The Impact of Olfactory and Wind Stimuli on 360 Videos Using Head-mounted Displays

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Consuming 360 audiovisual content using a Head-Mounted Display (HMD) has become a standard feature for Immersive Virtual Reality (IVR). However, most applications rely only on visual and auditory feedback whereas other senses are often disregarded. The main goal of this work was to study the effect of tactile and olfactory stimuli on participants' sense of presence and cybersickness while watching a 360 video using an HMD-based IVR setup. An experiment with 48 participants and three experimental conditions (360 video, 360 video with olfactory stimulus, and 360 video with tactile stimulus) was performed. Presence and cybersickness were reported via post-test questionnaires. Statistical analysis showed a significant difference in presence between the control and the olfactory conditions. From the control to the tactile condition, mean values were higher but failed to show statistical significance. Thus, results suggest that adding an olfactory stimulus increases presence significantly while the addition of a tactile stimulus only shows a positive effect. Regarding cybersickness, no significant differences were found across conditions. We conclude that an olfactory stimulus contributes to higher presence and that a tactile stimulus, delivered in the form of cutaneous perception of wind, has no influence in presence. We further conclude that multisensory cues do not affect cybersickness.

CCS Concepts: • **Human-centered computing → Virtual reality**;

Additional Key Words and Phrases: Virtual reality, multisensory stimulation, presence, cybersickness, olfactory, tactile, immersion

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1 INTRODUCTION

One of the main goals of Virtual Reality (VR) is to be able to immerse a user in a Virtual Environment (VE) in such a way that the technology becomes somewhat transparent and the user experiences this environment as a real experience, thus serving as a medium to achieve different purposes. VR has been successfully used in several different areas of study, including medicine [Larsen et al. 2009; Seymour et al. 2002], education [Merchant et al. 2014; Padgett et al. 2005], and operational training [Bhagat et al. 2016; García et al. 2016]. The effectiveness and/or quality of a VE is commonly evaluated through the sense of presence that it evokes on the end-user [Meehan et al. 2002; Witmer and Singer 1998]. Presence can be defined as a state of consciousness, i.e., the psychological sense of being in the VE and corresponding modes of behavior [Slater et al. 1996]. According to Witmer and Singer [1998], presence is the sense of "being there," the subjective experience of being in a place or environment, even when one is physically situated in another. The literature presents several approaches for measuring presence that can be divided into two major categories: subjective and objective measures [Van Baren and IJsselsteijn 2004]. With subjective measures, the participant is asked for a conscious judgment of his/her psychological state/response related to the mediated environment. These are the most commonly used measures and they consist mainly of post-test questionnaires [Lessiter et al. 2001; Schubert et al. 2001; Witmer and Singer 1998]. Objective measures attempt to measure user responses that are automatic and are made without conscious deliberation; these are less common for several reasons, including the often need for special equipment and greater difficulty in analyzing the data. Examples of such responses are heart rate and galvanic skin response [Sallnäs 1999; Wiederhold et al. 2001].

Presence is likely improved by adding sensory information besides visuals and audio [Dinh et al. 1999]. Our experiences in the real world are inherently multisensory [Gallace et al. 2012], therefore, it is natural that the number and consistency of sensory outputs of a VR system is a relevant contribution for the sense of presence [Lombard and Ditton 1997]. However, the addition of sensory information may also cause cybersickness, an exhibition of symptoms that can occur during/after the exposure to a VE [LaViola Jr 2000]. Measuring cybersickness is relevant, because it enables us to evaluate if an additional stimulus is inducing negative effects on the user; and because it has a known negative correlation with presence [Witmer and Singer 1998], which helps us analyze if lower values of presence were a consequence of cybersickness. Although there is a growing body of research into the influence of multisensory stimuli on VE's, there are limited works concerning the effects of tactile and olfactory stimulation on users' sense of presence and cybersickness in VE's. The motivation of this article is to contribute to this body of research by studying the impact of wind and smell on participants' presence and cybersickness.

The experimental scenario used in this study consisted on having participants experience a VE based on a 360 video where the tactile stimulation was achieved by projecting air directly to the participants to give a cutaneous perception of wind and the olfactory stimulation was achieved through the release of basil smell to the proximity of the participants. Presence and cybersickness questionnaires were used to evaluate the effect of each sensory modality.

