Virtual Reality for training - The impact of smell on presence, cybersickness, fatigue, stress and knowledge transfer

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***Abstract*— The area of professional training using virtual reality technologies has received considerable investment due to the advantages that virtual reality provides over traditional training. In this paper, we present an experiment whose goal was to analyse the impact that an additional stimulus has on the effectiveness of a virtual environment designed to train firefighters. The additional stimulus is a smell, more specifically the smell of burnt wood, which is consistent with the audio-visual content presented, and the effectiveness of the VE is measured through participant's feeling of presence, cybersickness, fatigue, stress and transfer of knowledge. The results indicate that, although the VE was successful in transferring knowledge, the addition of smell did not influence any of the measured variables. In the discussion section, we present the various factors that we believe have influenced this result. As future work, more experiments will be performed, with other stimuli, to understand better which stimuli increase participant's feeling of presence in the VE.**

Keywords—Virtual Reality, Olfactory Sense, Multisensory Stimulation

I. Introduction

Virtual Reality (VR) is in a period of strong growth. According to a report from MarketsAndMarkets [1], VR is expected to grow from 7.9 billion USD in 2018 to 44.7 billion USD by 2024. Two significant factors fueling this growth are the availability of affordable VR devices and considerable investments in the VR market. One area that has been receiving a large amount of investment is the training of professionals. Training with VR can bring several advantages to companies when compared to traditional training, including the ability to simulate any situation without exposing trainees to its risks and the ability to repeat a training session for an unlimited number of times [2].

Given the importance of VR as a training tool, it becomes relevant to measure the effectiveness of Virtual Environments (VE) designed for training. There are several ways of evaluating the quality and effectiveness of a VE, the most common one is through presence [3], the subjective experience of being in one place or environment, even when one is physically situated in another [4]. Other examples include using a written test to see if the intended knowledge was successfully passed, and the ability of a VE to evoke the same reactions as a real scenario [5].

This paper presents the results from an experiment conducted with a VE that is designed to train firefighters. Its main goal is to study the influence that an additional stimulus has on the effectiveness of a training VE. The additional stimulus is the smell of burnt wood, which is coherent with the audio-visual content presented, and the effectiveness of the training VE is measured through several metrics, namely: the participant's sense of presence, cybersickness (the exhibition of symptoms that occur during or after exposure to a VE [6]), stress, fatigue and knowledge transfer.

We chose to study the olfactory sense because it plays an essential role in our daily lives, especially at the subliminal level [7], [8]. It can provide information on objects that the other senses cannot, such as pleasant smells (e.g., the smell of roses and fresh bread), or odours that evidence danger (e.g. gas smell) [9], [10]. However, it is one of the least understood and least exploited in Human-Computer Interaction (HCI) [11]. Thus, our research also aims to contribute to the body of research regarding the stimulation of the olfactory sense on VE's.

This paper is organized into six sections. Section one introduces the subject of VR in training and defines the primary goal of this paper. Section two presents studies in the literature related to the study of olfactory stimulation and its influence on VE's. Section three describes the materials and methods used in this study, describes the sample, instruments, dependent and independent variables, materials and experimental procedure. Sections four and five present the results obtained and the discussion of such. Finally, section six presents the conclusions of this study.

II. Related Work

The stimulation of the olfactory sense is not a new subject. Attempts have been made for several decades to use scents to complement various types of media. The first attempt to combine artificial smells with audio-visual content dates back to 1906 when the audience of a movie theatre received the scent of roses while watching the screening of the Rose Bowl football game [12]. Since then, other attempts to use scents to improve user experience have been made, such as the AromaRama and Smell-O-Vision systems introduced in the late 1950s [13]. However, despite the efforts, there has never been a system that was widely adopted and considered a success.

