) proposed that the mental simulation an individual undergoes can lead to satiation similar to actual consumption of the food item and found support for this in their study. As such, the sensory simulations one experiences in an IVE with a food item may activate memories of sensory characteristics of the food item and lead to satiation.

1.2 Experimental Overview

Studies based on situational cues or self-perception theory provide support for the notion that touching and smelling a virtual food item may lead to increased consumption as a result of modeling expected behavior. In contrast, studies grounded in embodied cognition show that it is likely that satiation may take place as a result of mental simulation that resembles actual consumption behavior. As such, we propose the following research question: How will the experience of a touch and scent of a virtual food item in an IVE influence an individual's subsequent consumption of the food item? To answer this, we designed an experiment to explore the effects of feeling the touch and smelling the scent of a virtual donut on subsequent consumption behavior. In our study, participants saw an embodied hand in an IVE holding a virtual donut.

In choosing the food item, we needed one that people are familiar with and also which can be placed in the embodied hand in a realistic manner. While other food items such as fruits have distinct scents and haptic cues, we also wanted a food item that people tend to have an appetite for. The human body's taste preferences are naturally shaped by a need to seek out foods that are high in energy. As such, food items that are high are in sugar and fat have greater sensory appeal to us (Krebs, 2009), and subsequently lead to an activation of appetite (de Castro, Bellisle, Dalix, & Pearcey, 2000). With 391 million units sold, which accounts for $580 million in sales annually, the donut is a popular food item that is high in energy and appeals to many Americans (IRI, 2016). Hence, the donut was selected as the food item that participants were exposed to. The manipulations came in two forms: participants either felt the touch of a donut (using a fake rubber donut) or did not, and either smelled the scent of the donut or did not. Participants were then asked to help in a taste test of donuts, where their subsequent consumption was measured and analyzed. We were also interested in their experience of presence and perceived hunger and fullness, and therefore asked them to fill out a questionnaire at the end of the study that measured these variables.

2 Method

2.1 Participants

Participants consisted of undergraduates from a medium-sized West Coast university who received course credit for their participation. Since actual donut consumption was a dependent variable, participants who reported as diabetic or gluten intolerant were not permitted to participate in the experiment. Participants were also asked to refrain from eating at least two hours before the study, to ensure that prior fullness was not a confounding variable. A total of 110 participants took part in the study. However, nine were dropped from the initial sample as they reported eating within two hours of the study. The final sample ($N = 101$) consisted of 44 men and 57 women between the ages of 18 and 31 ($M = 20.54$, $SD = 2.17$). Initial analyses revealed no significant differences in age or gender across the experimental conditions.

2.2 Materials

Participants viewed the virtual environment through an HMD that provided a fully immersive experience. The HMD used was an HTC Vive (HTC, New Taipei City, Taiwan) with a resolution of 2160×1200 pixels, latency of 22 ms and a refresh rate of 90 Hz which produces less latency than its predecessors. The Vive lighthouse system is comprised of two beacons placed on opposite ends of the room that emit infrared light through LEDs. These beacons, or base stations, track physical head orientation in the HMD and presented the virtual world accordingly. To display participants' hand movements in the virtual environment, a Vive controller was strapped to the participant's right hand and similarly tracked by the lighthouse system. The virtual environment was programmed and generated using Vizard 5 software (Worldviz, San Francisco, CA) running on a 3.4-GHz Intel i5 computer with an Nvidia Geforce GTX 980 graphics card. Participants had a first-person view of the virtual world, which consisted of the virtual representation of the room they were in. They could not see their entire virtual bodies, but only their right hand.

Participants were told that they would be handed a food item in the virtual environment, and that their task was to count the number of sprinkles on the food item. In all conditions, the food item consisted of a virtual chocolate donut with colored sprinkles. To manipulate the sense of touch, participants in the touch present condition had a fake rubber donut placed in their right hand when they saw the virtual donut. The fake donut was approximately the same size as the virtual donut that participants saw through the HMD. With regard to scent, while adding the scent to the fake donut would have improved the immersive experience, only participants in the touch condition would have held the donut. To prevent the source of the donut scent from being a confounding variable, the following procedure was conducted to simulate the smell of a donut. First, a cotton bud was dipped in approximately 5 ml of chocolate donut scented aromatic oil (The Flaming Candle, Dallas, GA) and secured to a piece of Velcro. Another piece of Velcro was affixed onto the front of the HMD. At exactly the same time that participants in the smell condition saw the virtual donut, the scented cotton bud was attached to the front of the HMD via the Velcro strips. Since the participants were looking through the HMD, they could not see the cotton bud, but could smell the scent of the chocolate donut. The setup for a participant in the condition where both touch and scent are present is shown in Figure 1.

