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Evaluation of Presence in Virtual Environments: Haptic Vest and User's Haptic Skills

Gonzalo García-Valle, Manuel Ferre, *Member, IEEE*, Jose Breñosa, and David Vargas

***Abstract*—This paper presents the integration of a haptic vest in a multimodal virtual environment, which consists of video, audio and haptic feedback. Its main objective is to determine how users, who interact with the virtual environment, benefit from the tactile and thermal stimuli provided by the haptic vest. Some experiments, which use a game application of a train station after an explosion, are performed. Participants have to move inside the environment, while receiving several stimuli that check whether improvement in presence or realism in that environment is reflected on the vest. It is done by comparing similar scenarios without haptic feedback. These experiments are carried out by three groups of participants who are classified depending on their experience in haptics and virtual reality devices. Some relevant differences among the groups have been found. Such differences are related to the levels of realism and synchronization of all elements in the multimodal environment that fulfill particular expectations and maximum satisfaction level. According to end-users, there are two different levels of requirements defined by the system. These levels are specified in order to comply with the expectations for professional and conventional users.**

***Index Terms*—Haptic Interfaces, Human Computer Interaction, Human Factors, Thermal Actuators, Vibrotactile Actuators, Virtual Reality**

I. INTRODUCTION

After several years of research, we can now perceive Virtual Environment (VE) similar to real environment. Moreover, we can also feel complete immersion inside the environment, perceiving all possible stimuli through all body senses. We are in the 'virtual reality time' [1]. The aim of VEs is to achieve the best user experience by improving realism or sense of presence, in such a way that the user feels a full integration inside the VE. Advances in virtual reality (VR) technologies have allowed creating realistic VEs, and thereby making systems surprisingly realistic [2]. Likewise, many haptic devices have been developed oriented to VR since 90's [3]-[4], but the lack of dissemination or sale to general public have been the main problems for their improvement during the past years. The evolution of VR technologies has allowed creating innovative systems, achieving a great number of applications to interact with them [5]-[7].

This paper presents the use of a haptic vest to perceive VEs by using two kinds of stimuli: tactile and thermal [8]. Therefore, on the one hand, the vest includes vibrotactile actuators to create tactile stimuli through vibration patterns; these patterns simulate virtual interactions such as the contact with people or objects inside the VE. On the other hand, the vest also displays thermal stimuli through thermoelectric actuators, creating hot and cold sensations so that users perceive a temperature change when they are approaching to a thermal focus. All haptic patterns have to be recognizable and quite similar to real interactions, looking for haptic interactions that are as realistic as possible. Then, the objective is to improve the realism and the immersion or sense of presence through haptic perception, achieving experience that is much similar to reality by including both tactile stimuli.

The paper also shows differences among three groups of participants about their perception of a VE when haptic devices are included, focused on some aspects such as realism, immersion and presence. Users have been classified as Haptic Experts (HE), Technology Experts (TE) and Non-Experts (NE). Therefore, some experiments are performed to evaluate the vest and the benefits of including it inside a VR system.

Thus, it is important to relate the concepts of realism and presence. On the one hand, the realism is related to some technical aspects, such as high quality computer graphics or the amount and quality of stimuli that users receive from the VE [9]. On the other hand, presence is considered as the sensation of being physically in a virtual place, having the ability of interacting with it [10] [11], broadening the original definition by Minsky [12]. It is also important not to mix up immersion and presence since immersion is described as an objective experience depending on some technical characteristics [13]. Taking into account the definitions per se, an increase of system realism can generate improvement in the sense of presence inside the VE [10]. Therefore, haptic vest could be a proper element to increase realism, perceiving virtual elements more realistically in order to increase presence. Thus, a questionnaire has been made in order to analyze haptic stimuli based on the answers from users, demonstrating whether the haptic vest is useful in order to increase realism and sense of presence in a VE.

