Shaken, not Stirred

Visualizing Vibrotactile Feedback in Virtual Reality

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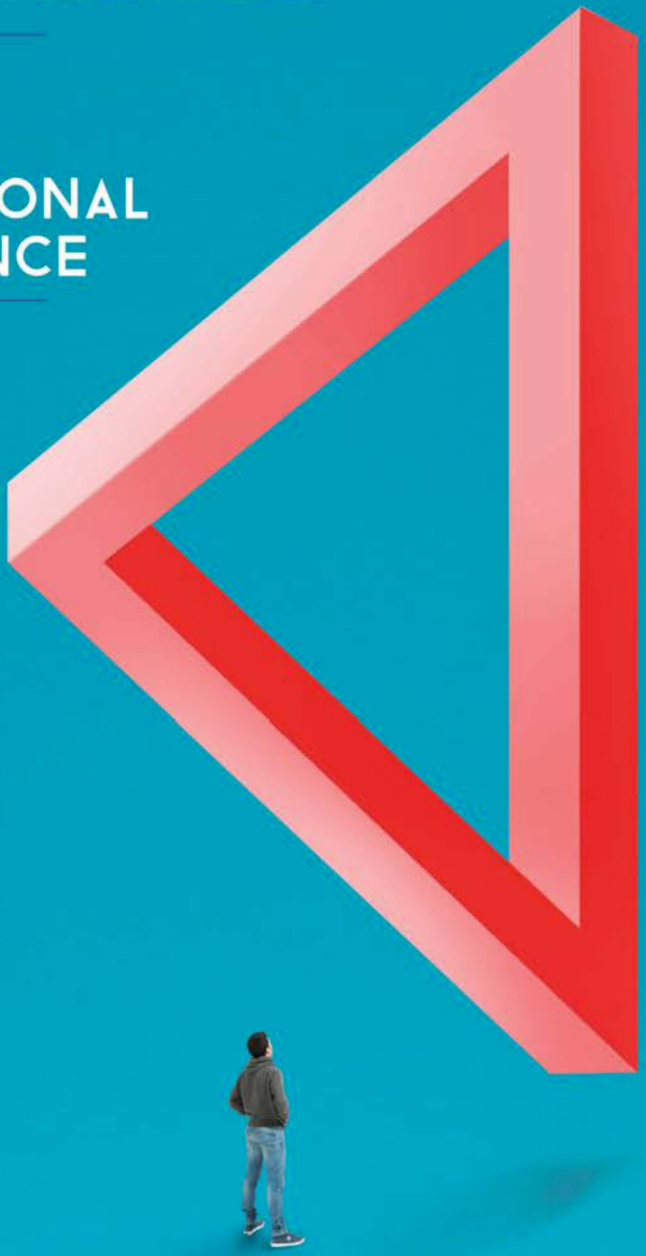

PROCEEDINGS

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HUMAN CENTERED EXPERIENCE

Session Chairs: Olivier CHRISTMANN, Arts et Métiers, LAMPA
Geoffrey GORISSE, Arts et Métiers, LAMPA

Virtual Classroom's Quality of Experience: a collaborative VR platform tested *in situ*

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Abstract

As collaborative VR for learning is coming to the general market, its evaluation *in situ* becomes more pregnant. Our purpose is: 1) implement collaborative VR for learning *in situ* in various conditions, 2) propose a questionnaire-based method to evaluate Quality of Experience (QoE) and 3) identify potential parameters influencing QoE. 88 participants divided into 4 groups completed questionnaires after participating to different VR activities. Our results show that QoE is influenced by the technical specificities of the Head Mounted Display as well as by the learning instructions and materials but not by the relative locations of the users (distant or sharing the same physical space). We suggest that trainers should take advantage of Collaborative VR in the design of the training activities to support interactive and trainee-centered approach. Presence, Flow, Visual Discomfort, and User eXperience can be considered as a minimum way to proof base the quality of deployment.

1. Introduction

1.1. Collaborative VR and Learning

Virtual Reality (VR) is resurging with a new generation of Head-Mounted Displays (HMDs) available on the consumer market (K. C. C. Yang, 2019). There is an enthusiasm for this technology, particularly in education and training (Arnaldi *et al.*, 2018) as it seems robust enough for large adoption (Anthes *et al.*, 2016). In their review, Slater and Sanchez-Vives point out the advantages of VR to learn: embodying, acting, repeating (Slater & Sanchez-Vives, 2016). Increasing the motivation of learners and trainees also appears as one of the main advantages of VR compared to other apparatuses (Freina & Ott, n.d.; Kavanagh *et al.*, 2017). Two issues for the adoption of VR remain learner's acceptance of VR as a learning medium (Velev & Zlateva, 2017) and the instructions' creation (Jensen & Konradsen, 2018). Yet, little experimental evidences support the benefits of using VR and its learning efficiency, except for specific fields such as surgery training (Alaker *et al.*, 2016). Therefore, testing VR for on-campus learning and *in situ* has been pointed out as an issue to tackle (Nersesian *et al.*, 2019; Selzer *et al.*, 2019). One modality of teaching and learning with such technology is collaborative VR (Churchill & Snowdon, 1998). Collaborative VR consists in joining a common space in the virtual environment to interact no matter where users' real physical space is (Hoppe *et al.*, 2018). In the learning context, collaborative VR is pointed out by Marky *et al.* for its ability to focus attention and connecting learners to the learning materials (Marky *et al.*, 2019). Therefore, we decide to implement Virtual Classroom, a collaborative VR tool, for learning purpose in real conditions, with a focus on 3 fields: process engineering, particle physics, and management. We test on-campus and distant learning.