Throughout this article, when we mention VE's, we are referring to what we might call Immersive Virtual Environments (IVE), or VE's that use Immersive Virtual Reality (IVR) technology. The main criterion for distinguishing immersive from non-immersive VE's is the visualization method. With IVE's, more advanced visualization systems such as Cave Automatic Virtual Environments (CAVE) [Cruz-Neira et al. 1993] and Head Mounted Displays (HMD) are used. Moreover, these are commonly coupled with tracking systems and interaction devices such as gloves, omnidirectional treadmills, and joysticks that are used together to isolate the user from the real world and achieve high feelings of presence and user immersion [García et al. 2016].

The remainder of this work is as follows: a literature review over the pertinent related work for the purposes of the present study; a Material and Methods section that describes the experimental study that was conducted; the Results section where the obtained results are reported; the Discussion section where the results are analyzed and compared with the literature to obtain insights and knowledge over the research questions raised in this article; and, last, the conclusions and final remarks of the study are presented.

2 RELATED WORK

Wind simulation and smell delivery are not a novelty on VR applications. In fact, one of the first multisensory VR simulators was developed by Morton Heilig in the early 1960s. The simulator was named "Sensorama Simulator" and it was capable of delivering visual, auditory, olfactory, and tactile senses to engage the user in a virtual motorcycle ride in New York [Heilig 1962]. Nowadays, even though almost 60 years have passed, the idea behind multisensory VE's remains fairly the same but technology has evolved to a point where it is possible to provide more fidelity when displaying each sensory modality.

A few wind simulators have been proposed, mainly in the entertainment industry, to enhance experiences essentially based on ride simulators, as can be found in amusement parks, where a powerful fan is included to simulate speed sensation to users [Cardin et al. 2007; Verlinden et al. 2013]. Despite the existence of such simulators, there are not many papers regarding the influence of cutaneous wind perception on a participant's sense of presence and cybersickness. One of such is Moon and Kim [2004], where the authors developed "WindCube," a custom wind display system involving several small fans attached to a cubical structure, to study the influence of wind on presence. The results from a small presence questionnaire showed the device to be effective in terms of inducing higher presence on its users. A similar work where a custom wind delivery device was used to study its influence on presence was Cardin et al. [2007]. In this study, the authors used eight fans, distributed around a Head Mounted Display (HMD), to simulate the surrounding wind in a flight simulator. Besides positive results in wind direction estimates, users reported the device as being natural to use and to greatly enhance the sense of presence. To study if different wind output devices would have different impacts on presence, Lehmann et al. [2009] conducted an experiment where head-mounted wind was compared with stationary wind. The results, obtained with the Igroup Presence Questionnaire (IPQ) [Schubert et al. 2001], showed that wind increased presence and indicated a tendency towards stationary wind output. Using eight fans, coupled with a sail simulator, Verlinden et al. [2013] explored the influence of wind on users' sense of presence. The results, obtained with a reduced version of Witmer's presence questionnaire [Witmer and Singer 1998], indicated that wind positively influenced presence. More recently, Hülsmann et al. [2014] presented a setup to create wind and warmth on VE's. The authors attached eight fans in a circle above the projection walls of a CAVE [Cruz-Neira et al. 1993] and performed a pilot study to evaluate the influence of wind and warmth on user experience. According to the authors, users' presence and cybersickness were evaluated using questionnaires; however, no results were presented.

Moving on to the olfactory sense and its stimulation on VE's, this particular sense is one of the least studied due to reasons such as the difference in its activation, which happens through a chemical stimulus rather than a physical stimulus, and because a set of base odors that can represent the thousands of existing odors has not yet been found [Yanagida et al. 2004]. Despite the associated complexity, its stimulation should not be devalued due to its strong influence on our daily existence, especially at the subliminal level [Davide et al. 2001; Kimmelman 1993]. The olfactory sense can provide information about objects that other senses cannot, such as the fragrance of roses or fresh-baked bread [Barfield and Danas 1996]. Also, it can warn of hazards, as is the case of the odorants added to natural gas, so we can detect gas leaks in our homes [Sanders and McCormick 1993]. Several olfactory displays have been developed in both academic [Hirota et al. 2013; Ischer et al. 2014; Kadowaki et al. 2010; Nakamoto and Minh 2007; Papin et al. 2003; Yanagida et al. 2004] and business contexts [VaporJet™, ScentAir, and SensoryCo). However, there is little research into the influence of olfactory stimulation on a participant's sense of presence and cybersickness in a VE.