2.3 Procedure

The study used a 2 (touch: present/absent) $\times$ 2 (smell: present/absent) between-subjects factorial design. Participants were randomly assigned to one of the four conditions. The study comprised two segments and participants were briefed on them when

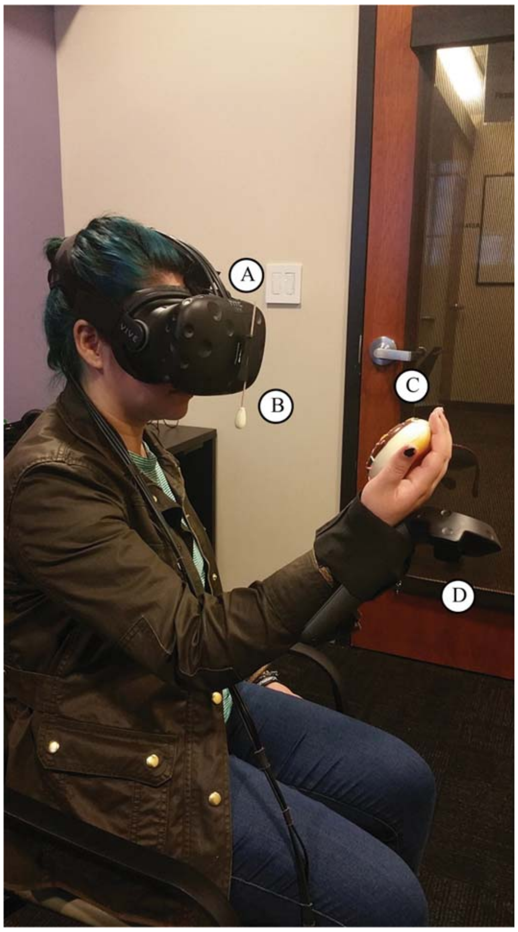

Figure 1. *A participant in the touch and scent present condition. The figure depicts: (A) an HTC Vive HMD, (B) a cotton bud dipped in chocolate donut scented aromatic oil to simulate the scent of a donut and attached to the HMD using Velcro strips, (C) a fake rubber donut to simulate the sense of touch, and (D) the HTC Vive hand controller.*

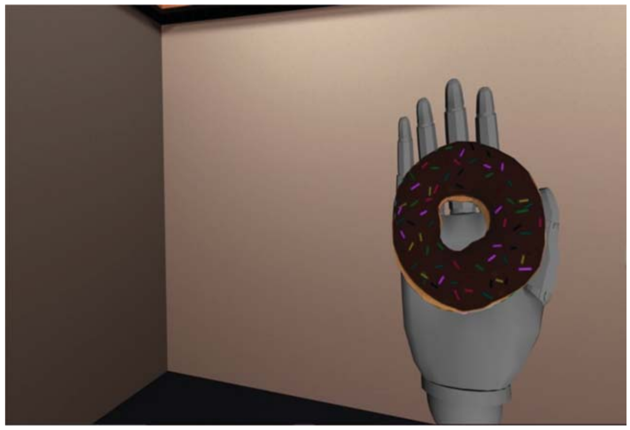

Figure 2. *A participant's viewpoint during the virtual reality task. Participants were asked to count the number of sprinkles on the virtual donut.*

they first arrived at the lab. In the first segment, participants sat on a chair in the middle of the room. When the virtual experience began, participants were asked to look around the virtual room and to move their right hand around to get used to the experience and to familiarize themselves with the IVE. After 45 seconds, the image they saw through the HMD faded to black. During this time, the fake rubber donut was placed in the right hand of participants who were in the touch present condition, while participants in the smell present condition had the cotton bud attached to the front of their HMDs. The screen then faded from black to the virtual room and participants saw a chocolate donut with colored sprinkles in their right hand (see Figure 2). Participants were given 75 seconds to count the number of sprinkles on the donut. This task had no bearing on the study, and was used as a filler to explore the effects of exposing participants to the additional cues of touch and smell. The entire virtual experience lasted for two minutes. Participants then proceeded to fill out the questionnaire for the virtual experience segment, where they guessed the number of sprinkles on the virtual donut and answered questions on the dependent variables (see Appendix A).