The first use of smells in the realm of VR occurred in 1962 when Morton Heilig presented a VR simulator titled "Sensorama simulator". It stimulated the visual, auditory, olfactory and haptic senses to involve the user in a virtual motorcycle ride [14]. The "Sensorama simulator" was never widely adopted. However, its work remained as one of the most advanced in the area for a long time. Since the innovative work of Heilig, there has been some research on olfactory stimulation in VE's, albeit on a much smaller scale when compared to the stimulation of the visual and auditory senses. This is due, in part, to some factors that hinder the delivery of an olfactory stimulus. One of these is its activation, which occurs through a chemical rather than a physical stimulus,

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another is the lack of a set of base odours that can represent the thousands of existing odours [15].

There are currently several olfactory displays developed by academics (*e.g.*: [16]–[18]) and professionals (*e.g.*: [19]–[21]). Also, commercial solutions have already begun to apply to the most popular HMDs, such as VAQSO [22] and Feelreal [23]. However, there is little research related to the influence of smell on the feeling of presence and, to the best of our knowledge, none on its influence on cybersickness.

The first work we found in the literature is that of Dinh, Walker, Song, Kobayashi, and Hodges [24], the authors studied the influence of stimulating different human senses in the feelings of presence and memory of the participants. The presence was measured using a Presence Questionnaire (PQ) adapted from two original PQ's ([25], [26]) and the results showed that there was a significant increase in presence with the addition of haptic and auditory clues and a tendency for olfactory clues. A few years later, [27] studied the influence of an olfactory stimulus on the immersion of a participant during a virtual military training. Their results, measured through an augmented immersion questionnaire (not specified), indicated that olfactory stimulation did not increase immersion. The authors justified this result by saying that the high immersion of the VE created a surprise effect and as a result, the olfactory stimulus went unnoticed. More recently, [28] studied the effect of different types of smell on presence, evaluated through a small PQ of 1 item and the PQ from [29]. The results revealed that, among the types of smells used, the bad smell was the only one that significantly increased presence. However, none of them produced a significant increase in the remaining scales of sense of reality and sense of realism.

Another work concerning the influence of olfaction in the sense of presence is that of Ranasinghe *et al.* [30], the authors studied the influence of delivering heat, wind and smell on participants' sense of presence. Presence was measured using a PQ, adapted from [31] PQ, and participants' Heart Rate (HR). The results from the PQ showed that, in the sensory factors, one of the four measured presence scales, there was a significant increase with any of the additional stimuli, and that the combination of all stimuli brought an even more significant presence increase. The results from the HR showed that, with wind and heat, HR rose the moment they were delivered, whereas with smell HR rose but only after some time of exposure to the stimulus. The authors attributed this result to the saturation of the olfactory sense caused by the continuous exposure of the smell. Finally, another interesting result was that the combination of all stimuli showed no influence on HR.

In the literature there are other works that stimulate the olfactory sense in VE's, however, rather than studying their influence on the presence or cybersickness, they focus on other factors such as relaxation [32], learning [33], memory [34], training benefits [35] or telemedicine [36]. Olfactory stimulation is a subject that is not much explored in the literature. Our work is relevant because it adds knowledge regarding the influence of smell in the sense of presence, cybersickness, fatigue, stress and knowledge transfer of participants in a training VE. Our main goal is to study the influence of adding a stimulus, namely smell, on participants' sense of presence, cybersickness, fatigue, stress and knowledge transfer, while performing a virtual training exercise that is directed to firefighters. The added smell is burnt wood, which is consistent with the presented VE.

III. Materials and Methods

This is an experimental study with a quantitative focus. The main goal is to study the influence that an additional stimulus, namely smell, has on participants' sense of presence, cybersickness, fatigue, stress and knowledge transfer. Questionnaires were used to assess presence, cybersickness and knowledge transfer. In addition, visual analogue scales [37] were used to assess fatigue and stress. The study design used was group differences, and the type of study design was between-subjects.

The exercise performed in the VE consisted of a firefighting training exercise that aims to accustom trainees to heat, smoke and lack of visibility in closed compartments. To this end, participants performed different tasks inside a virtual closed container where experienced firefighters were holding a fire.