The first paper to appear on the literature concerning the influence of olfactory stimulation on participants' sense of presence is Dinh et al. [1999]. The authors evaluated the impact of tactile, auditory, and olfactory cues on presence, and what the results showed is that the addition of a tactile or auditory stimulus caused a significant increase in presence while the olfactory stimulus only showed a positive tendency to increase presence. Jones et al. [2004] presented a related work where the impact of an olfactory stimulus on users' sense of presence was tested for the purpose of enhancing military training environments. The results of this study showed that the addition of an olfactory stimulus was unable to cause a significant increase in presence. In a more recent work, an experiment was performed to study the effect of olfactory stimuli upon participants' sense of presence during a session of exposure therapy (treatment for anxiety and trauma-related disorders) [Munyan III et al. 2016]. The results of this study, obtained using the Igroup Presence Questionnaire [Schubert et al. 2001], showed that presence increased significantly with the addition of an olfactory stimuli.

Regarding the influence of an olfactory stimuli on cybersickness, to the best of our knowledge, there are only two works on this subject. Paillard et al. [2014] were the first; they studied the influence of adding a pleasant, unpleasant, and neutral smell on participants' motion sickness while being exposed to off-vertical rotations. The results showed that the addition of either pleasant or unpleasant smells did not affect motion sickness symptoms. The following, more recent work, studied whether pleasant smells could alleviate cybersickness symptoms [Keshavarz et al. 2015]. The results contrasted those obtained by Paillard et al. [2014], showing that the pleasant smell (roses) significantly reduced the severity of the symptoms, thus suggesting that a pleasant smell can potentially reduce cybersickness. In both studies, the Simulator Sickness Questionnaire was used to evaluate the severity of the symptoms.

There are other works incorporating olfactory information in VE's but with different purposes such as studying its effects on learning [Richard et al. 2006; Tijou et al. 2006] and memory [Tortell et al. 2007] or benefits in training [Cater 1994] and telemedicine [Keller et al. 1995].

Because there are few works on the influence of wind and smell on participants' sense of presence and cybersickness on VE's, we believe that further investigation is needed in this area of research. The present article aims to contribute to this area of research; its major goal is to answer the research question: "What is the influence of wind and smell on participants' sense of presence and cybersickness in a VE?" To answer this question, several specific goals where defined: to study the influence of olfactory and tactile stimuli at the level of presence (spatial presence, realness, involvement); to study the influence of olfactory and tactile stimuli at the level of cybersickness (nausea, oculomotor discomfort, disorientation); and to correlate the different dimensions of presence with those of cybersickness. Based on the existing literature, we hypothesize that either stimuli increases presence but does not cause a significant difference in cybersickness. The influences of the olfactory and tactile stimuli are studied separately, because we want to evaluate how each stimulus individually impacts presence and cybersickness. Moreover, this allows us to compare the results with the existing body of literature.

3 METHODS AND MATERIALS

This is a quasi-experimental, cross-sectional study with a quantitative focus and a between-subjects design. Its main goal is to study the effect of additional sensory (tactile and olfactory) cues besides audio and video on participants's sense of presence and cybersickness while watching a 360 video using an IVR setup.

3.1 Sample

The sample consisted of 48 participants (30 male and 18 female) between 18 and 51 years old ($M = 24.50$, $SD = 6.624$). Participants were recruited on the university campus and they were either students or researchers. There was no compensation for participating in this study. Sixteen participants were assigned to each condition: a first

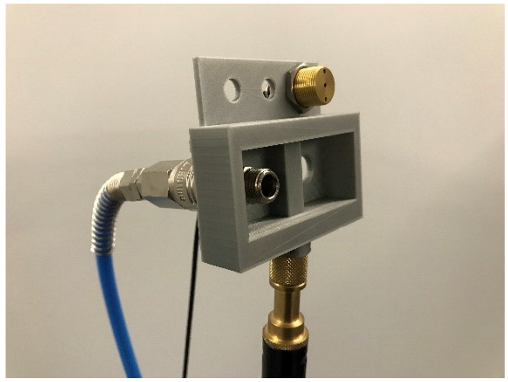

Fig. 1. Smell nozzle and compressed air hose mounted on the custom support attached to a generic tripod.

control group where only visual and auditory stimuli from a 360 video was provided; a second group where the olfactory sense was stimulated together with the visual and auditory; last, a third group that experienced the visual and auditory content of the 360 video with the addition of simulated wind. All participants reported normal or corrected to normal vision.