VEs are usually made up of a visual system in which most of the virtual stimuli are perceived. Moreover, in most cases, an audio system that allows to perceive all sounds produced in the environment. The integration of haptic devices so as to

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G. García-Valle, M. Ferre, J. M. Breñosa and D. Vargas are with the Centre for Automation and Robotics (UPM-CSIC), Madrid, 28006, Spain (e-mail: gonzalo.gvalle@upm.es)

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achieve a complete interaction with the system is the next step, getting multimodal environments using most of the senses and approaching realistic VEs. High quality computer graphics is the first requirement in order to create a multimodal system since aural haptic stimuli must be properly synchronized with the system and the stimuli spatial origins have to be coherent with the VE, and thereby achieving a better immersion in the virtual system [14]. Considering previous factors, this paper presents an environment that involves three senses: vision, audio and haptics, in order to achieve the greatest presence inside the system and verify whether the developed haptic device really improves the performance of the VE.

The outline of this paper is as follows: related work is discussed in chapter II. Chapter III described the haptic vest developed for the VE. Chapter IV shows the serious game application and the devices used for the experiments. Chapter V summarizes the experiment procedures, the questionnaire, the number of people involved during the experiments. The experiment results are shown in chapter VI and a discussion about those results is developed in chapter VII. Finally, main conclusions are summarized in chapter VIII.

II. RELATED WORK

There are diverse studies about improving realism of VEs. Some studies prove better computer graphics produce higher realism and imply better experience and, thereby improving performance [15]. Moreover, it has also been reported that adding more stimuli (as aural or haptic), improves realism since users interact with the VE through senses [16]. Other works compare and demonstrate how greater performances are obtained with multimodal environments (audio-visual, visual-haptic or visual-audio-haptic systems) compared to using unimodal systems [17] [18]. Generally, multimodal interaction implies an improvement in the sense of presence, obtaining these results using questionnaires that measure the improvement attending to user answers [19] [20]. Many works have demonstrated how haptic interaction improves the performance of VE interactions [21], perceiving the VE more realistically through touch, e.g., feeling virtual textures [15] [16] or the handled tissues during a robotic surgery [22]. There are several developments in gloves, platforms [23] or surfaces [24] that are really useful in VR applications.

Regarding haptic vests, there are some previous developments and most of them are oriented to applications related to navigation in unknown environments, guidance or object detection [25] [26] [27]. These developments are usually based on vibrotactile stimulation, although they also use more sophisticated methods such as shaped-memory alloys (SMA) or thermal actuators [25] [28]. Moreover, there are some serious games using haptic devices focused on learning or training purposes, combining stimuli to improve realism, immersion or sense of presence in VEs. Therefore, those improvements generate benefits for objectives of the game (learning or training) due to larger similarities with the real scenario. One of the examples is a haptic vest used for tactical training [29] or applications oriented to medicine [30], rehabilitation [31] or student learning [32].

Finally, haptic vibration patterns are a key factor for improving realism of haptic interaction. These patterns are usually programmed based on vibration sequences that orient users inside a VE. It also indicates how to interact [33] [34] or associate particular patterns with events in order to improve a task performance [35]. Moreover, those patterns have been tested, verifying the usefulness to transmit information [36], in most cases over upper limbs [34]. In this paper, the aim is to create haptic patterns that are reproduced, as realistic as possible, over the user trunk by using usual parameters for creating patterns [37] [38].

III. HAPTIC VEST DESCRIPTION

The haptic vest is a device to generate tactile and thermal stimulation over users due to interactions with a VE. This feedback is performed through vibrotactile and thermal actuators distributed on different areas of the torso and the back. Figure 1 shows the front and rear views of the haptic vest.

The vest has to be tightly fitted so that users can wear it in such a way that all actuators are in contact with the user's body. In such manner, users will better perceive the haptic patterns. Thus, two vests have been tailored (a medium and a large size) so as to achieve best fitting for the bodies of participants. The distribution of the actuators has been determined according to the results of previous experiments about discrimination distances [8], allowing haptic patterns to be reliable and easy to perceive by users. The actuators are:

- Vibration motors (model '304-116', Precision Microdrives, www.precisionmicrodrives.com): these motors have a frequency range between 0 and 350 Hz when being powered between 0 and 5 volts. Motors are fitted in a 3D printed support in order to avoid relative movements on the vest. This support is sewn on the selected vest locations. Motors are distributed over the upper chest, upper back and shoulders with a distance between motors of 55 millimeters (distance slightly greater than resolution distance [8]). The distribution follows an equilateral triangle configuration, as shown in Figure 2. Therefore, according to the dimensions of the vest, 54 motors and 38 motors are placed for the large and medium size, respectively.