A. Sample

The sample used for this study consisted of 24 participants with ages between 20 and 33 years old (M= 25.38; SD = 4.073). Participants were selected using simple random sampling technique. 12 Participants were assigned each group: a first group that completed the training without the addition of smells; a second group that completed the virtual training with the addition of burn wood smell. All participants reported normal hearing and normal or corrected to normal vision.

B. Instruments

A total of five instruments were used to collect data from the experiment: a sociodemographic questionnaire, to collect data such as age and previous experience with VR technology; the Igroup Presence Questionnaire Portuguese (IPQp) [38], a Portuguese version of the original IPQ [39], to collect participants sense of presence; a Portuguese version of the Simulator Sickness Questionnaire (SSQ) [40], to gather data on cybersickness; visual analogue scales [37], to collect data on participant's stress and fatigue; lastly, a multiple choice test, to evaluate the transfer of knowledge enabled by the VE. The IPQp and SSQ were both adapted to Portuguese by following the back-translation method [41], [42] and performing the respective content validity assessment. Moreover, the multiple-choice test was validated by the commander of a local firefighting unit.

C. Variables

The independent variable of this study is SMELL, from which we have the groups WITH_SMELL and WITHOUT_SMELL. The dependent variables are presence, cybersickness, stress, fatigue and knowledge transfer. Presence is measured with a questionnaire that divides presence into four dimensions: immersion, realness, spatial presence, and overall presence, a combination of the first three. Cybersickness is measured using a questionnaire that divides cybersickness into four dimensions: nausea, oculomotor discomfort, disorientation, and overall cybersickness, a combination of the first three.

D. Materials

A set of equipment was used to immerse the user in the VE. The following equipment was used: HTC Vive, to allow the participant to have a 360 and 3D view of the VE; Bose QuietComfort 25 headphones with acoustic noise cancellation technology, to deliver the audio from the VE and to prevent the user from hearing real-world sounds; OptiTrack Motion Capture System, a tracking system that used 12 OptiTrack Prime 13 tracking cameras to track the participant's feet and hands. Based on the information acquired from the motion capture system and HMD, inverse kinematic was used to correctly animate the avatar's body. Participants could move freely on an area of 4 x 4 m. Fig. 1 shows an equipped participant performing the training exercise.

To deliver the smell to the participant's vicinity, 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 (See Fig. 2).

Fig. 1. Fully equipped participant during the experiment. Aroma system in the background.

Fig. 2. SensoryCo SmX-4D proprietary nozzle mounted on a standard camera tripod.

E. Experimental Procedure

The first step of the experimental procedure was asking the participant to read the consent form and the preamble regarding the experiment. If the participant agreed to participate in the experiment, his consent was given in the form of a signature. He/she was then asked to complete two questionnaires, the socio-demographic questionnaire and the Simulator Sickness Questionnaire (SSQ) [40]. When the questionnaires were completed, the researcher gave the participant a brief introduction to VR and asked him/her to equip the necessary material for the virtual training: optitrack trackers (hands and feet), HMD and headphones. During the placement of the equipment, the researcher ensured that everything was well placed and that the participant was comfortable. The virtual training began when the participant felt ready and comfortable. Depending on the condition, the participant performed the virtual training with or without the addition of burning wood smell. At the end of the virtual training, the researcher asked the participant to complete the questionnaires and multiple-choice test used to analyse presence, cybersickness, fatigue, stress and knowledge transfer. Also, the participant was asked if he/she noticed any smell and, if so, what smell, or smells did he/she identified.

The total time taken by each participant to complete the experiment was approximately 40 minutes. The experiment was conducted in a temperature-controlled room with air extraction switched on.

F. Statistical Procedure

In a preliminary analysis, one outlier from the WITHOUT_SMELL condition was identified because it showed distant values from the remaining participants. Thus, it was removed from the sample to ensure the normal distribution of the data [43]. The resulting sample consisted of 23 participants, 17 males and 6 females, with ages between 20 and 33 years old (M = 25.57, SD = 4.054).