Once they were done, they were told to engage in a taste test, which was framed as the second segment of the study. Participants were asked to rate two donuts which were similar in size and shape and instructed as follows:

> *Please taste and rate each of the food items on the table in front of you, on the dimensions of taste, texture, and freshness. This is a fresh serving and everyone receives a new plate. You will make your ratings on the next page of the questionnaire. As it is important to make an accurate rating of each type of food item, you can taste as much or as little of the food items as you think is needed. Once you are done, you are welcome to help yourself to any of the remaining food items.*

Participants were also specifically told to remain in the room until the experimenter returned. This was to ensure all participants did not rush through the study but had reasonable time to consume more donuts if they wished to do so. This technique was successfully implemented in previous studies on food consumption (Houben, 2011; Rogers & Hill, 1989). After five minutes, the experimenter returned and debriefed the participants.

2.4 Measures

2.4.1 Weight of Donuts Eaten. We adapted the method from past studies on food cues and priming on consumption behavior (Federoff, Polivy, & Herman, 1997; Harris, Bargh, & Brownell, 2009) by weighing both donuts before the start of and at the end of the study after each participant was done. The difference in the weight of the donuts before and after the study was calculated in grams, resulting in the total weight of donut eaten.

2.4.2 Hunger and Fullness. Two visual analogue scale (VAS) questions, based on a 100-point scale, measured participants' perceived level of hunger and fullness after the study. The questions asked were "How hungry do you feel right now?" and "How full do you feel right now?" respectively.

2.4.3 Spatial Presence. Seven questions, measured on a five-point Likert scale, were adapted from Lessiter, Freeman, Keogh, and Davidoff (2000) to measure spatial presence. Examples include "I had a sense of being in the scene displayed" and "I felt I could reach out and touch things." Cronbach's alpha for the seven items was strong at .79.

2.4.4 Food Presence. Since a current measure of food presence does not exist, items were modified from Lessiter et al.'s (2000) measure of physical presence. Four items, presented on a five-point Likert scale, measured participants' perception of food presence. Items include "The food seemed believable" and "I felt that the food was part of the real world." Cronbach's alpha was strong at .75.

2.4.5 Subjective Ratings. Regarding the virtual experience, participants were asked two questions: how much they wanted to taste the donut and how pleasant they thought it would have tasted. These questions, based on past research on food and emotions (Macht & Dettmer, 2006; Stirling & Yeomans, 2004), were measured on a seven-point scale.

A list of the exact wordings for all measures, together with their means and standard deviations, can be found in Appendix A, while a Pearson correlation matrix of the weight of donuts eaten and participant ratings is presented as Appendix B.

3 Results

A two-way multivariate analysis of variance was conducted using *IBM SPSS Statistics 23* (Armonk, NY) to evaluate the effects of touch and scent on the above-mentioned variables.

3.1 Manipulation Checks

Participants were asked to respond to two statements at the end of the study to ascertain that the manipulations for touch and scent were successful. The two statements were "I could feel the touch of the food item in the virtual experience" and "I could smell the food item in the virtual experience," respectively. Responses ranged from *Strongly Disagree* to *Strongly* Agree on a five-point Likert scale. Analyses showed that participants in the touch present condition agreed more strongly with the statement that they could feel the touch of the food item as compared to those in the touch absent condition ($M_{touch} = 3.73$, $SD = 1.05$ vs $M_{no\ touch} = 1.88$, $SD = 1.01$, 95% CI [1.45, 2.26], $t(99) = 9.01$, $p < .001$, $d = .67$). Participants in the scent present condition agreed more strongly with the statement that they could smell the food item as compared to those in the scent absent condition ($M_{scent} = 4.31$, $SD = 1.05$ vs $M_{no\ scent} = 1.83$, $SD = .96$, 95% CI [2.08, 2.88], $t(99) = 12.40$,

$p < .001$, $d = .77$). These checks showed that the manipulations were successful.

3.2 Weight of Donuts Eaten

The number of donuts eaten in each condition appear to be normally distributed (with the exception of notable outliers, as explained below) as assessed by a visual inspection of the Normal Q-Q plots (see Appendix C). There was also homogeneity of variances, as assessed by Levene's test for equality of variances ($p = .078$). However, analyses revealed there were a few outliers. Based on the moderately conservative judgement suggested by the median absolute deviation technique, outliers were defined as being 2.5 standard deviations away from the overall median (Leys, Ley, Klein, Bernard, & Licata, 2013). Five subjects ate the entire plate of donuts presented in the taste test, which resulted in the weight of donuts eaten by these five subjects being more than 2.5 standard deviations above the sample median. Since ANOVA tests are extremely sensitive to the presence of outliers, Cook's distances were calculated to measure the influence of these outliers on the analyses (Cook, 1977). Values greater than $4/n$ (.040 in our study) are considered high influence (Bollen & Jackman, 1990). Cook's distances of these five subjects are substantially higher than those of the remaining subjects, and are also considerably higher than the .040 cut-off value. Given the influence of these outliers, two analyses for donuts eaten were conducted. In the first analysis, the data were winsorized where the values of the five outliers were replaced with the median value plus 2.5 standard deviations. The second analysis was conducted without the presence of these five outliers. Table 1 shows the number of participants in each condition, when outliers are either included or excluded.