3.2 Materials

To deliver the visual and auditory content of the 360 video in an immersive manner, we used an Oculus Rift DK2 HMD and Bose QuietComfort 15 headphones with acoustic noise cancellation. To stimulate the olfactory sense, a SensoryCo SmX-4D aroma system was used. This system is fed by compressed air and a pre-loaded smell is released into the environment using SensoryCo's proprietary nozzle. In the 360 video, participants could see a stand selling basil, therefore, to provide a coherent olfactory stimulus the smell of basil was used. To ensure that the environment did not have other smells, an air conditioning and air extractor systems were used to constantly recycle the air in the room where the experiment was conducted. To stimulate the tactile sense, we used a customized wind simulation system that allowed us to control airflow delivered through a compressed air hose. A single air hose was used, because it showed efficiency in dispersing the air, thus giving participants an evenly distributed sensation of wind. Both the smell and wind output were assembled on a tripod using a custom 3D printed mount (Figure 1).

The 360 video used in the experiments was captured by the research team using a multi-camera rig from 360RIZE. Using an array of six GoPro Hero 3+ cameras, the footage was captured and afterwards synced, stitched, and rendered into a single video file using Kolor Autopano Video Pro. Since exposure time does not seem to influence presence or cybersickness of a participant watching a 360 video [Melo et al. 2018], we chose to create a three-minute video. The duration of the video was defined based on the study of Melo et al. [2018], which indicates that exposure times between one and seven minutes do not affect the sense of presence or cybersickness of participants during a virtual reality experience. This allowed us to study the effect of adding olfactory and tactile stimuli while keeping the experiment brief. The content of the video was captured in "Praça da Batalha," a famous square located at the city of Porto (Portugal); it shows the local daily routine: people and cars passing by (Figure 2). This video was chosen for the experiment because it was outdoors; this way wind would make sense in this environment, and because it had basil plants, which allowed us to implement a smell that is easily identified. While recording, the camera remained still.

To collect and analyze data from the experiment, two questionnaires were used:

- IPQp [Vasconcelos-Raposo et al. 2016]: an adapted and validated version of the original Igroup Presence Questionnaire (IPQ) [Schubert et al. 2001] for the Portuguese language. It is composed of a total of 14 questions that must be answered using a five-point rating scale;

Fig. 2. Screenshot of the 360 video used in the experiments.

- Cybersickness questionnaire, a Portuguese version of the Simulator Sickness Questionnaire (SSQ) [Kennedy et al. 1993]: This version of the SSQ was obtained by following the back-translation method [Brislin 1970; Hambleton and Zenisky 2011] and performing the respective content validity assessment. It has a total of 16 questions that must be answered using a scale of 1 to 4 describing the severity of the symptoms.

3.3 Variables

The independent variable of this study is stimuli, from which we have the conditions video 360 (control group), 360 video with smell, and 360 video with wind. The dependent variables are presence and cybersickness, which are both divided into smaller dimensions. Presence is divided into four dimensions identified in the IPQp: spatial presence, realness, involvement, and overall presence. Cybersickness is divided into four factors identified in the SSQ: nausea, oculomotor discomfort, disorientation, and overall cybersickness.

3.4 Experimental Procedure

When the participant arrived at the experimental room, he/she was given a small briefing about the experiment. The purpose was mainly to inform participants that they could rotate their heads to see the video but could not walk, as this action would not be reflected in the VE. Afterwards, the procedure of the experiment was explained without revealing any details that could bias him/her. Essentially, we explained to the participant that he was going to wear an HMD and headphones, and that, in the end, we would help he/she remove the equipment. The participant was then asked to give his/her consent to perform the experiment in the form of a signature and to fill out a sociodemographic questionnaire. Afterwards, the experimenter helped the participant to equip the HMD and headphones. At this moment, after the user was equipped with the HMD and before starting the experiment itself, the tripod containing the air and smell nozzles was adjusted to ensure that the stimulus was delivered to the participant. The tripod was placed at approximately 1.5 meters and its height was adjusted for each participant. After verbal confirmation that the equipment was properly fitted and that the participant was comfortable, the experiment started. The participant remained in a standing position and, depending on the condition the participant, would either watch the 360 video, watch the 360 video with the addition of an olfactory stimulus, or watch the 360 video with the addition of a tactile stimulus. The video had a duration of three minutes. After finishing the video, the experimenter helped the participant remove the equipment. Once the equipment was removed, the participant was asked to complete both the presence and cybersickness questionnaires.