Fig.1. Haptic Vest seen from front (left) and rear (right). The hardware control (microcontrollers, PCBs and power supply system) is strategically located at the back to make easier the user movements.

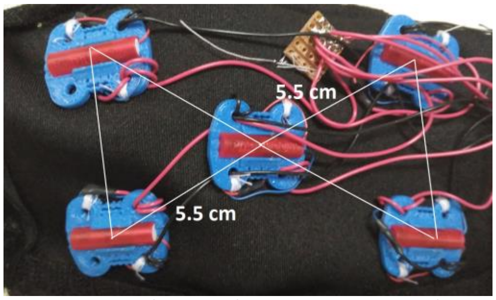

Fig.2. The distribution of motors follows the structure of an equilateral triangle. This figure shows the motors belonging to a shoulder.

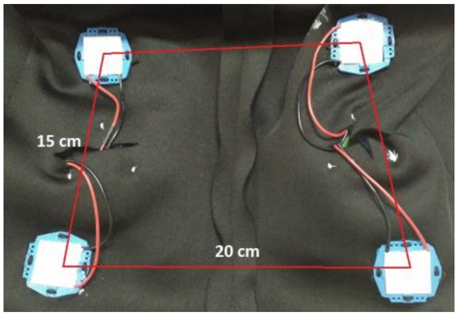

Fig.3. The distribution of Peltier cells follows a lineal structure. These cells belong to an internal part of the back.

- Peltier cells: (model 'TES1-07150', Everred Tronics, www.everredtronics.com): the model allows generating heat and cold sensations due to Peltier physical effect approximately between 0ºC and 100ºC. Literature shows non-pain temperature ranges from 15ºC to 45ºC [39], the created thermal stimuli is between such range. The cell is fitted in a 3D printed support that is sewn on the vest in the selected points where these actuators are placed. One of the sides of the Peltier is in contact with the user, whereas the other side faces outside, thus, a heat sink is placed on the free side of the Peltier in order to avoid cell overheating. The heat sink is also fitted in the same place as the cell, forcing the contact between the cell and the sink. The cells are located on the lower back and the abdomen according to a rectangular configuration with a distance of 15 x 20 cm among elements, as shown in Figure 3. Therefore, 12 Peltier cells are placed on the vest, independently of the vest size.

The actuators must be properly controlled in order to facilitate the programming of haptic patterns. Those patterns have to be properly synchronized with the visual and audio stimuli of the VR system. The control is made up of six microcontrollers (Arduino Lilypad, www.arduino.cc), that have the right outputs sufficient enough to control all actuators. Moreover, both the vibration motors and the Peltier cells require a Printed-Circuit Board (PCB) for the power stages, allowing to control 16 motors and 4 Peltier cells with the corresponding PCB. Thus, the complete control system consists of six Arduino boards, four PCBs for vibration motors and 3 PCBs for Peltier cells.

A. Haptic Stimuli

The interaction with the VE is made using haptic patterns that reproduce virtual tactile interactions as stimulations similar to real contacts, perceiving the VE in a more reliable way. These patterns have been done based on several parameters that develop haptic stimuli and some characteristics of the haptic device, such as actuators distribution, minimum vibration threshold, etc. Two haptic interactions have been developed:

- Collision. This interaction is reproduced with vibration motors. In the VE, there are several colliders surrounding the user's Point of View (PoV). They are placed at areas where motors are attached: shoulders, chest, and back. If a collider contacts with a character or an object, a signal is sent to the vest controller, the motors are turned on and the collision pattern is reproduced.