No significant differences were found when the outliers were winsorized for both independent variables of touch ($M_{touch} = 52.2$ g, $SD = 35.2$ vs $M_{no\ touch} = 59.5$ g, $SD = 34.5$, $F(1,97) = 1.02$, $p = .31$, partial $\eta^2 = .01$) and scent ($M_{scent} = 52.0$ g, $SD = 36.5$ vs $M_{no\ scent} = 59.3$ g, $SD = 33.3$, $F(1,97) = 1.03$, $p = .31$, partial $\eta^2 = .011$). When the outliers were excluded, participants in the touch present condition ate significantly less than those in the touch absent condition ($M_{touch} = 43.5$ g, $SD = 23.8$ vs $M_{no\ touch} = 59.5$ g, $SD = 34.5$, $F(1,92) = 7.42$, $p < .01$, partial $\eta^2 = .08$). Similar findings were observed for scent, where participants in the scent present condition ate significantly less than those in the scent absent condition ($M_{scent} = 44.7$ g, $SD = 28.1$ vs $M_{no\ scent} = 57.8$ g, $SD = 31.8$, $F(1,92) = 4.84$, $p = .03$, partial $\eta^2 = .05$). Results when outliers are excluded are presented in Figure 3.

Table 1. *Number of Participants in Each Condition*

	Smell Condition	No Smell Condition
Outliers excluded (N = 96)		
Touch Condition	26	26
No Touch Condition	23	26
Outliers excluded (N = 96)		
Touch Condition	22	25
No Touch Condition	23	26

3.3 Hunger and Fullness

There was no significant difference in participants' perceived level of hunger after the study for both touch ($M_{touch} = 47.4$, $SD = 29.3$ vs $M_{no\ touch} = 57.4$, $SD = 27.6$, $F(1,97) = 3.0$, $p = .09$, partial $\eta^2 = .03$) and scent ($M_{scent} = 48.7$, $SD = 28.6$ vs $M_{no\ scent} = 55.6$, $SD = 28.8$, $F(1,97) = 1.3$, $p = .25$, partial $\eta^2 = .01$).

With regard to the influence of touch and scent on perceived level of fullness, there was a statistically significant interaction ($F(1,97) = 4.48$, $p = .04$, partial $\eta^2 = .04$). Therefore, an analysis of simple effects was conducted. For participants in the touch absent condition, those who were in the scent present condition felt more full than those in the scent absent condition ($M_{scent} = 34.1$, $SD = 5.03$ vs $M_{no\ scent} = 19.2$, $SD = 4.73$, 95% CI [1.14, 28.57], $F(1,97) = 4.62$, $p = .03$, partial $\eta^2 = .05$).

Analyses also showed a marginally significant difference for participants in the scent absent condition, with those assigned to the touch present condition feeling more full than those in the touch absent condition ($M_{touch} = 32.7$,