Regarding the procedure of delivery of the additional olfactory and tactile stimuli, with the olfactory stimulus, the smell of basil was released a total of five times (5 seconds after the experiment started, at 30 seconds, 1 minute

Table 1. Properties of Each Wind Delivery throughout the Experiment

Delivery	Start Time	Duration	Air pressure (bar)	Volumetric flow rate (lpm)
1st	00:10	00:20	1.65	2.30
2nd	00:45	00:10	1.50	2.00
3rd	01:15	00:10	2.46	4.00
4th	01:50	00:30	1.65	2.30
5th	02:40	00:10	2.58	4.30

30 seconds, 2 minutes, and last, 2 minutes and 30 seconds). Each delivery had a duration of approximately three seconds. A similar time difference was used between deliveries so the stimulus was always present. To deliver smell, the aroma system uses scented cartridges that are put inside pressurized chambers. According to the manufacturer, each cartridge allows for 200 hours of continuous use before wearing out. Thus, the cartridge used in this experiment was above 90% of its capacity. Regarding the tactile stimulus, during the recording of the video, we did not capture the intensity of the wind at each moment; thus, in an effort to replicate the randomness with which wind occurs in the real world, we used different intensities and durations for each wind delivery. Table 1 describes the properties of each delivery. To measure the volumetric flow rate (measured in liters per minute—lpm), we have used an M-series mass flow meter from Alicat Scientific, placed exactly 10 cm away from the air pressure hose.

3.5 Statistical Procedure

The normality of the data was verified through the values of skewness and kurtosis, skewness varied from −.198 to 1.372 and kurtosis from −.788 to .902, indicating a normal distribution of the data [George and Mallery 2003]. Having a normal distribution, parametric statistics were used. To study the effect of the independent variable stimuli (360 video, 360 video with smell, and 360 video with wind) on the dependent variables (presence and cybersickness), two univariate ANOVAs were performed: one for overall presence and the other for overall cybersickness. When results from ANOVAs showed statistically significant differences in the p-value, univariate ANOVAs were performed as follow-up tests for each subscale of the independent variable that showed statistical significance. Bonferroni post hoc tests were also performed as follow-up tests when significant differences were shown in the univariate ANOVAs. Last, we performed a purely exploratory analysis to search for correlations between the variable overall presence and its subscales and cybersickness and its subscales. A Pearson correlation test was used to search for correlations, and the values were corrected for multiple comparisons using Bonferroni's approach.

Results are interpreted as statistically significant if $p < .05$. In all Bonferroni post hoc tests, the p-values presented are corrected for multiple comparisons. Unless otherwise stated, data are presented as mean ± standard deviation.

4 RESULTS

In a preliminary analysis, one outlier from the 360 video with wind condition was identified because it showed distant values from the remaining participants (above or below 1.5 times the interquartile range). Thus, it was removed from the sample to ensure the normal distribution of the data [Grubbs 1969]. The resulting sample consisted of 47 participants, 30 males and 17 females, between 18 and 51 years old ($M = 24.57$, $SD = 6.675$).

4.1 Presence

The univariate ANOVA analysis of the independent variable STIMULI regarding overall presence showed statistically significant differences between conditions: $F(2, .699) = 4.425$, $p = .018$, $p\eta^2 = .167$, $OP = .732$. To understand which of the conditions were significantly different, Bonferroni post hoc tests were performed.