  These vibrations simulate collisions with elements inside the VE. When a virtual collision is produced in a specific area, all motors associated to that area are turned on simultaneously during a 250 milliseconds interval. However, the collision strength depends on the avatar velocity during the contact: if the contact is produced at low velocities (< 1 m/s), vibration frequency is 150 Hz (smooth blow); if the contact is produced at high velocities (> 1 m/s), vibration frequency is 300 Hz (strong blow).
- Temperature simulation. This interaction is reproduced with Peltier cells. The side of the Peltier cell attached to the user skin reaches a temperature that considers the following three parameters:
  - Stress. The user feels stress sensation because he/she is moving around in an unfriendly environment (post-explosion scenario). Stress produces increase in temperature. That is why, the temperature of the user increases a bit during the time in the VE [40].
  - Physical activity. If the user moves at high velocities, the temperature of the user increases due to the physical exercise. The equation (1) corresponds to the evolution of temperature according to stress and physical activity, which depends on velocity (v) and time (t) [41].
  - Closeness to the fire. If the avatar is at 100 meters from the fire, the cells will reach the temperature of 34.9 ºC. Thereon, if the avatar approaches, the temperature increases lineally until a maximum value of 45 ºC (corresponding to 0 meters). The equation (2) varies depending on an internal variable named 'HeatMag'. Moreover, the vest controller activates the Peltier cells depending on the orientation of the avatar with respect to the heat source.

$$Temp_{s+pa} = (0.02 + 0.01 \cdot v) \cdot t \tag{1}$$

$$Temp_{hs} = 0.112 \cdot HeatMag + 34.9 \tag{2}$$

Then, the final temperature generated by the cells is the addition of both quantities (3). The temperature due to the closeness to the fire is only displayed when the heat source is activated (HS = 1).

$$Temp = Temp_{s+pa} + HS \cdot Temp_{hs} \tag{3}$$

It is important to explain that the increase in temperature due to stress or physical activity is not reversible. The successive increment is then kept during the simulation. However, if the user distances away from the fire, the temperature diminishes, at the most, until the value provided due to stress and physical activity.

IV. VIRTUAL ENVIRONMENT DEVELOPMENT

VE is used as a tool for evaluating the functionalities of the vest and its capabilities, using a serious game for first responders training. The evaluation is carried out by using the simulation of virtual events through haptic stimuli (tactile and thermal interactions). Users can thereby evaluate how those interactions affect their experience inside the VE. Moreover, high quality computer graphics is required for the game as mentioned in the previous section. The VE has then been developed using Unity since it provides powerful tools in order to create high realistic computer graphics.

Users wear a Head-Mounted Display (HMD) [HTC Vive, www.vive.com] and the haptic vest, assigning the role of a first responder. The user moves inside a scenario configured as a train station during a post explosion state, accessing to the area and evaluating the emergency situation, so they can interact with the whole virtual system. Figure 4 shows the VE developed.

Vest control is based on a master-slave architecture, where a computer runs the master application and the vest controller acts as the slave. In such manner, the communication always flows in a single direction towards the vest via Bluetooth. The interface communicates with the vest controller which activates actuators using the corresponding drivers. The power supply is taken from a wall plug or a power source.

The vest is wirelessly controlled using Bluetooth 4.0 protocol, also known as BLE (Bluetooth Low Energy), to ensure operation compatibility with a wide range of devices. It will be assumed that the MAC address of the Bluetooth module connected to the controller is known, and the master where the environment runs is synchronized with that module before the VE starts. Figure 5 shows the complete communication scheme of the haptic vest.

Once the connection is established, information messages will be generated and transmitted to the controller depending on the user interactions with the VE. Messages generated will contain simple commands about the patterns to display over users. The controller receives these messages through the Bluetooth channel and triggers the corresponding signals to control the proper actuators.

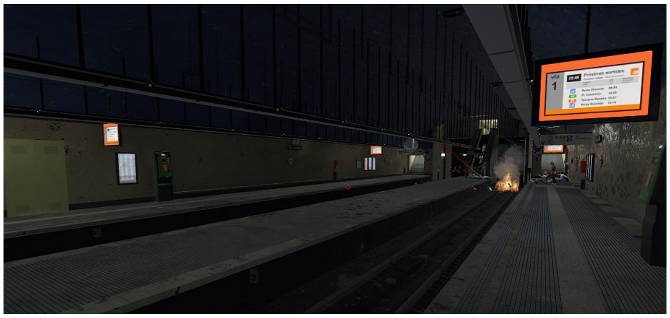

Fig.4.The Virtual Environment corresponding to the train station where the experiment is displayed. The fire simulation is at the end of the station.