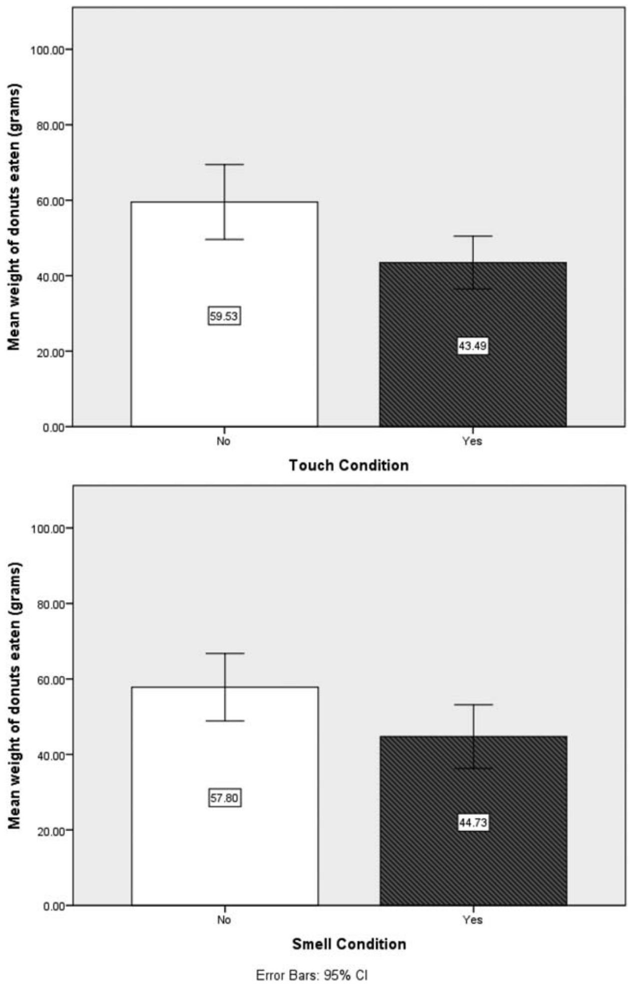

Figure 3. *Mean weight of donuts eaten by condition when outliers are excluded.*

$SD = 4.73$ vs $M_{no\ touch} = 19.2$, $SD = 4.74$, 95% CI [.135, 26.71], $F(1,97) = 4.02$, $p = .05$, partial $\eta^2 = .04$). The mean scores of perceived fullness by touch and smell conditions are presented in Figure 4.

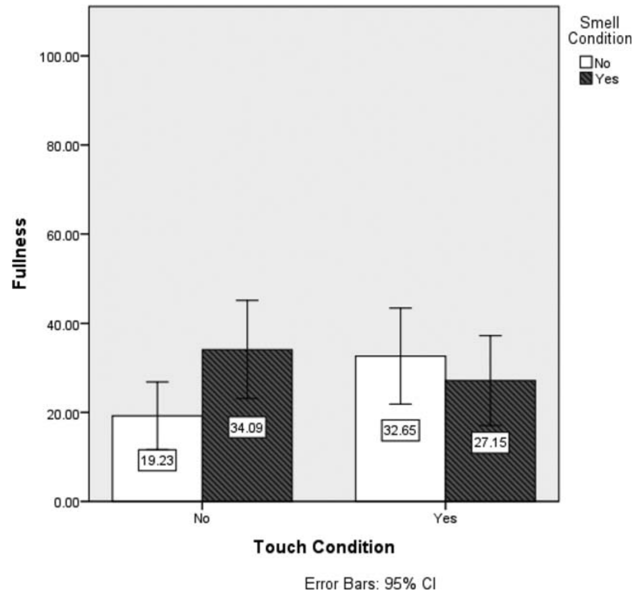

Figure 4. *Mean scores of perceived fullness by touch and smell conditions.*

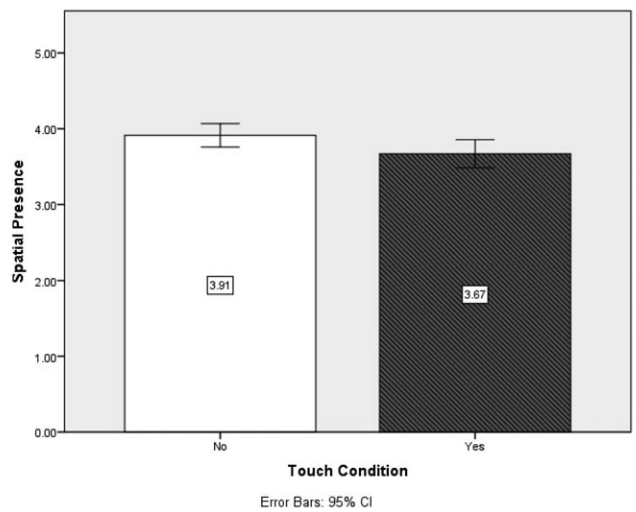

Figure 5. *Mean scores of perceived spatial presence by condition.*

3.4 Spatial Presence

There was a marginally significant effect of touch on participants' perceived spatial presence. As shown in Figure 5, participants in the touch present condition felt less spatial presence than those in the touch absent condition ($M_{touch} = 3.67$, $SD = .63$ vs $M_{no\ touch} = 3.91$, $SD = .54$, $F(1,97) = 4.12$, $p = .05$, partial $\eta^2 = .04$). In contrast, there were no significant differences between the scent present and scent absent conditions ($M_{scent} = 3.67$, $SD = .63$ vs $M_{no\ scent} = 3.80$, $SD = .54$, $F(1,97) = .01$, $p = .91$, partial $\eta^2 < .01$).