Table 2. Means and Standard Deviations of Participants' Overall Presence and Its Subscales in Each Condition

	360 video	360 video with smell	360 video with wind
	$M \pm SD$	$M \pm SD$	$M \pm SD$
Spatial presence	3.33 ± .40	3.70 ± .50	3.57 ± .24
Realness	2.98 ± .69	3.42 ± .51	3.05 ± .68
Involvement	2.92 ± .77	3.38 ± 1.00	2.75 ± .59
Overall presence	3.12 ± .44	3.51 ± .42	3.19 ± .31

Table 3. Means and Standard Deviations of Participants' Overall Cybersickness and Its Subscales in Each Condition

	360 video	360 video with smell	360 video with wind
	$M \pm SD$	$M \pm SD$	$M \pm SD$
Nausea	69.76 ± 4.57	70.36 ± 5.91	71.23 ± 7.09
Oculomotor discomfort	65.38 ± 13.80	62.06 ± 11.15	63.17 ± 10.59
Disorientation	118.32 ± 19.69	112.23 ± 16.45	107.65 ± 17.02
Overall cybersickness	91.40 ± 11.75	88.36 ± 10.91	88.01 ± 11.47

Results from Bonferroni post hoc tests for overall presence showed a statistically significant increase of .39 ($p = .023$, 95% CI, .02 to .71) from the 360 video to the 360 video with smell group, and a non-significant increase of .07 (p = 1, 95% CI, −.29 to .43) from the 360 video to the 360 video with wind group.

Because a statistically significant difference was found on the univariate ANOVA of overall presence ($p < .05$), univariate ANOVAs were performed for each subscale of overall presence to provide additional insight into which dimensions of presence were affected the most. The results from univariate ANOVAs performed on the subscales of presence showed that a significant difference was found for spatial presence (F (2, .545) = 3.453, $p = .040$, $p\eta^2 = .136$, $OP = .617$) and no significant differences were found for realness (F (2; .885) = 2.220, $p = .121$, $p\eta^2 = .092$, $OP = .429$) or involvement (F (2, 1.632) = 2.490, $p = .095$, $p\eta^2 = .102$, $OP = .474$). To understand which of the conditions were significantly different on the subscale spatial presence, Bonferroni post hoc tests were performed. Results from Bonferroni post hoc tests for spatial presence showed a statistically significant increase of .36 ($p = .038$, 95% CI, .02 to .71) from the 360 video to the 360 video with smell group, and a non-significant increase of .23 (p = .328, 95% CI, −.12 to .59) from the 360 video to the 360 video with wind group. The means and standard deviations for overall presence and its subscales in all conditions are presented in Table 2.

4.2 Cybersickness

A univariate ANOVA analysis of the independent variable STIMULI regarding overall cybersickness showed no statistically significant differences between conditions, F (2, 54.644) = .422, $p = .658$, $\eta 2p = .019$, $OP = .114$. Because there were no statistically significant differences, no follow-up tests were performed. The means and standard deviations for overall cybersickness and its subscales in all conditions are presented in Table 3.

4.3 Correlation Between Presence and Cybersickness

To analyze possible correlations between overall presence and its subscales and overall cybersickness and its subscales, a purely exploratory analysis based on the Pearson correlation test was performed (Table 4). The results from the analysis showed no statistically significant correlations between any of the dependent variables.

Table 4. Pearson's Correlation between Presence and Cybersickness

		Nausea	Oculomotor discomfort	Disorientation	Overall cybersickness
Spatial presence	Pearson Corr.	.221	−.042	.020	.032
	Sig. (2-tailed)	>.999	>.999	>.999	>.999
Realness	Pearson Corr.	.054	−.319	−.274	−.272
	Sig. (2-tailed)	>.999	.232	.504	.052
Involvement	Pearson Corr.	.133	.031	.220	.138
	Sig. (2-tailed)	>.999	>.999	>.999	>.999
Overall presence	Pearson Corr.	.200	−.144	.003	−.033
	Sig. (2-tailed)	>.999	>.999	>.999	>.999

5 DISCUSSION

The main goal of this work was to study the effect of stimulating additional sensory modalities—namely, olfactory and tactile—on participants' sense of presence and cybersickness while experiencing a 360 video-based VE (with sound).