1.2. QoE in VR

The quality of experience (QoE) (Gaggioli *et al.*, 2003) is traditionally measured in order to assess user's acceptance of a VR experience (Kong & Liu, 2019). Soler-Dominguez *et al.* point out Flow, Presence and Cognitive Load as measures of the learning experience in VR (Soler *et al.*, 2017). Slater's definition of Presence is: "*the strong illusion of being in a place in spite of the sure knowledge that you are not there*" (Slater, 2009). Csikzentmihalyi describes Flow as an optimal state of intrinsic motivation mobilizing all the resources of a person towards the action undertaken, finding himself totally absorbed and to the maximum of his capacities (Csikzentmihalyi, 1990). VR is known to provoke visual fatigue (Yuan *et al.*, 2018) which can be evaluated subjectively through Visual Discomfort (Lambooij *et al.*, 2009). In addition, User eXperience (UX) is commonly evaluated for interactive software. Cybersickness defines negative symptoms users report after exposition to VR (Davis *et al.*, 2014) and is known to impair the QoE. Collaborative VR training is usually measured with a higher QoE than non-immersive apparatuses (Zizza *et al.*, 2018). High Presence and Flow are associated with high QoE and seems covariant: the higher the one, the higher the other (Tcha-Tokey *et al.*, 2018).

Sagnier et al. (Sagnier et al., 2020) have propose a model to evaluate VR QoE that aggregates cybersickness, usability and acceptability. However, due to the design and specificities of the VR environment we used (very low movements and interactions), those parameters didn't appear relevant in our context. Users were sitting on a chair, with little interactions with the environments compared to previous literature which was concentrating on one user at a time. Overall subjects had very limited time for answering questionnaires as they were administered on top of real activities, not in-lab controlled experiments. The User eXperience in Immersive Virtual Environment Model (UXIVE) (Tcha-Tokey et al., 2018) has recently emerged and achieved recent progress for learning purposes. However, results show that englobing UX in VR and comprehend confounding variables is still an ongoing issue. Therefore, here we concentrate on specific QoE assessment for VR using 4 variables: Presence, Flow, Visual Discomfort and UX and try to have broader User eXperience components differently than previous works (Sagnier et al., 2020).

1.3. Experimental results of QoE in VR learning

1.3.1. Experimental results of Presence in VR

Schroeder *et al.* compare Presence reported by 75 subjects and the learning (retention) of engine assembly steps deployed within three conditions: PC or HMD (Oculus Rift DK2) with or without gestures (Schroeder *et al.*, 2017). Their results lead them to conclude that Presence is not predictive of VR learning. Nevertheless, Selzer *et al.* compare 3 groups: PC, Low-End HMD (VR-Box + Motorola Moto G5), High-End HMD (Oculus Rift CV1) with 42 subjects learning geography and fauna of Wetland, Argentina (Selzer *et al.*, 2019). Selzer *et al.* show that Presence is related to better VR learning and a learning difference between Low-End HMD and High-End HMD. Subjects report higher cybersickness with Low-End HMD but it does not negatively impact learning. Yet, Weech *et al.* show that cybersickness impacts negatively Presence: the more cybersickness, the less Presence (Weech *et al.*, 2019). Gorisse *et al.* compared 3 different avatars types with 34 males (Gorisse *et al.*, 2019). They conclude that when subjects embody an avatar with a representation of their own face (photorealistic): they are rating a higher self-Presence compared to a robot avatar and a complete suit. In summary, there is no consensus on rather Presence is influencing learning in VR. Yet, high Presence is associated with a high QoE. Therefore, it is necessary to measure it in different learning contexts to comprehend learners' subjective experience.

1.3.2. Experimental results of Flow in VR

Chu *et al.* show that 34 participants declare high Flow in VR and that learning Special Relativity Theory is efficient (Chu *et al.*, 2019). When the same content (sport) is displayed in VR and on a computer screen, the VR condition drives to a higher Flow (Kim & Ko, 2019). Pirker *et al.* compare the Flow between a physics lab displayed on HTC-Vive and Samsung Gear VR with 17 participants (Pirker *et al.*, 2018). Their results show that Flow is lower with the Samsung Gear VR due to its low resolution. Kwon shows that Flow is equivalent in a VR learning environment whether it provides authentic interactions or not (Kwon, 2019). The higher the interactivity, the higher the Flow (Zhang *et al.*, 2019). A high Flow has a positive effect on working memory (Gabana *et al.*, 2017). Flow seems correlated to creativity level in VR (X. Yang *et al.*, 2019). In summary, high Flow appears to be a condition for a high QoE while learning in VR. Compared to other apparatus, VR drives to higher Flow. Yet, Flow has been little investigated in collaborative implementations of VR.