3.5 Food Presence

There was no significant difference in participants' perception of food presence between the touch present and touch absent conditions ($M_{touch} = 2.84$, $SD = .62$

vs $M_{no\ touch} = 2.71$, $SD = .78$, $F(1,97) = .84$, $p = .36$, partial $\eta^2 = .01$). Similarly, perceived food presence did not differ significantly between the scent present and scent absent conditions ($M_{scent} = 2.84$, $SD = .62$ vs $M_{no\ scent} = 2.73$, $SD = .76$, $F(1,97) = .53$, $p = .47$, partial $\eta^2 = .005$).

3.6 Subjective Ratings

Between the touch present and touch absent conditions, no significant differences were found in how much participants wanted to taste the donut ($M_{touch} = 38.5$, $SD = 28.4$ vs $M_{no\ touch} = 42.3$, $SD = 29.9$, $F(1,97) = .50$, $p = .48$, partial $\eta^2 = .005$). Similarly, no significant differences were observed between the scent present and scent absent conditions ($M_{scent} = 45.2$, $SD = 27.0$ vs $M_{no\ scent} = 35.8$, $SD = 30.5$, $F(1,97) = 2.66$, $p = .11$, partial $\eta^2 = .03$).

No significant differences were found between the touch present and touch absent conditions in how pleasant participants felt the donut would have tasted ($M_{touch} = 56.0$, $SD = 30.1$ vs $M_{no\ touch} = 54.5$, $SD = 30.7$, $F(1,97) = .03$, $p = .86$, partial $\eta^2 < .001$). Differences were also not found between the scent present and scent absent conditions ($M_{scent} = 60.5$, $SD = 27.0$ vs $M_{no\ scent} = 50.3$, $SD = 32.5$, $F(1,97) = 2.92$, $p = .09$, partial $\eta^2 = .03$).

4 Discussion

Our preliminary study sought to explore the influence of feeling the touch and smelling the scent of a virtual donut on subsequent consumption behavior. Findings showed that participants in the touch and scent present conditions ate significantly fewer donuts than those who were not exposed to these cues. However, we are cautious in interpreting these results, since the main finding of donuts eaten was found only when outliers were excluded. Whether the people who ate all the donuts did so because they were extremely hungry, or because donuts are their favorite food, is unclear. This uncertain reason behind their consumption behavior compels us to run two sets of analyses and we stress here the exploratory nature of this study. While past studies suggest the possibility of increased consumption due to situational cues or self-perception theory, findings from this preliminary study appear to provide support for embodied cognition, where exposure to haptic and olfactory cues of the food item facilitates sensory simulations of tasting it, which results in satiation for the food item.

We found further support for this claim in participants' reported satiation after exposure to the IVE, with those in the touch present condition feeling more satiated than those in the touch absent condition. It is worth noting that this effect exists only in the absence of smell. There was a similar interaction effect with regard to scent: participants in the scent condition felt more satiated than those in the scent absent condition, but only among those who did not touch the donut. Taken together, these results suggest that when both touch and scent are absent, people tend to feel less full when they are just exposed to a virtual food item. But when either touch or scent is introduced, the addition of one of these cues is sufficient to facilitate sensory simulation and stronger perceived satiation. Interestingly, when both haptic and olfactory cues are present, no significant effect on weight of donuts eaten was found. While this finding is not intuitive, one possible explanation could be the inclusion of both senses results in an effect not unlike the "uncanny valley" phenomena (Seyama & Nagayama, 2007). It might be possible that the combination of visuals, smell, and touch culminated in a highly realistic experience for participants, resulting in an "uncanny valley" scenario for virtual foods. This could have influenced participants' consumption of donuts. Anecdotally, some participants exposed to both haptic and olfactory cues gave feedback during our pretests that they felt the experience was so real that it felt strange, hinting that such a phenomenon might be possible. However, because the findings were not significant, we are not able to draw conclusions on the effects of the presence of both senses but we are merely postulating this as a possible reason for the counterintuitive results.

It is interesting to note that while there was a significant difference in the number of donuts eaten, this did not translate to hunger and subjective ratings on desire to taste the donuts and how pleasant participants perceived them to taste. This inconsistency between attitudes and behavior might have occurred as a result of their explicit attitude being measured instead of their implicit attitude (Fazio, 1990). The subjective ratings in our study appear to measure the explicit attitudes of participants toward consuming a relatively unhealthy food, which can influence the answers as participants consciously analyze the costs and benefits of consuming donuts (Craeynest et al., 2005). Studies have shown that implicit attitudes may influence individuals to engage in behaviors in a more affective manner without considering the costs and benefits associated with it (De Houwer, 2001; Roefs & Jansen, 2002). It will be interesting for follow-up studies to examine possible links between implicit attitudes, measured using tools such as the Implicit Association Test, and consumption behavior.