Before discussing the results, there is a limitation of this study that is worthwhile to point out, because several works suggest that it influences users' presence and cybersickness. This limitation concerns the inability of the participant to physically move in the VE. As mentioned earlier, the participant could not physically move in the VE because it was based on a 360 video and, as is well known, it is not possible to dynamically change user point of view during a pre-recorded video. Such limitation may influence participants' sense of presence and cybersickness. What the literature seems to suggest is that this limitation, which imposes less control of movement by the user, results in less sense of presence and fewer symptoms of cybersickness when compared to greater movement control. One of the studies that suggests this is Stanney et al. [2002], where the authors studied the influence of user movement control, among other variables, on the participants' performance, presence, and cybersickness. The results indicated that a greater sense of presence can be expected when the user has complete control of movement; however, at the same time, the results indicate that greater control heightens users' cybersickness. A similar study, conducted by Slater et al. [1998], obtained the same result. The authors studied the influence of body movement on the sense of presence in VE's, and the results indicated a positive association between reported presence and body movement, thus suggesting that greater body movement leads to greater user sense of presence. Regarding the impact of user movement on cybersickness, the results from an experiment carried out by So et al. [2001] indicated that limiting the user movement causes a decrease in cybersickness. The authors evaluated the influence of visual movement within a VE on participants' cybersickness, and the results suggested a strong positive relationship between both, indicating that greater visual movement causes more symptoms of cybersickness. Based on the results of the mentioned works, we postulate that participants' ratings of presence and cybersickness would begin at a higher level across all conditions if they could physically move in the VE. A factor that we believe is also relevant to mention here, as it may have influenced the results, is the movement of the users' head. Our view, formed by observing the experiences, is that the observation of the VE was similar across conditions, i.e., participants explored the VE similarly regarding head movements, however, because we did not make any digital record of this information, we cannot test whether there were indeed differences in head movements between the different conditions or not.

Having mentioned these limitations of the study, we now move on to the results on the independent variable presence. The results from the statistical test indicate that the addition of an olfactory stimulus increases spatial presence and overall presence, while the addition of a tactile stimulus does not influence overall presence or any presence subscale. We did not expect this outcome; our hypothesis was that either stimuli would significantly increase presence. Moreover, the literature seemed to suggest that wind was more likely to cause a significant difference in participants' presence because related works that studied the influence of wind on presence [Cardin et al. 2007; Lehmann et al. 2009] obtained significant differences, whereas those who studied the addition of an olfactory stimulus showed a tendency [Dinh et al. 1999] or even no significant differences [Jones et al. 2004].

An important factor that should be taken into consideration when comparing the results of our study with those of the related literature is the immersion of the VR system. All related works use older technology that does not provide the same level of immersion as that achieved in this work through a high-performance HMD. For instance, Verlinden et al. [2013] and Lehmann et al. [2009] use a non-immersive VR setup, i.e., they do not display the VE's content through an advanced display device such as an HMD or CAVE but rather with a non-immersive device such as a regular computer monitor or a single projector. Moon and Kim [2004] and Cardin et al. [2007] present their VE's content through HMDs; however, these are low-performance HMDs that do not provide the same level of immersion, because their properties (resolution, refresh rate, field-of-view, tracking accuracy, etc.) are much lower than those of a high-performance HMD. This is relevant to mention, because the level of user presence with current technology begins at a higher level, hence the addition of sensory modalities other than visual and auditive may be less noticeable.

We believe that a factor that contributed to the significant increase of spatial presence and overall presence was the coherence between the olfactory stimulus and the content of the video. As other works have suggested, there is a link between visual attention and coherent smells [Chen et al. 2013; Harvey et al. 2018]. Thus, it seems possible that the coherence of the olfactory stimulus with the visual content enhanced visual attention, which eventually contributed to a greater sense of presence. Furthermore, we postulate that scores in the spatial presence scale were especially higher possibly because this coherence made participants feel more spatially aware of the environment surrounding them. As for the significant difference in overall presence, we justify this as a result of the combination of higher values across presence subscales. A final note that we want to make on the 360 video with smell condition is that, although the smell was not instantly noticed by the participants, over time they realized that a different smell was present in their surroundings. At the end of each experiment, after completing the questionnaires to avoid participant bias, we asked participants if they noticed the addition of smell, to which in most cases the response was positive. Some even asked before we mentioned it, if there was an intentional addition of smell or if for some reason this was just an impression made up in their minds.