1.3.3.Experimental results of Visual Discomfort in VR

According to Souchet *et al.*, Visual Discomfort does not seem to impact the quality of the learning curves in VR (Souchet *et al.*, 2018). Yet, Visual Discomfort is still an issue with HMDs (Guo *et al.*, 2019, 2017; Mohamed Elias *et al.*, 2019). Cybersickness and Presence appear to be negatively corelated (Weech *et al.*, 2019). Moro *et al.* expose 20 participants to two different HMDs: Samsung Gear VR or Oculus CV1 and compare the learning performance of the spine's anatomy (Moro *et al.*, 2017). The scores after exposure are equivalent for the two groups even if the Samsung Gear VR group reported higher Visual Discomfort (double vision for 40% of this group) which could have a negative impact on learning. According to Jung *et al.* as well as Terzić and Hansard, Visual Discomfort is partly due to sensory-motor cue impairments (Jung *et al.*, 2015; Terzic & Hansard, 2017). Chao *et al.* show that Visual Discomfort is time related: the longer exposure, the higher discomfort (Chao *et al.*, 2019). In summary, Visual Discomfort is one of the risks when using HMDs. Little experimental proofs support a negative influence on learning. Yet, it has a negative influence on the overall QoE. One way to lower those impairments consists in not displaying stereoscopy. Therefore, it needs to be measured in several HMD deployment scenarios: collaborative VR with bi-ocular imaging is one of them.

1.3.4.Experimental results of User Experience (UX) in VR

UX questionnaires have been used to assess user interface in VR. Kojic *et al.* show that users prefer gamified data visualization of boat speed in VR (Kojic *et al.*, 2019). In a Pedestrian paradigm, Löcken *et al.* used UX questionnaire and show that users' rate higher the interactions and cues they are the more familiar with (Löcken *et al.*, 2019). Ćwil and Bartnik used UX questionnaire to assess users' perception of railway training simulation which has been positively rated (Ćwil & Bartnik, 2019). Overall QoE is rarely assessed with collaborative VR in real classroom deployment, this is pointed out as future needed works (Jacoby *et al.*, 2019). Papachristos *et al.* indicate no difference of QoE between High-End HMD (HEH) and Low-End HMD (LEH) when learning in VR (Papachristos *et al.*, 2017). Such QoE seems affected by previous experience with the technology (Sagnier *et al.*, 2020). In summary, UX is used in VR but rarely in Collaborative setups and for learning purposes. Questionnaires are mainly used for interface validations but not for comparing deployment options. Therefore, our specific paradigm needs to be addressed regarding UX.

1.4. Research questions

Despite the emergence of models for the evaluation of VR experience (Sagnier et al., 2020; Tcha-Tokey et al., 2018), it appears that collaborative VR for learning purposes still lacks scientific contributions regarding QoE. Here, we focus on 4 components: Presence, Flow, Visual Discomfort and UX. Measuring them in the context of *in situ* deployment for real courses cases appears necessary. Such deployment is strongly related to HMDs characteristics as well as learning instructions and possibly user’s location (in the same room or distant). Thus, the questions we propose to focus on are: 1) Is QoE influenced by LEH and HEH? 2) Is QoE influenced by learning instructions? 3) Is QoE influenced by relative participant location? In addition, the general purpose is to test if the QoE approach is enough in order to evaluate users' acceptance of the VR deployment.

2. Material and Methods

2.1. Use cases

Each use case is displayed with bi-ocular imaging (without stereoscopy). None of the users are seeing their own avatar but they see the others' avatars. Lecturers in all groups embodied personalized photo realistic avatars. Table 1 summarizes the specificities of use cases implementations. We present the context and detailed scenarios hereafter.

Table 1 : Groups distribution and exposure conditions summary

	Group**1**	Group**2**	Group**3**	Group**4**
n Participants	29	41	10	8
Participants	University students	High school Students	Employees	Employees
Participants per session	8	10	20	20
Location of participants	Same room	Same room	Distant	Distant
Previous VR experience	Poor	Poor	Yes	Yes
Photo-realistic avatar	Non-related	Non-related	Personalized	Personalized
Duration of VR session	20 minutes	20 minutes	60 minutes	120 minutes
HMD	Low-End	High-End	High-End	High-End
Learning instructions	Lecture	Lecture	Lecture	Lecture
Learning material	Slides + 2D videos	3D objects + 360° videos	Slides + 2D images	Slides + 2D images

2.1.1.Process engineering in biology in engineer school (Group1)

The objective is to complement the active pedagogy developed in previous work for graduate engineers' students as part of their training in unit operations (Azouani *et al.*, 2019), risks management, bioprocess (Elm'selmi *et al.*, 2019) and industrialization. For this pedagogical sequence, in the context of process industrialization, educational engineering was based on filling operations in the pharmaceutical industry. We developed functional analysis about different components, critical points to better dose control and 5M analysis to identify the origin of potential failures affecting dose volume. See Figure 1 in the Appendix section.