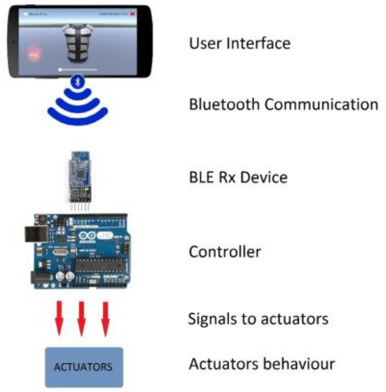

Fig.5. Vest communication and control scheme

The operation of the actuators depends on the interactions of the avatar with the VE. There are two types of interactions (collision and heat) that can be activated during the user interaction with the VE.

V. EXPERIMENTAL SYSTEM

The main objective of the experiments is to evaluate if the vest, using tactile and thermal actuators, improves the performance of a serious game, increasing the realism or sense of presence inside the VE. In order to do that, participants have been classified into three groups depending on their experience with haptic and VR technology (HE, TE and NE groups). In such manner, it takes into account how experience affects multimodal system, figuring out possible differences in the perception of the VE and how an additional device (the haptic vest) affects the multimodal environment performance.

A. Experimental Procedure

The user has to wear the HMD with headphones and the haptic vest to start the procedure of the experiment. The vest is previously configured in order to interact properly with the VE. Besides, the HMD is calibrated to limit the space for the movement of the user during the experiment, carrying out this process with the help of the HMD trackers. Figure 6 shows some participants during the experiments.

Once the system is initiated, the user interacts with the

Fig. 6. Two participants during the experiment.

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environment in two different phases:

- First phase. The virtual avatar is displayed in a central point of the train station and the users are asked to move around freely in the VE. In this manner, the user can perceive tactile interactions with the rest of the characters and the objects when it makes contact with any of them. This phase takes around two minutes so that the user can explore the scenario completely.
- Second phase. The fire simulation is activated and fire appears on one side of the train station. The user is requested to approach that area and when the user approaches the fire, the vest produces gradual increase in temperature. Thus, the user will feel strong sensation of heat being next to the fire inside the established limits. Finally, it is important to consider that the fire is not the only stimulus generating sensation of heat inside the VE. Body temperature can also increase due to internal parameters of the virtual avatar. This phase takes around 4-5 minutes.

B. Participants

23 healthy people took part in the experiment, with ages between 23 and 53 years (M = 33.43; SD = 7.34). These participants have been divided into three different groups depending on their knowledge of haptics and VR devices. The division in groups was done after analyzing the results of a questionnaire, where some questions were oriented to creating these groups.

C. Evaluation Questionnaire

Once the experiment has been performed, participants are asked to complete a questionnaire with two objectives: on the one hand, classifying participants depending on their knowledge of haptics and VR and, on the other hand, analyzing how haptic devices affect the sense of presence inside the VE. It is important to consider that presence is a subjective parameter, such is why the results depend on human opinion and, thus, all answers will depend on their level of expertise.

TABLE I
EVALUATION QUESTIONNAIRE

Block	Questions
Classification of participants	1. Have you ever used any haptic device? 2. Have you ever used any VR device? 3. Have you ever worked with haptics and VR devices?
Haptic Devices Contribution to Realism or Presence	4. Regarding the VR experience you have tried, how do you evaluate the realism level? 5. Do you think a haptic device could be useful to improve presence and/or realism in VEs? 6. What parameter? Presence or realism?
Evaluation of Tactile Stimuli	7. Have you perceived any tactile stimulus? 8. Could you associate those stimuli with events that happened inside the VE? 9. Select what event you could associate with the stimulus? 10. Value the realism level of the sensations perceived
Evaluation of Thermal Stimuli	11. Have you perceived any tactile stimulus? 12. Could you associate those stimuli with events that happened inside the VE? 13. Select what event you could associate with the stimulus? 14.Value the realism level of perceived sensations

The questionnaire is divided into four blocks with fourteen questions as shown in Table I. The first block consists of three questions that allow classifying participants into 3 different groups (HE, NE and TE). The second block establishes user expectations regarding abilities of a haptic device in order to improve realism or sense of presence in a VE.

The two final blocks correspond to the evaluation of tactile and thermal stimuli. Each block contains similar questions focused on the corresponding haptic interaction. The aim is to know if users have perceived any kind of stimuli and if they are capable of relating those stimuli with the events that happened in the VE.