Regarding the results obtained in the 360 video with wind condition, although values were for the most part higher than the control condition, they did not show a statistically significant increase. Although participants showed physiological reactions to this stimulus, we believe some factors prevented the feeling of presence from being higher. One of them is the sound emitted by the air hose, even though participants wore headphones with acoustic noise cancellation, the sound was loud enough for participants to hear it. We believe that this sound, emitted during the deliveries of wind, increased participants' awareness of the real world and thus weakened their sense of presence in the VE. Another factor we believe can possibly be related to this outcome is the way we simulated wind. We used different air pressures for each delivery of wind, however, from start to end of each delivery, the air pressure remained equal. Although this can happen in the real world (i.e., in an outdoor space, we feel wind for a certain time with a constant force), it is more common to feel varying forces of wind. Therefore, we argue that a more precise simulation of wind, enabled by capturing real-world conditions using a special device such as an anemometer, would increase the VE coherence and consequently heighten participants' ratings of presence.

In the analysis of cybersickness, our results showed no significant differences between conditions, thus indicating that either addition of olfactory or tactile stimulus in a VE does not influence participants' cybersickness. Our result on the influence of smell on cybersickness is consistent with that obtained in the work of Paillard et al. [2014] but not with Keshavarz et al. [2015], where smell has been shown to significantly reduce participants' cybersickness. Our justification for this result is that the level of cybersickness in the control condition was low, which makes it difficult for any other condition to show a statistically significant reduction. Concerning the outcome on the influence of wind on cybersickness, we cannot compare it to related work, because we could not find any. Nevertheless, we consider that both outcomes were a positive result, because it suggests that the addition of multisensory cues, in the form of smell and wind stimuli, have no influence on cybersickness.

In our view, the major factor that has contributed to this outcome is the way the stimuli were delivered. In the 360 video with smell condition, participants did not realize when the stimulus was being delivered—they just eventually became aware of its existence; furthermore, the stimulus itself consisted of a floral smell, something that people in general find to be pleasant. In the 360 video with wind condition, although there were some limitations on its delivery (namely, the noticeable sound and constant air pressure), the stimulus itself was not too intense such as strong gusts of wind but rather light to moderate breezes of air. We believe that if either stimulus were too intense, such as a strong gust of wind or a very intense aroma, an increase of cybersickness could possibly occur. It is also important to take into consideration that the participant was told before the experiment that he/she could look around in any direction but not physically move around; in doing so, we avoided one of the leading causes of cybersickness, which is the cue mismatch between the motion shown in the VE and the difference in movement and motion cues perceived by the observer [LaViola Jr 2000].

Last, regarding Pearson's correlation test between the independent variables presence and cybersickness, the results showed no significant correlations between any of the measured variables. The motivation behind this test was to study if, as Witmer and Singer [1998] indicate, there was a correlation between presence and cybersickness—more specifically, a negative correlation in which higher cybersickness is correlated with lower presence. It is easy to understand why cybersickness would negatively influence participants' sense of presence; feeling sickness symptoms distracts people from the VE and this lowers the sense of presence. However, if cybersickness was not present in the first place, then this specific correlation would not exist. This is what we postulate has happened in our experiment, since cybersickness was low, it did not influence overall presence or any of its subscales. However, it should be considered that this was an exploratory test and due to the high number of variables and low sample, further tests would have to be performed to corroborate this result.

6 CONCLUSIONS

This article presents an investigation over the effect of adding olfactory and tactile stimuli in participants' sense of presence and cybersickness while watching a 360 video using an HMD-based IVR setup.

The main conclusion of this work is that the addition of an olfactory stimulus significantly increases presence, while the addition of a tactile stimulus shows a positive, but not statistically significant, impact on presence. This indicates that olfactory stimulus should be privileged over tactile stimulus, as it is more effective. Another conclusion from this study is that the use of olfactory or tactile stimuli in an IVE does not affect cybersickness.

This work is not free of limitations, as it contemplates a coherent and pleasant smell in the olfactory condition and the tactile feedback is limited to a cutaneous perception in the form of simulated wind. Hence, future work will contemplate the study of additional smells, including a non-coherent smell and an unpleasant one. Furthermore, additional stimuli such as force feedback and temperature will be studied to generate more knowledge over the addition of multisensory cues in 360 video experienced through IVR setups. Also, this work only considers the individual impact of each stimulus. Further research will be conducted to study the cross-modal effects and establish guidelines on which and how different stimuli should be combined to maximize the video 360 experience.

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