The normality of the data was verified through the values of skewness and kurtosis, skewness varied from -1.217 to 2.075 and kurtosis from -1.129 to 5.65, indicating a normal distribution of the data [44]. Having a normal distribution, parametric statistics were used. The independent-samples t-test was used to determine if a difference existed between the means of the two groups (WITH_SMELL and WITHOUT_SMELL) on the variables presence, cybersickness, fatigue, stress and knowledge transfer. In addition to analysing the differences between groups, we used the pairwise t-test to verify if there were significant differences within each group in the variables cybersickness, fatigue, stress and knowledge transfer.

IV. Results

In this section, we present the results of the tests performed with the goal of measuring the influence of an additional stimulus, the smell of burning wood, on participant's presence, cybersickness, fatigue, stress and knowledge transfer. We chose a critical p-value lower than 0.05 as significant and a p-value between 0.05-0.10 as indicative.

A. T-tests

TABLE I. T-TEST RESULTS FROM THE INFLUENCE OF SMELL ON CYBERSICKNESS SUBSCALES, STRESS, FATIGUE AND KNOWLEDGE TRANSFER.

State	Indep. variable	Between groups		Test results	
		WITHOUT_SMELL	***WITH_SMELL***	***Levene's p***	***p***
Before	Nausea	6,94 ± 6,17	12,72 ± 16,94	0,54	0,298
	Oculomotor discomfort	22,05 ± 18,71	20,21 ± 20,01	0,226	0,823
	Disorientation	21,51 ± 19,05	11,60 ± 11,62	0,65	0,143
	Overall cybersickness	19,38 ± 15,76	18,08 ± 17,38	0,322	0,853
	Stress	2,82 ± 2,27	1,70 ± 1,49	0,488	0,203
	Fatigue	3,64 ± 1,80	3,10 ± 2,64	0,232	0,59
	Knowledge transfer	4,36 ± 1,36	3,92 ± 1,17	0,491	0,406
After	Nausea after	6,07 ± 8,82	5,57 ± 6,38	0,553	0,875
	Oculomotor discomfort	19,29 ± 15,30	8,84 ± 13,65	0,526	0,98
	Disorientation	20,25 ± 21,89	10,44 ± 16,92	0,34	0,24
	Overall cybersickness	17,34 ± 16,15	9,35 ± 11,56	0,292	0,184
	Stress	1,82 ± 1,60	0,82 ± 1,25	0,443	0,118
	Fatigue	2,18 ± 1,40	1,91 ± 2,34	0,435	0,744
	Knowledge transfer	6,09 ± 0,83	6,00 ± 1,13	0,985	0,829

TABLE II. T-TEST RESULTS FROM THE INFLUENCE OF SMELL ON PRESENCE SUBSCALES.

Indep. variable	Between groups		Test results	
	WITHOUT_SMELL	***WITH_SMELL***	***Levene's p***	***p***
Spatial presence	3,73 ± 0,44	3,69 ± 0,39	0,387	0,852
Realness	3,64 ± 0,63	3,25 ± 0,60	0,821	0,147
Involvement	3,14 ± 0,91	2,77 ± 0,69	0,678	0,287
Overall presence	3,50 ± 0,47	3,24 ± 0,32	0,498	0,131

B. Paired T-tests

TABLE III. WITHOUT SMELL - CYBERSICKNESS, STRESS, FATIGUE AND KNOWLEDGE TRANSFER.