Our results concur with past studies that support the satiation effects of sensory simulation. Morewedge et al. (2010) showed that imagined consumption of food can lead to lowered consumption of the food item, while findings from Larson et al.'s (2014) study showed that evaluating pictures of food items can result in decreased enjoyment of the food that is consumed subsequently. One interesting thing of note is that Morewedge et al. (2010) demonstrated that the satiation effect was dependent on the task participants were asked to complete. In their study, participants who were asked to imagine moving the food item did not display increased satiation, while those who imagined consuming the food did. Participants in our study were not asked to bring the food item close to their mouths or to move their jaws in a chewing motion to simulate eating, but nevertheless displayed higher satiation. One possible explanation is that the perceptual symbols linked to the food item which are stored in memory are a powerful source for mental simulations. As such, the effect of sensory simulation through haptic and olfactory cues is strong enough to result in satiation, regardless of the task participants were asked to engage in. One thing to note is that the results in Morewedge et al.'s (2010) study and ours are short-term and part of experimental measures. It will be interesting to see if the effects are lasting and if so, what the long-term implications are for sensory simulation effects.

We found it intriguing that the participants who touched the donut perceived lower spatial presence as compared to those who did not. Previous studies found associations between haptic cues and perceived presence (Biocca, Kim, & Choi, 2001; Klimmt & Vorderer, 2003), and there is no theoretical reason to believe otherwise in our study. One likely explanation is that in our manipulation of touch, the donut was placed in participants' hands by a third party. Since participants did not reach out and touch the donut on their own accord, this might have interfered with their sense of presence in the IVE. Another possible reason could be that the fake donut elicited less realism than if participants had held a real donut. A fake donut was used instead of real ones since we wanted to standardize the feel, size, and shape of the donut. Having participants hold real donuts would have resulted in different dimensions and especially touch (since the donuts become harder as they turn less fresh with time), but this might have affected participants' sense of realism and subsequent perceived presence. In any case, the marginal significance of these findings ($p = .05$) suggests that the results should be interpreted with caution. Further experimentation needs to be conducted to establish its validity.

There is an increasing interest in the use of virtual reality to assess and treat eating and weight disorders (Wiederhold, Riva, & Gutiérrez-Maldonado, 2016). Findings from this study can be useful for researchers and health practitioners involved in this area. One particular treatment of binge eating, cue exposure with response prevention, exposes individuals to foods that trigger binge eating and trains them to refrain from consuming the foods (Jansen, Broekmate, & Heymans, 1992; Martinez-Mallén et al., 2007). Researchers have begun exploring the use of IVEs to overcome the logistical and environmental constraints of cue exposure (see Pallavicini et al., 2016). Our results show promise in using IVEs for this purpose: increased satiation as a result of introducing haptic and olfactory cues into virtual food interaction, which ties in well with the target effects of cue exposure. It appears that food-related IVEs can be a useful tool in this regard.

From a more hedonistic perspective, there have been innovative approaches in how food is delivered and presented to the dinner table (Spence & Piqueras-Fiszman, 2013). For example, The Fat Duck restaurant in

Berkshire, England hands out earphones together with a seafood dish and instructs diners to listen to sounds of the sea through the earphones while consuming their meal. The inclusion of auditory cues has led to some diners rating the dish as substantially more pleasant (de Lange, 2012). Researchers are also developing virtual and augmented reality applications that allow the size and colors of foods to be changed as viewed through an HMD (Narumi et al., 2012; Sakai, 2011). With our results showing that the inclusion of haptic and olfactory cues lead to increased satiation, innovative restaurants and researchers should consider these findings in the application of technology in dining and their effects on satisfying the human appetite.

Our study explored the influence of two relevant cues, with participants finding themselves in an IVE replicated to look like the lab they are in. Other cues are worthy of further investigation. One such cue that is relevant and arguably important when it comes to food is that of the environment. Having a virtual donut in your hand while you are sitting on a chair in a research laboratory is a different experience compared to sitting on a comfortable sofa in a café with the smell of coffee and the sounds of an espresso machine running in the background. As our study is an exploratory one, future studies can design various locales in IVEs and explore how the environment, presented through atmospheric cues, can influence a person's satiation as he or she interacts with virtual foods.