Students were divided into three subgroups of 8 students in addition to the lecturer per 30-min session. The lecturer and the students were in the same room. Students were sitting in a semi-circular disposition while the lecturer was standing in front of them, also with an HMD. Participants were in a similar spatial position in the VR environment. Students embodied standing photo-realistic avatars, non-relating to their actual aspects.

The course of each session is as follows: 1) Introducing generalities about volumetric and positive displacement pumps; different types and Supplier, 2) Functional analysis of the piston-pumps filler, 3) Projection of a 2D video with the actual size of the machine and its positioning within a production unit, 4) Return of feedback on dose fluctuation and quality indicators used to avoid fluctuation with an industrial partner, 5) Q&A session.

2.1.2.Bases of particle physics in high school (Group2)

Virtual Classroom was used to complement a session of the international masterclasses on particle physics[1], using the CERN CMS case. During a regular session, high-school students follow introductory courses to particle physics in the morning, then individually sit in front of a computer to identify and sort real particle-collision events. They finish by sharing and piling up their results (together and with other classes around the world), to reach and experience the statistical methods and thresholds of particle discovery, in that case of the Higgs boson (CMS, 2012). The students grasp the real size and lay-out of the gigantic apparatus that allow particle discoveries. See Figure 2 in the Appendix section.

High-school students (and accompanying lecturers) were extracted from the exercise in groups of 6 to join for 20-30 minutes their virtual lecturer in the same physical room, as well as in the virtual classroom. Students were sitting in a semi-circular disposition and were equipped with the HMD. The lecturer was standing in front of them, also with an HMD. Participants were in a similar spatial position in the VR environment. Students

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[1] International Masterclasses - Hands on Particle Physics (n.d.) [Online]. Last accessed: 01/10/2019. Retrieved from https://physicsmasterclasses.org/

embodied standing photo realistic avatars, non-relating to their actual aspects. Note that the high school teachers, researchers and journalists joined the groups.

The lecturer guided them through various particle-physics experiments and footages. The course of each session is as follows: 1) a 3D sketch of the CMS apparatus (CMS, 2008) was built and manipulated by the lecturer, who could explain the different layers of detector, 2) the students were then virtually teleported inside the real-size model where they could see a real-size event display of a 15-meter high Higgs decaying boson, 3) 3D images and movies from CERN and the Kamiokande 40-meter high underground cavern in Japan (Super-Kamiokande, 2003).

2.1.3. Management techniques and behavior in a multinational company (Group3 and Group4)

Virtual Classroom was used to complement a training program for managers from an international company. The main objective is to promote the participants' leadership skills. The program included 80 persons worldwide and was planned over 8 months. It was launched with a physical meeting, allowing the participants to meet each other. The program was then implemented, alternating several phases and using various means of communication. Virtual reality was used for the 4 Virtual Learning Modules (VLM). A VLM runs over a one-month period, starting with an "Insight" session (2 hours) and ending with a "Reflect" session (1 hour), to wrap up the VLM. Participants were requested to conduct several activities in between, not using VR. See Figure 3 in the Appendix section. For each Insight and Reflect session, several sessions were proposed to allow participants to connect more easily according to their personal agendas. Up to 20 people joined simultaneously, all embodying a personalized photo-realistic avatar, sitting around round tables. They joined the virtual environment through their own HMD, wherever they were (office, home, etc). The trainer was able to control participants' audio, allowing everyone to hear each other or isolating tables from each other for specific activities. Distant technical support was available before and during each session. The collaborative mode is expected to contribute to creating links between participants that has otherwise no direct connections. Such approach has been investigated for similar purpose with positive results (Kelly, 2019).

2.2. Apparatuses

Virtual Classroom is a platform allowing to connect (TCP and UDP protocols) up to 20 people in the same virtual environment through HMDs. Users can connect using an HMD and dedicated Client software, for the course sessions previously created and planned. The trainers and trainees are immersed in a 3D environment, represented by photo-realistic avatars. They can share different files and media (PDF, JPG (2D or 360°), PNG (2D or 360°), MP4 (2D or 360°)), interact between them and follow the lecture by the trainer who keeps total control of the session. Group1 uses Samsung Gear VR HMDs model SM-R325 with Samsung Galaxy S8 smartphones. Group2, Group3 and Group4 use Oculus Go HMDs model MH-A32.

2.3. Procedures and measures

Our purpose was to evaluate the quality of experience in situ. The participants included distant users (located worldwide), between 5 to 20 simultaneously in the same sessions and several sessions followed one another. Considering those constraints, we selected questionnaires which is an easy method to collect information. We selected robust questionnaires, previously tested with large population and statistically evaluated links between items and synthetizing numerous questionnaires. Therefore, our result can then be compared to previous studies using those questionnaires.

First, the participants assist the courses with the VR content (one of the described use cases). Second, the participants fill up a questionnaire regarding demographics and VR previous uses right after VR exposure. Third, the QoE is assessed via 4 questionnaires (Likert scales graduated from 1 to 5 and 1 to 7 for the UEQ-S):

- Presence: measured via the Multimodal Presence Scale by Makransky *et al.* consisting in 14 items (Makransky *et al.*, 2017),
- Flow: measured via the Flow Short Scale by Engeser and Rheinberg consisting in 9 items (Engeser & Rheinberg, 2008),

- Visual Discomfort: measured via the questionnaire by Zeri and Livi consisting in 11 items (Zeri & Livi, 2015),
- User Experience: measured via the Short User Experience Questionnaire (short UEQ-S) by Laugwitz *et al.* consisting in 11 items (Laugwitz *et al.*, 2008).

