Olfaction in VR: The Effects of Olfactory Congruence on Users' Sense of Presence

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ABSTRACT

Every submission should begin with an abstract of about 150 words, followed by a set of keywords. The abstract should be a concise statement of the problem, approach, and conclusions of the work described. It should clearly state the paper's contribution to the field of HCI.

Author Keywords

Authors' choice; of terms; separated; by semicolons; commas, within terms only; this section is required.

1. INTRODUCTION

1.1 Virtual Reality (VR) Technology

In the last few years one of the biggest trends in technology has been the increased desire for virtual reality by consumers. This can be seen in the various products being released by technology companies. Virtual reality is best defined in the paper, *Virtual Reality: A Definition History - A Personal Essay*, as "Virtual Reality is the use of computer technology to create the effect of an interactive three-dimensional world in which the objects have a sense of spatial presence". This most closely adheres to the dictionary definitions of "virtual" and "reality".

The first instance of virtual reality that could be credited to something that is a resemblance of what we have today would be Ivan Sutherland's Head Mounted Display (HMD) in 1968. This was done in combination with Bob Sproull at the university of Utah (HI, 2004). At the time these devices were so large and cumbersome that in order to place one on your head it had to be suspended from a ceiling via a series of pulleys and cables. Since then there have been massive improvements to this technology, the price has dropped dramatically over the years and the technology has become vastly more efficient and powerful. Moving from university labs to arcades and now finally to the homes of consumers, with the last step only happening just recently for middle class individuals. In the past VR systems, between a VR compatible computer and the actual goggles, could easily cost $1,000 if not more; now with the ability to connect VR goggles to gaming platforms the cost has dropped very quickly with someone being able to get something like the Oculus Go for $199 or the Sony VR headset for $299 (Neiger, 2016). While these might not necessarily be cheap it does allow people to access VR in greater numbers and gives more people the opportunity to experience presence in VR.

Presence in VR is a user's subjective experience and understanding that the world around them, while virtual, is within their ability to manipulate and explore. This concept was originally devised by Marvin Minsky when he coined the term "telepresence" to explain the sensation of embodying a remote device as if it was a part of that individual's being (Minsky, 1980). While inherently subjective, presence refers to "*the illusion of "being there" in the environment depicted by the VR displays – in spite of the fact that you know for sure that you are not actually there*", the sense of presence is critical for users to be interested in the interactions they have with these virtual environment (Slater & Sanchez-Vives, 2016). Interestingly, since we interact with the world through a multitude of senses, and there are many theories about the causes of presence that involve multisensory stimulation (Schuemie, Van Der Straaten, Krijn, & Van Der Mast, 2001).

1.2 Senses and Presence

The interaction between types of sensory information and people's perception of 'compellingness' has been explored in many different forms of visual entertainment (Warren & Welch, 1981). Various studies have explored the effects of different senses on presence in VE. For instance, studies like Barfield and Hendrix (1995) have found that increasing levels of visual realism also increases one's sense of presence. As a designer increases visual detail however, there is a decrease in system responsiveness. The system responsiveness being affected in turn negatively affects one's sense of presence, and possibly cause cybersickness

(LaViola, 2000). Simply increasing the level of visual detail does not always increase users' sense of presence (Dinh, Walker, Song, Kobayashi & Hodges, 1999).

In addition to the visual sense, auditory sense has also been tested in relation to sense of presence (Hendrix & Barfield, 1996). Serafin (2004) showed how the audio could increase the sense of place, despite the visual cues being unclear. This suggests that the audio cues can be used to increase the sense of presence even when the level of visual detail is low. The addition of audio to a VR environment does not heavily increase computational costs, thereby preventing lag responses (Dinh et al., 1999).

Studies also show the interaction between the audio and visual stimuli effect on presence. The results from Dinh et al. (1999) show that in general, increasing the modalities of sensory input increases the sense of presence in the environment. They used combinations of visual, tactile, olfactory and auditory cues to increase the sense of presence. Interestingly, they found that within these combinations, the level of visual detail did not result in a higher sense of presence (Dinh et al., 1999). This reiterates the idea that simply visual cues do not guarantee a higher level of presence. On the contrary, a study by Hendrix and Barfield (1996) shows that in context of a navigation task, the changes in the visual detail affected the sense of presence more than the auditory clues (Hendrix & Barfield, 1996).