In some questions, the participant is asked to select one or more options from a list of possible events that happened in the VE. The list is composed of events truly displayed on the vest (e.g., closeness to fire, stress, etc.), although there are non-displayed events (such as snow or air conditioning). In such a way, it demonstrates if participants identify the events that were truly displayed. The last question of this block is referred to the realism of haptic stimuli.

All questions about realism are evaluated using a numeric scale associated to different realism or artificiality levels about visual or haptic stimuli. The scale and the associated levels are shown in Table II.

- Options 0-1: these two options indicate that the environment or stimuli are not realistic.
- Options 2-3: these options indicate poor environment or stimulation, i.e., although it could be similar to real, there are many factors that make the system perceived as low realistic. The two options are differentiated depending on the level of presence reached in spite of the artificiality.
- Options 4-5: these options indicate realistic environment or stimulation, i.e., there are many similarities with reality. Once again, the two options are differentiated according to the level of presence since it is possible to perceive the environment realistically but not in an immersive way.
- Option 6: the option indicates a scenario or stimulation with high amount of realism, being very similar to a real environment or stimulus. There may be some details revealing that it is VE but those details do not affect presence.

TABLE II
SCALE FOR MEASURING PRESENCE INSIDE VEs

Score	Perception
0	Not realistic, unnatural
1	Poorly credible
2	Artificial, non-immersive
3	Artificial but immersive
4	Realistic, non-immersive
5	Realistic and immersive
6	Real, some details are not immersive
7	Totally Real

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- Option 7: the option indicates a scenario/stimulation that is totally realistic. There are some differences, or even absent, between reality and the VE.

VI. EXPERIMENT RESULTS

A. Participant Classification

The first three questions are used so as to classify the participants into three groups as defined in the previous section. According to the results, participants are classified as follows:

- Haptic Experts (HE): 9 participants have experience working with haptic or VR systems. These participants are aged between 24 and 53 years (M = 35.89; SD = 9.64).
- Technology Experts (TE): this group is made up of 6 participants that have tried some haptic or VR device, but they have not worked in research activities. These participants are aged between 26 and 31 years (M = 26.5; SD = 2.95).
- Non-Experts (NE): 8 participants, 4 of them have no experience either with haptics or VR systems. The other 4 participants had previously tried VR devices. These participants are aged between 34 and 40 years (M = 37.13; SD = 1.75).

B. Virtual Environment Realism and Usefulness of Haptics

The next step is to evaluate VE without considering additional stimuli from the haptic vest. In this manner, participants have a starting point in order to evaluate the haptic stimuli that influence on presence or realism, i.e., all subsequent results will be referred to that reference. The results are shown in Table III.

Moreover, this block finds out whether users believe the haptic vest is useful for a VE and, more specifically, to improve presence or realism. These answers are used for analyzing the subsequent blocks. Generally, all participants believe that a haptic vest improves presence and realism. However, there are some HE participants that believe realism is not improved with this kind of device. The answers are summarized in Table IV.

TABLE III
VIRTUAL ENVIRONMENT EVALUATION

Group	Realism Score
All participants	3.62 ± 1.73
HE	2.44 ± 1.88
TE	3.67 ± 1.03
NE	4.75 ± 1.16

TABLE IV
INFLUENCE OF THE HAPTIC DEVICE IN VE PROPERTIES

Group	Usefulness	Presence	Realism
All participants (23)	All	All	20
HE	All	All	6
TE	All	All	All
NE	All	All	All

TABLE V
TACTILE STIMULATION EVALUATION

Group	Perception	Association to Events	Kind of Events	Realism Score
All (23)	All	18	---	3.89 ± 1.18
HE	All	5	Collisions, wind	3.5 ± 1.07
TE	All	5	Collisions	3.8 ± 1.1
NE	All	All	Collisions	4.38 ± 1.3

TABLE VI
THERMAL STIMULATION EVALUATION

Group	Perception	Association to Events	Kind of Events	Realism Score
All(23)	21	18	---	4.31 ± 1.65
HE	7	4	Closeness to fire, temperature	3 ± 1.32
TE	All	All	Closeness to fire	4.17 ± 1.33
NE	All	All	Closeness to fire, stress, fatigue	5.75 ± 0.89

C. Evaluation of Tactile and Thermal Stimuli

Next blocks address about the influence of haptic stimuli during the experiment. Firstly, participants are asked about if they had perceived any stimuli (tactile or thermal) and about the possibility of associating them with events that happened inside the VE. Next, participants have to select the associated events among a list of options offered in the questionnaire. Finally, participants are requested to evaluate the realism level of identified stimuli according to the scale previously defined (Table II). This evaluation is requested for two types of stimuli: tactile and thermal; the results are shown in Tables V and VI, respectively.