2.4. Participants

Participants were divided in 4 groups:

- Group1: 13 females, 15 males, mean age: 21.9 ± 0.94,
- Group2: 17 females, 24 males, mean age: 22.0 ± 9.3,
- Group3: 6 females, 4 males, mean age: 33.5 ± 2.5,
- Group4: 2 females, 6 males, mean age: 33.8 ± 2.25.

2.5. Analysis, statistics and hypotheses

Tests are carried out between groups. The significance level is tested with a confidence of $\alpha = 0.05$. Jamovi version Solid 1.0.7[2] is used for statistical tests. Shapiro-Wilk tests were performed to test the distribution for each set of data and determine the appropriate tests to perform. R version 3.6.0 is used for plots generation (R Core Team, 2013). Hypotheses are:

- **H1**: QoE (a: Presence, b: Flow, c: Visual Discomfort, d: short UEQ-S) is different between LEH and HEH.
- **H2**: QoE (a: Presence, b: Flow, c: Visual Discomfort, d: short UEQ-S) is different between learning instructions and materials (taking advantage immersive capabilities versus only reproducing real situations).
- **H3**: QoE (a: Presence, b: Flow, c: Visual Discomfort, d: short UEQ-S) is different between distant and on-campus learning.

3. Results

3.1. Presence

We observe that when Presence is tested (Friedman test) all items together between groups, difference is not statistically significant (p=0.074). However, pairwise tests on items show that Group1 is usually experiencing lower Presence than others (Group1≠Group4, **p=0.017**) and Group4 is reporting higher Presence than Group2 (Group1≠Group4, **p=0.030**). Looking at the items more in detail, we observe that Group1 is reporting lower results than Group3 for 2 self-Presence items (SELF_4, **p=0.011**; and SELF_7, **p=0.049**) and one social Presence item: SOC_7 (**p=0.024**) which measures feeling of "*interacting with other people in the virtual environment*" (Makransky *et al.*, 2017). We note that Group1, as well as Group2, did not have avatar with their own faces and were in the same room, while Group3 and Group4 own personalized avatars and were remotely located. On the other hand, Group1 use LEH while Group2, Group3 and Group4 use HEH. Then, the personalization of avatars and the relative location of participants doesn't seem to impact the Presence (self-Presence and social Presence), while the quality of the HMD used could. Therefore, H1a: "Presence is different between and HEH" is partly verified but only in the scope of self-Presence, H2a: "Presence is different between learning instructions and between learning materials" is supported. H3a: "Presence is different between distant and on-campus learning" is not supported.

3.2. Flow

We observe that when Flow is tested all items together between groups, difference is statistically significant, with Group3 reporting the highest score and Group1 the lowest. Pairwise tests show that Group1 is usually experiencing lower Flow than others. See Table 2. The FSS_4 item which measure concentration is particularly at stake as Group1 rated it low with a median at 1.5 while other groups rated it with a median at 4. FSS_8 relating to knowing what the user must do all along was rated higher than other groups by Group2.

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[2] The jamovi project (2019). jamovi (Version 1.0.7) [Computer Software]. Retrieved from https://www.jamovi.org

We note that Group2 is using learning material specifically designed for VR, such as 3D interactive models and 360° videos, while Group1, Group3 and Group4 are using 2D slideshows, pictures and videos. Then the nature of the learning material seams to impact the Flow.

Table 2 : Flow comparison with Friedman test

Item	Significant	p-value	Pairwise Significant	Which groups ≠	p-values Pairwise
FSS_1	no	0.258	no		
FSS_2	no	0.768	no		
FSS_3	no	0.114	**yes**	Group1≠Group2	**0.016**
FSS_4	**yes**	**0.002**	**yes**	Group1≠Group2	**<0.001**
				Group1≠Group3	**<0.001**
				Group1≠Group4	**<0.001**
FSS_5	no	0.267	no		
FSS_6	no	0.892	no		
FSS_7	no	0.464	no		
FSS_8	no	0.093	**yes**	Group1≠Group3	**0.037**
				Group1≠Group4	**0.023**
FSS_9	**yes**	**0.005**	**yes**	Group1≠Group2	**0.001**
				Group2≠Group3	**<0.001**
				Group2≠Group4	**<0.001**
All together	**yes**	**< 0.001**	**yes**	Group1≠Group2	**<0.001**
				Group1≠Group3	**<0.001**
				Group1≠Group4	**0.004**

Therefore, H1b: "Flow is different between LEH and HEH" is supported: Flow is particularly affected on "concentration" and "knowing what to do". H2b: "Flow is different between learning instructions and between learning materials" is supported: learning material taking advantage of VR capabilities (360° video and 3D interactive objects) are associated with higher Flow, while 2D contents are associated with lower Flow. H3b: "Flow is not different between distant and on-campus learning" is supported if we compare Group2 to Group3 and 4 as we previously see that the HMD quality influences QoE.