In addition to using visual and auditory stimuli, researchers have also investigated the impact of some other senses on presence. Ranasinghe et al. (2017) developed Ambiotherm, which uses a Samsung Gear HMD equipped with technology that simulates wind and heat conditions. Their results indicated that the inclusion of these stimuli greatly increased the users' sense of presence. Dinh et al. (1999) incorporated tactile feedback into their VRE and concluded that tactile feedback had an influence on the increase of presence. Harley et al. (2018) designed two Proof of Concept sensory experiences which incorporated olfactory, haptic and gustatory stimuli found in the real world to the Virtual Reality Environment (VRE) being experienced. They surmised that allowing the player to create a real-life environment that would be congruent with the virtual world they want to experience, would significantly increase their sense of presence. One of the senses researchers have investigated with regards to presence is olfaction, but the few studies that have currently addressed the subject provide inconclusive evidence, therefore further investigation is necessary.

1.3 Olfaction and Presence

Olfaction is a sense that is inherently difficult to understand because it is subjective in nature and it, out of all the senses, has the highest discriminatory capacity (Bushdid, 2014). However, a few of studies have been conducted that examined the effect of olfaction on a user's subjective experience of presence. These studies have provided mixed results regarding the effects of olfaction on presence.

Munyan et al. (2016) for instance, conducted a study through which they discovered that introducing an olfactory stimulus increases participants' sense of presence and withholding the scent after a participant has been exposed to it decreases their sense of presence. Another study investigated whether there are differences between exposure to pleasant odors and unpleasant odors (Baus & Bouchard, 2017). The results showed that the unpleasant odor had a significant impact on presence, while the pleasant odor did not. However, Baus and Bouchard (2017) surmise that this may have been due to the subtleness of the pleasant scent used in the experiment. Dinh et al. (1999) investigated the impact of multisensory input on presence and memory, and concluded that olfaction, along with tactile and auditory stimuli, led to the highest increase of presence and memory for objects in the VE. Taken together, the results of these studies show that olfaction may increase presence.

However, certain studies indicate contradicting results. In attempting to investigate whether an olfaction enhanced VE would be rated higher on user Quality of Experience (QoE), researchers discovered that olfaction does not have a significant impact on enjoyment, immersion, or comfort (Egan et al., 2017). In a different study that more specifically addressed presence, researchers manipulated a Virtual Reality Mood-Induction Procedure (VR-MIP) to test the effects of touch and smell on presence and relaxation (t). The authors hypothesized that the inclusion of sensory feedback would significantly increase presence; however, the results did not support this hypothesis. Furthermore, they discovered that haptic feedback had a more robust impact on presence than did olfaction.

1.4 Current study

Previous studies investigated how general olfactory stimulation would affect a user's sense of presence. However, the only study which looked at a more specific characteristic of the olfactory stimuli was Baus and Bouchard's (2017) study comparing pleasant odors with unpleasant odors. The type of smell is just one of the many features of the stimulus that can be scrutinized. Congruence of smell with visual information is also an important characteristic to be considered, due to VREs generally using vision as the primary means of conveying information. Therefore, the current study aims to compare the impact of congruent smells and incongruent smells on users' sense of presence. This would be carried out by comparing the levels of presence indicated by three groups of participants on a self-reported questionnaire, after being exposed to a VRE under one of the three conditions: no smell (control), congruent smell, or incongruent smell. It is hypothesized that, 1) Both smell conditions will increase presence compared to no smell, and 2) Congruent smell will increase presence more than incongruent smells.

2. METHOD

2.1 Participants

The participants were thirty-five college students of ages ranging from 18 to 27 (14 Male, 13 Female, 8 undisclosed). These participants voluntarily signed up for the experiment and either earned class credit or community service. The participants were randomly assigned to one of the three conditions.

2.2 Design

To measure the effects of olfactory congruence on presence, a between-subjects experiment was designed. To manipulate the olfaction variable, participants were assigned in to one of three conditions, namely: Congruent, incongruent and control. A questionnaire was used to quantify the level of presence experienced by each participant (Persky and Blascovich, 2008). The data collected from each participant were used to assess the mean presence felt by each group and compare the groups for statistically significant differences.

2.3 Materials

2.3.1 Virtual Reality Environment (VRE)

Participants were immersed into a VE called Nature Treks (Carline, 2017) using an Oculus Go HMD. In the Nature Treks app, participants were asked to select the option named 'Green Meadows' which featured a grassy field with flowers, trees and deer, bordered by a stream. For each condition, the environment used remained consistent.