Moreover, participants can provide some comments about the complete VR system. The main drawbacks are related with desynchronization between events in the VE and vibrotactile responses and, in addition, with the need to improve the realism of tactile stimuli. Furthermore, there are several comments about the possibility of including more tactile sensations. Some problems have also been reported about unequal heating in different areas of the vest. Regarding the positive aspects, most of the participants have emphasized about the improvement of presence and realism by using the vest in VR systems.

VII. DISCUSSION

The valuation of the VE (only audio and video) realism is around 3.5 over 7 points, with high standard deviation in some groups, as shown in Table VI and in figure 7 graphically. Thus, these high values require an analysis among groups in order to evaluate them. Moreover, the VE realism valuations are the reference to evaluate the influence of the haptic vest. These differences are analyzed using an ANOVA [42] test with the three group samples, obtaining a p-value of 0’015, which indicates a significant difference between groups. However, it is not possible to find out the cause of those differences with this test, so three Student t-tests are

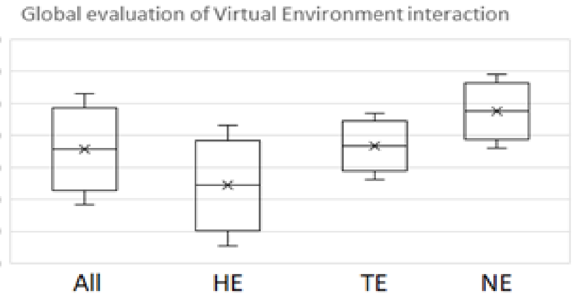

Fig.7. Evaluation of the Virtual Environment realism. The scale is defined from 0 to 7 according to Table II. 'All' includes the results of all users, HE (Haptic Expert), TE (Technology Expert) and NE (Non-Expert).

performed between pairs of samples. The results of t-tests show that there is a significant difference among TE-NE (p-value = 0'045) and HE-NE (p-value = 0'004) groups and there is no significant difference among HE-TE groups, whose p-value is greater than 0'05 (limit value for considering significant differences). Thus, the NE group perceives a greater realism and presence since they have never tried a similar system (including haptics), which increases the number of sensations provided by the VE; whereas, the HE and TE groups need an experience more realistic to perceive meaningful improvements.

Regarding evaluation of tactile patterns, only 5 participants did not associate the stimuli with events inside the VE, which can be a result of event-haptic patterns desynchronization or a lack of stimuli realism respect to real contacts. However, most of the participants were able to relate the events and the haptic responses. Once again, these 5 users belong to HE group and, in this case, the differences could be due to those users need a perfect stimulation to identify and value them positively. Likewise, 2 participants did not perceive thermal stimuli and 3 additional participants did not associate the stimuli with virtual events. All those participants also belong to HE group. Just as the previous case, the participants need greater level of realism in order to appreciate the events and relate them with VEs properly (e.g., improving heat control or tightening the vest to the body).

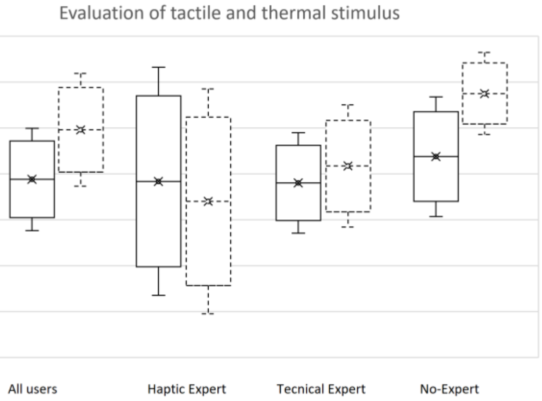

Fig.8. Evaluation of tactile (solid line) and thermal (dash line) stimulus according to the realism scale in Table II.