Indep. variable	Within-group		Test results
	BEFORE - WITHOUT_SMELL	***AFTER - WITHOUT_SMELL***	***p***
Nausea	6,94 ± 6,17	6,07 ± 8,82	0,756
Oculomotor discomfort	22,05 ± 18,71	19,29 ± 15,30	0,635
Disorientation	21,51 ± 19,05	20,25 ± 21,89	0,846
Overall cybersickness	19,38 ± 15,76	17,34 ± 16,15	0,708
Stress	2,82 ± 2,272	1,82 ± 1,601	0,46
Fatigue	3,64 ± 1,804	2,18 ± 1,401	0,212
Knowledge transfer	4,36 ± 1,362	6,09 ± 0,831	0,004

TABLE IV. WITH SMELL - CYBERSICKNESS, STRESS, FATIGUE AND KNOWLEDGE TRANSFER.

Indep. variable	Within-group		Test results
	BEFORE - WITH_SMELL	***AFTER - WITH_SMELL***	***p***
Nausea	12,72 ± 16,94	5,57 ± 6,38	0,121
Oculomotor discomfort	20,21 ± 20,01	8,84 ± 13,65	0,111
Disorientation	11,60 ± 11,62	10,44 ± 16,92	0,809
Overall cybersickness	18,08 ± 17,38	9,35 ± 11,56	0,125
Stress	1,70 ± 1,494	0,82 ± 1,250	0,138
Fatigue	3,10 ± 2,644	1,91 ± 2,343	0,11
Knowledge transfer	3,92 ± 1,165	6,00 ± 1,128	0,001

V. DISCUSSION

The results will be discussed here in the same order as they were presented. Starting with Table 1, the results showed that there were no differences between groups in all subscales of cybersickness, namely: nausea, oculomotor discomfort, disorientation and overall cybersickness. The lack of significant differences in all subscales of cybersickness is a positive result. It indicates that the addition of smell does not influence cybersickness and, therefore, does not detract participants experience due to cybersickness symptoms. As for stress and fatigue, the results also indicate that the smell did not influence the participant's perception of stress or fatigue. This was a somewhat expected result for the variable fatigue; the presence of smell would hardly increase one's fatigue. On the other hand, with stress, we hoped to see an increase in this variable because of the increased coherence of the virtual environment. However, this did not happen, it seems that smell alone does not make participants exhibit the same kind of response as in the real world.

The last variable presented in Table 1 is knowledge transfer and, as the results show, the smell did not influence this variable. We are convinced that the addition of smells has the potential to make training more complete. However, it may be difficult to prove its benefits on a questionnaire. For instance, the smell can help a mechanic identify the origin of an engine leak, but it is not possible to use a written questionnaire to ask a mechanic to identify a specific smell. A justification that can partially explain this outcome is that we did not use questions that referred to the smell or depended on its identification, because that would benefit participants who experienced the smell condition.

Moving on to Table 2, the results from presence show that smell did not cause a significant difference between groups in any presence subscale, namely: spatial presence, realness, involvement and overall presence. We expected a significant increase, especially in subscale realism, because the smell used was consistent with what the participants were seeing and hearing. However, the results showed no significant differences in any of the subscales. One could argue that participants missed the presence of the burn wood smell, but the final questionnaire contained a question that asked participants if they felt the presence of smell and if they could identify it. The results for this question showed that, from the 12 participants in the WITH_SMELL group, 11 detected the presence of smell and 7 identified it correctly (the remaining 4 reported related smells such as smoke). Interestingly, 2 participants from the WITHOUT_SMELL group reported having felt a smell and identified the same smell that was used in the WITH_SMELL group (Note that the room had air extractors and the groups performed the experiment on separate days). Based on the results, it seems that although the smell is noted, its presence by itself is not enough to produce a significant difference in any of the presence subscales.

Tables 3 and 4 show the results for the before-after comparisons performed for each group. Table 3 presents the before-after comparisons of all variables (except for presence because it does not make sense to be evaluated before the virtual training) for the WITHOUT_SMELL group, and Table 4 presents the before-after comparisons of the same variables for the WITH_SMELL group. The results show that in both groups, there were no significant differences in any of the variables measured except for the variable knowledge transfer.