2.3.2 Olfactory Stimuli

AirWick Essential Mist Diffusers (Reckitt Benckiser Group, plc) were used to manipulate the smell of lavender for the congruent condition, and the smell of cinnamon for the incongruent condition. The diffusers were placed in the room corresponding to the condition, and the mist was released twice after the participant had worn the headset. The control condition was held in a similar room in which the smell was not manipulated in any way.

2.3.3 Presence Questionnaire

Presence was measured using the presence questionnaire devised by Persky and Blascovich (2008). The questionnaire consisted of eight statements such as "I lost track of time while playing the game.", and the participants had to choose whether they agreed or disagreed with each statement from a seven-point scale.

2.4 Procedure

Participants were asked to sign-up for scheduled time slots and were tested individually. Before they could select a time, they were asked to complete a survey which assessed their eligibility for the study based on information such as being of legal age and sensitivity to smells. Basic information such as age and gender were also collected through the survey.

Upon their arrival, each participant was randomly assigned to a condition and were asked for their consent. To prevent the results from being biased, they were told that they would simply be assessing the usability of a VR app for five minutes. Then, the participant was led to the room associated with the condition they were assigned to, where they were taught the controls and explained the task. To make sure the participants meaningfully interacted with the VR environment, they were also given one simple instruction, which was to plant five flowers and five trees. They were then told to wear the VR headset, begin the task, and that they would be told when five minutes had elapsed.

If the participant was assigned to either the congruent or the incongruent condition, after they had put on the headset, the researcher released the corresponding smell through the mist diffuser twice and left the room. If the participant was assigned to the control condition, they simply had to interact with the VRE for five minutes in a similar room. After five minutes had elapsed, each participant was brought back to the initial room and asked to complete the presence questionnaire. Once this was done, the participants were debriefed and dismissed.

3. RESULTS

To test the hypotheses stated earlier, we conducted several descriptive and inferential statistics tests. Table 1 summarizes the results of descriptive and inferential statistics tests conducted on the dependent variable of the experiment.

	M (*SD*)	*F* *(2, 34)*	*MSE*	*p*
Sense of Presence		.23	1.57	.796
No Smell	4.77 (1.83)			
Incongruent	5.05 (.833)			
Congruent	5.09 (.734)			

MSE = mean square error. Alpha level was set at .05.

Table 1. Summary of Descriptive and Inferential Tests

Hypotheses 1 and 2 were concerned with the effects of olfactory feedback on sense of presence levels. To test these hypotheses, a one-way analysis of variance was conducted (Figure 1). Results revealed no significant differences in sense of presence levels among the three smell conditions, $F(2, 34) = .23$, $p = .796$. These results indicate that the presence or lack of olfactory feedback had no significant influence on sense of presence, contradictory to our hypotheses.

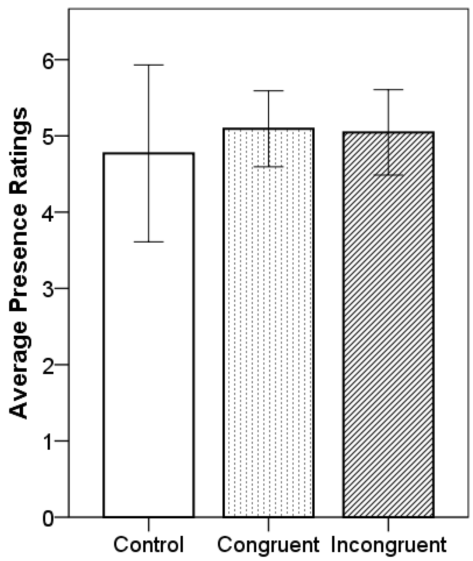

Figure 1. Sense of Presence Levels

4. DISCUSSION

An analysis of the experimental data indicated the follows; the participants average presence rating for the control condition was 4.77, the congruent condition was 5.09 and the incongruent condition was 5.05. This conclusion was determined by running a one-way analysis of variance on the data from the control and two subcategories of the experimental group, namely the congruent and incongruent smell factors. The results of this can be seen in the bar graph above (Figure 1). The bars of the graph do show a slight difference between the non-smell and two non-smell conditions with a difference of approximately 0.29 between them. Unfortunately, due to the lack of statistical significance between both the test conditions and the IV and DVs, the results of this study where unable to support the previously stated hypothesis. This provides evidence supporting the notion that olfactory stimuli, regardless of being congruent or incongruent, do not have a meaningful effect on presence in VR.