3.3. Visual discomfort

All items analyzed together, we observe that the Visual Discomfort is different among groups, Group4 and Group1 experiencing the highest level of discomfort. Pairwise tests show that Group1 is usually experiencing higher Visual Discomfort. Looking at items individually, we observe that Group 4 reported a higher Visual Discomfort than others for Irritation, Dryness and Blur (See Table 3). We note that Group4 performed very long session in VR (2 hours), as compared to other groups (20 to 60 minutes), which could explain the high Visual Discomfort, despite the use of HEH. In contrast, Group1 had a short VR experience (20 minutes) but used LEH. Then, it seems that a long VR experience (more than 60 minutes) or a LEH can induce Visual Discomfort.

Table 3: Visual Discomfort comparison with Friedman test

Item	Significant	p-value	Pairwise Significant	Which groups ≠	p-values Pairwise
Burning	no	0.324	no		
Irritation	no	0.105	**yes**	Group2≠Group4	**0.017**
Tears	no	0.196	no		
Ache	no	0.144	**yes**	Group1≠Group2	**0.045**
Dryness	no	0.061	**yes**	Group1≠Group4	**0.024**
				Group2≠Group4	**0.018**
Strain	no	0.114	**yes**	Group1≠Group2	**0.027**
Blur	no	0.065	**yes**	Group1≠Group2	**0.012**

				Group1≠Group3	**0.040**
Double vision	no	0.153	**yes**	Group2≠Group4	**0.026**
Headache	no	0.122	**yes**	Group1≠Group3	**0.020**
Dizziness	no	0.601	no		
Nausea	no	0.577	no		
All together	**yes**	**< 0.001**	**yes**	Group1≠Group2	**<0.001**
				Group1≠Group3	**<0.001**
				Group2≠Group4	**<0.001**
				Group3≠Group4	**0.005**

Therefore, H1c: "Visual Discomfort is different between LEH and HEH" is supported but since Visual Discomfort is rated as high by Group1 and Group4, the duration of experience seems to have also a major influence in our conditions. H2c: "Visual Discomfort is different between learning instructions and materials" is supported as Group2 has rated Visual Discomfort lower than the other two groups that also used the Oculus GO but with different learning materials. It seems that the learning material had more impact on Visual Discomfort than the quality of HMDs. H3c: "Visual Discomfort is different between distant and on-campus learning" is not supported as Group1 (same location) and Group4 (distant location) reported higher Visual Discomfort than Group2 (same location) and Group3 (distant location).

3.4. User Experience

Group2 rated the Higher compared to other groups. Group1 overall rated the lower. As show in Table 4 both pragmatic and hedonic qualities are rated higher by Group2 followed by Group3 then Group2 and finally Group1. In summary, we observe that when User Experience is tested all items together between groups, difference is statistically significant. Pairwise tests show that Group4 group is usually experiencing higher User Experience than others. See Figure 4 in the Appendix section.

Table 4 : Short User Experience Questionnaire comparison with Friedman test

Item	Significant	p-value	Pairwise Significant	Which groups ≠	p-values Pairwise
UEQ-S_1	**yes**	**0.013**	**yes**	Group1≠Group2	**0.002**
				Group1≠Group3	**0.003**
				Group1≠Group4	**0.009**
UEQ-S_2	**yes**	**0.023**	**yes**	Group1≠Group2	**0.002**
				Group2≠Group3	**0.046**
				Group3≠Group4	**0.009**
UEQ-S_3	**yes**	**0.002**	**yes**	Group1≠Group2	**<0.001**
				Group2≠Group3	**0.003**
				Group2≠Group4	**0.002**
UEQ-S_4	no	0.063	**yes**	Group1≠Group2	**0.007**
UEQ-S_5	**yes**	**0.005**	**yes**	Group1≠Group2	**<0.001**
				Group1≠Group3	**0.004**
				Group1≠Group4	**0.004**
UEQ-S_6	no	0.139	**yes**	Group1≠Group2	**0.026**
UEQ-S_7	no	0.816	no		
UEQ-S_8	no	0.728	no		
All together	**yes**	**< 0.001**	**yes**	Group1≠Group2	**<0.001**
				Group1≠Group4	**0.007**
				Group2≠Group3	**0.005**
				Group2≠Group4	**0.038**

4. Discussion

4.1. This experiment

Our results show that Presence is globally the same within each experimental condition which is in line with previous work (Selzer *et al.*, 2019). None of the participants within the 4 conditions were seeing their own avatar. Selzer *et al.* show that LEH drives to similar Presence than High-End HMD. Weech *et al.* show that cybersickness impacts negatively Presence (Weech *et al.*, 2019). In our case, we measure Visual Discomfort. Yet, Visual Discomfort is not the higher with LEH. Therefore, in our conditions, Visual Discomfort that can be associated with some symptoms of cybersickness, did not drive to lower Presence. Gorisse *et al.* show that Presence can vary with users' avatar (Gorisse *et al.*, 2019). Our results for specific items relating to self-Presence (assessing body ownership) are in line with their work, even if they are based on different variables. This is somehow surprising as participants could not see their own avatar. We can thus hypothesis that their ability to be recognized or not as themselves by other users has contributed to the Presence. Interestingly, since Group3 and 4 were remote users while Group1 and 2 were in the same physical room, we could have expected Presence differences, especially variations over social Presence. Only one item SOC_7 relating to social Presence is different among two groups and relative participant location doesn't explain this difference. Learning material could account for such results in our experimental conditions: Group1 had only 2D learning material (videos, pictures or PDF) projected while Group2 had different media such as 3D objects and 360° videos. In summary, Social Presence seems more impacted by the HMD quality and the learning material, rather than if users are in the same physical room or not.