TABLE VII
STATISTICAL ANALYSIS VE EVALUATION

Groups	Test	p-value
All	ANOVA	0.014
HE-TE	Student t-test	> 0.05
TE-NE	Student t-test	> 0.05
HE-NE	Student t-test	0.004

Most of the cases, participants properly relate the events with the haptic patterns displayed. For instance, tactile stimuli were always associated with objects or characters contacts; whereas thermal stimuli were associated with closeness to fire or environmental temperature. In some cases, the NE group associated thermal stimuli with stress or fatigue, indicating a greater willingness to perceive non-physical events due to their lower expertise and greater impressionability.

Valuations for both types of stimuli show that thermal stimuli are better evaluated than tactile, probably due to those stimuli are more similar to real sensations, generally; even so, there is room for improvement to increase the realism, according to the results of HE and TE groups. Regarding tactile stimuli, valuations are similar between groups, indicating that realism levels can be substantially improved since all evaluations are around 3.5 over 7 points. Results are shown in Figure 8 in order to establish a comparison.

Two ANOVA tests are performed in order to evaluate tactile and thermal stimuli, showing only differences between groups regarding thermal stimuli (p-value = $5\cdot10^{-4}$). Likewise, six Student t-tests are performed comparing groups in pairs, confirming the hypothesis of tactile stimuli (all p-values are greater than 0'05). However, the t-test results for thermal stimuli show that HE and TE groups perceive in a similar way; whereas NE group has significant differences with HE group (p-value = $8'33\cdot10^{-5}$) and NE group (p-value = 0'018). These results are attributable to the lack of experience of NE group, whose users perceive a new kind of stimuli more satisfactorily with considerable similarities with a real interaction. Results of all tests are shown in Table VIII.

In conclusion, the valuation of all groups regarding haptic interactions is greater than 3.5 points and, nevertheless, there is a great room for improvement. Although the vest improves the presence and realism in the VE, HE users have identified problems as desynchronization or heat control that need to be improved. There are significant differences between experts and novel, indicating it is possible to create less realistic systems that are orientated to general public since they have fewer expectations than experts. Once these systems are

TABLE VIII
STATISTICAL ANALYSIS FOR TACTILE AND THERMAL STIMULI

Groups	Test	p-value (Tactile)	p-value(Thermal)
All	ANOVA	> 0.05	$5\cdot10^{-4}$
HE-TE	Student t-test	> 0.05	> 0.05
TE-NE	Student t-test	> 0.05	0.018
HE-NE	Student t-test	> 0.05	$8.33\cdot10^{-5}$

TABLE IX
MAIN FEATURES OF PROFESSIONAL AND GENERAL USERS

Features	General Users	Professional Users
Event Synchronization	Medium	High
Vest Fitting	Medium	Medium
Tactile Stimuli	High	High
Thermal Stimuli	Medium	High

accessible to general public, greater realism levels will be needed in order to achieve the same evaluations.

Finally, results show that the level of expertise of end-users should be taken into account in the design of the haptic vest due to different expectations being expected by haptic experts (professionals) and non-experts (general users). Table IX summarizes main features of two kinds of users.

VIII. CONCLUSION

This paper evaluates the influence of a haptic vest inside a VR system upon performing some experiments. During the experiments, the participants would have to move around the VE, perceiving multimodal stimuli: video, audio and haptics. After the experiment, users had to fill in a questionnaire to evaluate the VE and their interactions while using the haptic vest. The results forwarded by participants show that the haptic vest has improved realism of VE and the sense of presence. Thermal stimuli have received better valuation than vibrotactile due to their similarities with real sensations.

There are some differences among the groups that have been analyzed, obtaining two kinds of users: professional and general. Professional users have experience in haptics, VR or experience with serious games (learning, training, etc.); whereas, general users have little to no experience at all. The differences are related to the expectations with VEs or haptic interactions. Professionals need high quality stimuli and proper synchronization among VE events and multimodal stimulation (audio, video and haptics). However, general users need less quality of stimuli to achieve a sense of presence and a proper level of VE realism.

Moreover, groups are directly related to VE applications. Professionals are more focused on serious games, whereas general users are more concentrated on VR systems for entertainment. Therefore, a stronger effort is needed in order to develop quality stimuli and proper synchronization for serious games instead of applications for VE entertainment.

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