The results for the cybersickness subscales are again positive, they reveal that although the participants are exposed to a virtual training environment for about 20 minutes and use their natural walk to move inside it, this exposure does not cause symptoms of cybersickness to the participants.

Regarding the variables stress and fatigue, the results show that there are no significant differences in the before-after comparison in both groups. We expected both variables to increase, the stress caused by the feeling of being in a training environment that is stressful, and the increase in fatigue caused by the natural walking of the participant to move in the virtual environment.

The results show an opposite trend if we analyse the means of the variables for both environments, we see that participants reported lower values of stress and fatigue after the virtual training. Our justification for the fact that stress has not increased relates to the room where the experience is carried out. In the real environment, the firefighters are fully equipped with protective gear, and they enter a container that has an active fire inside it. Fire is a strong element that will inherently increase the participant's stress because our natural human response is to keep away from such dangers. In our view, it is harder to evoke stress using virtual reality because the participant subconsciously knows that he would never be deliberately endangered in a virtual environment. In addition, we believe that the simple fact that the participant can view the real-world room where the virtual exercise takes place reassures him because it gives him a sense of the space where he will do the exercise and what is around him. We believe that controlling these two factors, namely the requirement to use all safety equipment and total lack of knowledge of the room properties (to allow this the participant would enter a room while "blindfolded" with the Head-Mounted Display), would allow an increase in the participant's perception of stress.

Concerning fatigue and its tendency to decrease after the virtual training, our justification is that although the participant physically moves through the virtual environment, most of the time he/she remained seated (this happens in the real-world training for safety reasons), which made them relax rather than cause them fatigue. During the tests, we began to see that it was common for participants to report lower fatigue values after the experiment, after asking a few participants to explain this reduction, the general explanation was that the environment even helped to relax because there was little physical effort and because virtual reality was an engaging medium to learn content. Of the 24 participants, 6 had never experienced VR before, 8 had experienced VR in less than 1 month ago and the remaining 10 had experienced VR in more than 1 month ago.

To conclude the discussion of the results, the only variable that showed a significant difference was the knowledge transfer. This was a positive result because it shows that, in both groups, the virtual environment was successful in the task of transferring knowledge.

VI. CONCLUSIONS

The main goal of this work was to study the influence that an additional stimulus, namely the smell of burning wood, had on participant's sense of presence, cybersickness, fatigue, stress and knowledge transfer. To achieve this, the following specific goals were defined: study the influence of smell on presence; study the influence of smell on cybersickness; study the influence of smell on fatigue; study the influence of smell on stress; finally, study the influence of smell on knowledge transfer.

To evaluate the influence of smell on the different variables several questionnaires were used, namely: IPQp [38], a presence questionnaire used to evaluate participant's sense of presence; SSQ [40], a questionnaire to evaluate cybersickness; two visual analogue scales [37], to evaluate stress and fatigue; a seven-question multiple choice test to evaluate transfer of knowledge. All questionnaires except for the presence questionnaire were applied before and after the virtual training, which allowed us to make a before-after comparison of the variables for each group in addition to the between groups comparison.

The results indicated that smell did not have an influence on any of the variables measured. Thus, we conclude that smell did not influence the participant's sense of presence, cybersickness, fatigue, stress or knowledge transfer. Regarding the before-after comparison of each group, the results were similar for both conditions, showing no significant differences in cybersickness, stress or fatigue, and a significant difference in knowledge transfer. Based on the results, we conclude that the virtual training, with or without smell, did not influence participant's cybersickness, stress or fatigue, but was successful in the task of transferring knowledge to the participants.

As future work, we will add other stimuli and compare the results with the ones obtained in this study. The objective is to add other stimuli that we consider to be relevant such as the use of protective equipment (complete uniform and breathing apparatus). Another factor that we would also like to study in the future is if the lack of knowledge about the physical room where the experiment takes place influences any of the measured variables. Hopefully, the combination of all the results will contribute to a better understanding of which stimuli are essential to replicate for the participant to have a more immersive experience.

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