The results from this study adds to the growing debate on the impact of olfaction on presence. A few reasonable observations can be made by comparing the current results against previous literature. Munyan et al. (2016) states in their paper that olfactory stimuli did indeed increase presence, contradicting the current results. However, it should be noted that the VRE used in the experiment is stated to be mildly-anxiety inducing, thus eliciting emotions in the user. This is of interest because arousal caused by emotions may play a significant role in increasing a user's subjective experience of presence (Diemer et al., 2015; Riva et al., 2007). Additionally, the sense of smell has been suggested to be linked to emotion due to being processed in the amygdala (Zald & Pardo, 1997) which is mainly responsible for emotional regulation, and its link to emotional, autobiographical memories (Herz, 2004). This suggests that the results from Munyan et al. (2016) may have been influenced by emotions.

Baus and Bouchard's (2017) study which examined the different effects of pleasant and unpleasant odors on presence discovered that only unpleasant odors had a significant positive effect on presence. They attributed this to the subtle nature of the pleasant odor, claiming that participants may not have detected it well enough. This implies two things for the current study. First, the odors used in the current study could both be categorized as generally pleasant smelling. If only unpleasant odors elicit more presence, that may be a reason why the current study did not get significant results. Second, it may be the case that the odors used in the current study were also too subtle, similar to the pleasant odor in Baud and Bouchard's (2017) study. This would mean that the experiment should be revised with better equipment to release the smell stimuli.

The study conducted by Dinh et al. (1999) concluded that olfactory stimuli, in combination with tactile and auditory stimuli, increased users' sense of presence. While olfaction did lead to a noticeable increase in presence, only tactile and auditory stimuli elicited independently significant main effects. This suggests that olfaction alone may not be enough to significantly increase presence, but it could be combined with other sensory inputs to alleviate presence when necessary. It should be noted that this study is a somewhat outdated, and the results may not be highly applicable to current technology.

Interestingly, the results supported the studies earlier cited as being contradictory to the hypothesis. The first of these is the study by Egan et al. (2017) which examined the effect of congruent visual and olfactory stimuli on users' subjective levels of enjoyment, immersion and discomfort. They concluded that olfaction had no significant effect on any of the constructs. To add to these results, the current results indicate that presence may also be another specific construct which may not be heavily influenced by olfaction, either congruent or incongruent.

The results of Serrano et al.'s (2016) study were also supported by the current results, as they demonstrated that while their VR-MIP was effective in inducing relaxation, stimulating the senses of touch and smell had no significant impact on presence. However, similarities such as the use of lavender scent, and the use of a mist-based diffuser placed in the room to manipulate the effects of olfaction may suggest that Serrano et al.'s (2016) study may have had the same limitations as the current study, thus producing similar results in which the levels of presence were almost identical to the baseline control measure.

A few main limitations can be identified with the current study. Due to the limited sample size of this study, the study lacks sufficient statistical power, so the conclusions here may not strongly represent the general public. Given a greater sample size, this experiment has the potential to make an impactful statement on olfaction and VR immersion due to the visible trend in the data that is in line with the hypotheses. In addition, changing the design of the experiment from a between-subjects design to a within-subjects design, would minimize the effect of individual differences in sensitivity to smell and an individual's subjective interpretation of presence. This would require bringing participants in for multiple sessions on different days, so they can take part in each of the smell conditions without interference from prior stimuli. As discussed earlier, the stimuli being too subtle to make an impression may also be a limitation that needs to be addressed. This could be addressed by simply increasing the intensity of the smells in the experiment rooms. The smells may also have been too similar or both smells may have been too congruent. This could be remedied by making the incongruent smell drastically different and making the congruent smell extremely scene-specific.

Future studies could consider a number of other factors that could be investigated with regards to olfaction and presence. A factor to consider would be the age of the participants and how that may affect the results of the experiment as it has been found that as age increases, for various reasons a person is more likely to have a dysfunction in the olfactory sense (Doty, et al 1984). A future study could also examine whether emotional arousal has a role to play in the impact of olfaction on presence, as studies have indicated links between emotions and presence (Diemer et al., 2015; Riva et al., 2007) and links between emotion and olfaction (Zald & Pardo, 1997; Herz, 2004)

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