To standardize the procedure and to reduce the possibility of donut placement as a confounding factor, all participants saw the virtual donut in their right hand. For those in the touch condition, the donut was likewise placed in their right hand. Casasanto (2009) found that left- and right-handers associate concepts of "good" with their dominant hand, and concepts of "bad" with their nondominant side. A later study showed that bodily actions related to emotional valence can lead to retrieval of emotional memories (Casasanto & Dijkstra, 2010). We wonder if these emotional concepts (good, bad, happy, sad, etc.) can translate into satiation if people were asked to hold food in their dominant hand? If a left-hander holds a donut in the left hand, will the association of the concept of "good" trigger mental simulations of good memories where he or she consumed a donut? How will this then affect subsequent consumption behavior? Future studies that explore these relationships in greater detail will give us greater insight into embodied cognition and their relevance in IVEs. One suggestion will be to include the Handedness Questionnaire by Cohen (2008) to calculate laterality index of individuals.

While the donut was chosen for its familiarity and popularity among Americans, we did not measure participants' preexisting attitudes toward it. Factors such as individual likings and preferences, their body mass index (BMI), diet, or eating behaviors may influence their consumption behavior. While we maintained some form of dietary control, such as recruiting participants who are non-diabetic and gluten-tolerant, and asking participants not to eat at least two hours before the study, future studies can control for preferences or predisposed cravings for certain kinds of foods, BMI, and other relevant demographic variables.

Although all participants had to refrain from eating at least two hours before the study, it is unclear at which point in time participants last ate. This might have some influence on participants' consumption behavior during the study, and might possibly explain why the five outlier participants consumed the entire serving of donuts. On this note, the type of food may be worthy of further examination. Will the satiation observed here with a virtual donut also be found in a healthier alternative, for example, an apple or a bowl of salad? Children exposed to pictures of vegetables were found to have an increased liking for vegetables (Houston-Price, Butler, & Shiba, 2009). It might be that when it comes to healthier foods, satiation decreases and there is an increase in subsequent consumption, which in turn lends support to the self-perception theory. Results from more studies on a variety of foods will lead to a better understanding on the influence of virtual foods and their related cues.

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Appendix A. Measurement items

Construct	Measurement Items	Mean (*SD*)	Cronbach's Alpha
Donuts Eaten	Difference in weight of donuts before and after study	56.5 (36.8)	N.A.
Hunger	Visual Analog Scale (1-Not At all, 100-Extremely)	52.3 (28.8)	N.A.
	How hungry do you feel right now?		
Fullness	Visual Analog Scale (1-Not At all, 100-Extremely)	28.1 (24.5)	N.A.
	How full do you feel right now?		
Spatial Presence	How much do you agree with the following statements about your virtual reality experience? (1-Strongly Disagree, 5-Strongly Agree)	3.79 (.60)	.79
	I had a sense of being in the scene displayed.		
	I could move my hand in the environment.		
	I felt I could reach out and touch things.		
	I could move the food item in the environment.		
	I felt as though I was in the same space as the objects in the room.		
	It felt realistic to move things in the displayed environment.		
	I felt as though I was participating in the displayed environment.		
Food Presence	How much do you agree with the following statements about your virtual reality experience? (1-Strongly Disagree, 5-Strongly Agree)	2.78 (.70)	.75
	The food seemed natural.		
	The food seemed believable to me.		
	I felt the food was part of the real world.		
	I had a strong sense that the food was solid.		
Desire to Taste	Visual Analog Scale (1-Not At all, 100-Extremely)	40.4 (29.1)	N.A.
	How much did you want to taste the food item?		
Food Pleasantness	Visual Analog Scale (1-Not At all, 100-Extremely)	55.2 (30.3)	N.A.
	How pleasant do you think the food item would have tasted?		

Appendix B. Pearson Correlation matrix of weight of donuts eaten and participant ratings (*N* = 101)

	Weight of Donuts Eaten	Hunger	Fullness	Desire to Taste	Food Pleasantness
Weight of Donuts Eaten	–	.22*	−.07	.23*	.05
Hunger	.22*	–	−.59**	.36**	.15
Fullness	−.07	−.59**	–	−.10	.15
Desire to Taste	.23*	.36**	−.10	–	.63**
Food Pleasantness	.05	.15	.15	.63**	–

Note. $^{*}p < 0.05$. $^{**}p < 0.01$.

Appendix C. Normal Q-Q plots of amount of donuts eaten in each condition