Total Flow is different between groups. Group1 is always different from the others. Our results with Flow show that HEH and learning material with higher interactivity drives to higher Flow which is in line with previous works (Kim & Ko, 2019; Pirker *et al.*, 2018; Zhang *et al.*, 2019).

Previous work showed that Visual Discomfort is still occurring with HMDs (Guo *et al.*, 2019, 2017; Mohamed Elias *et al.*, 2019). We note a different (higher) Visual Discomfort between LEH and HEH in line with previous works (Moro *et al.*, 2017). Yet, Group4 reported an equivalent or higher Visual Discomfort than Group1 which can be explained by time of exposure (20 minutes versus 120 minutes in our experiment) as showed by previous works (Chao *et al.*, 2019). Previous work are pointing stereoscopy as causal in Visual Discomfort (Jung *et al.*, 2015; Terzic & Hansard, 2017) . Yet, none of our conditions were displaying stereoscopy. This is a concern as even without displaying stereoscopy, users report Visual Discomfort.

Unlike previous work (Löcken *et al.*, 2019), our participants exposed to learning instructions and materials they are less familiar with (naming 3D objects rather than slides) during lectures have rated UX higher. However, Löcken *et al.* measured UX in a quite different learning paradigm compared to us. In line with previous work (Ćwil & Bartnik, 2019), participants rated VR overall positively for learning purposes. As asked by previous work (Jacoby *et al.*, 2019), we test collaborative VR in real conditions and our results show a positive acceptance by users. Unlike Papachristos *et al.* our results show a difference of QoE between HEH and LEH when learning in VR (Papachristos *et al.*, 2017). Here again, our experimental paradigm is quite different compared to theirs. UEQ-S has not been extensively used in previous works assessing different VR deployment options. Therefore, we have limited comparison with other experiments. Yet, using questionnaires built for other purposes than VR can allow comparison between apparatus for future works. As shown by previous work, previous experience with the technology (Sagnier *et al.*, 2020) can influence our results which could also explain differences with previous works.

4.2. Limitations

The 4 experimental conditions were very different but the learning situations that we tested are in line with real practices. Trainers could be tempted into bringing the same learning materials and instructions in VR as in "the real classroom." But our results show that taking advantage of VR possibilities (by showing contents that are usually too hard to show to learners, specific media) is what influences positively users' QoE. This article participates to characterize learning instructions (what is asked to learners) as pointed out as necessary by previous works (Jensen & Konradsen, 2018). Therefore, even though our ecological set up was less controlled than some previous works, we argue that it has validity from its' ability to depict real uses of day to day collaborative VR as it has been tested *in situ* as pointed out as necessary by previous works (Nersesian *et al.*, 2019). Yet, limitations due to statistical interpretation

(Friedman test) should be considered as most differences are not significant when each groups are compared but only when one group is compared to another (Pereira et al., 2015). Untested confounding variables (age, previous VR experience, gender) should also be considered as limits to the interpretations we provide in this paper.

The HMDs market is evolving fast. Therefore, the HMDs used in the described conditions have been used by the general public since more than a year when this article is about to be published. Even though technical characteristics are improving, institutions that invested in HMDs more than a year ago did not replace their current models. Therefore, the HMDs we used are representative of part of the early adopters of VR and our results participate into evaluating learners' acceptance of VR as pointed out as necessary by previous works (Velev & Zlateva, 2017). As mentioned above, we analysed QoE of collaborative VR experiences for learning purpose, but we did not measure learning outcomes. Therefore, our results should be taken at the light of previous works showing that a high QoE is not always an indicator of efficient learning (Schroeder *et al.*, 2017; Souchet *et al.*, 2018). Overall subjects had very limited time for answering questionnaires as they were administered on top of real activities, not in-lab controlled experiments. This show the difficulty at collecting data, even though questionnaires, *in situ* compared to in lab conditions.

4.3. Collaborative Virtual Reality and Future works

Not tested directly has hypothesis, one purpose was to evaluate such questionnaire based QoE indicators in order to compare users' acceptance of the VR deployment of the Virtual Classroom solution. The 4 questionnaires we used do seem to encompass part of users' QoE. Existing models could also be used for such experimental conditions (Sagnier et al., 2020; Tcha-Tokey et al., 2018) although due to logistical constraint we had to concentrate on 4 questionnaires here. Measuring Presence, Flow, Visual Discomfort and UX is a simple, fast, and first step at measuring VR learners experience in situ and not in controlled laboratory environment. Therefore, it should be considered for VR experience creators as a minimum way to proof base the quality of deployment. This should be combined with learning outcome evaluation when learning is a purpose of the experience.

The promising result of this study is that users that were distant (not in the same physical room) did not rate the QoE lower than other groups, the tendency show even better results as expected by previous work (Hoppe *et al.*, 2018). Another relevant use case we identified implies the use of VR-specific content, such as 360° videos and 3D models. Therefore, for the very type of experience that has been tested (lecture with a lecturer in front of learners) is efficient from the users' QoE perspective even when participants are distant. These observations from our experiment goes in line with previous' work prediction (Marky *et al.*, 2019).

Future works will concentrate on testing other HMDs models and learning material in collaborative VR, including learning outcome evaluation. Variation of users' representation (avatar) and level of interactions among users' as well as with the virtual environment should be tested in order to be implemented if suitable for learning purposes. Finally, monitoring learner’s psycho-physiological state as a deployment validation through measurement of biomarkers should be considered to enrich the experience evaluation. To this aim, Eye tracking appears as a promising tool, as it is now integrated into general market HMDs.

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Appendix

Figure 1: Group1, Photo of some users (left) and Screenshot in VR from a learner's viewpoint (right)

Figure 2: Group2, Photo of some users (left) and Screenshot in VR from a learner's viewpoint (right)

Figure 3: Group3 and 4, Screenshot from the lecturer's viewpoint

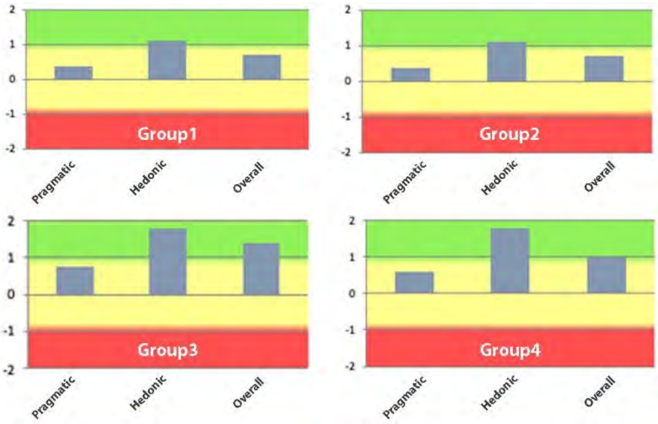

Figure 4 : Plots from Short UEQ-S: pragmatic, hedonic and ovrall quality

Effect of Physical Activity on VR Experience: An Experimental Study

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Keywords: Virtual reality, player experience, physical activity, presence, engagement

Abstract

The purpose of this study is to measure the effect of using the body activities on user experience, in a VR game. For measuring player experience with a subjective approach, we evaluated cybersickness, game user experience, presence and physical activity enjoyment via several standardized questionnaires.

The "Dragon Ride VR" game was developed with two different control scheme versions: One controlled with a standard game controller to be played in a less physically active seated position, while the other is controlled with a pair of magic wands to be played on a sports equipment hanged on the ceiling which lets the user to be more physically active.

Our results suggest that higher physical activity provides a higher sense of presence in several dimensions. On the other hand, there is a trade-off between presence and playability of the game, due to the physical effort required to control the game and cybersickness.

1. Introduction

Along with the widespread use of virtual reality technologies in the entertainment industry, - partly, the gaming industry-, users have a novel way of interacting with VEs (virtual environments) with higher physical movement possibilities. While playing a game on a computer screen, the player's movements were quite limited due to the position of the screen. Use of VR (virtual reality) HMD's (head mounted displays) created a space where the players can move independently from the screen location. For this reason, it is predicted that using VR technology as a physical activity routine has high potential and it is also a new area of research and development (Pasco, 2013) while it also provides a higher level of game user experience (Christensen, Mathiesen, Poulsen, Ustrup, & Kraus, 2018; Shelstad, Smith, & Chaparro, 2017; C. Yildirim, Carroll, Hufnal, Johnson, & Pericles, 2018).

In terms of physical activity, research on virtual reality combine efforts to help sports training and improve the athlete's performance (Appelbaum & Erickson, 2018). In addition, research on embodiment reveals that sensorimotor feedback effects the users experience in VEs (Bailey, Bailenson, & Casasanto, 2016). However, the effect of the physical activity level on user experience in virtual reality has not been widely explored.

This study explores the effect of users' physical activity on virtual reality user experience by exploring its effects on presence, game user experience and cybersickness.

2. Related Studies

2.1. Physical activity in VR

Designers of VEs assumed that a VR system should provide mechanisms to navigate and interact with the virtual world in a similar way that people interact with the real world. As a result, many locomotion devices and methods (Al Zayer, MacNeilage, & Folmer, 2018; Boletsis, 2017) emerged which simulate the real world walking in a physical manner. Research on these locomotion systems revealed that walking leads to a higher sense of presence for users either it is walking-in-place or real-walking, compared to non-physical locomotion methods (Lee, Kim, & Kim, 2017; Martin Usoh & Steed, 1995), better comfort in terms of cybersickness (Chance, Gaunet, Beall, & Loomis, 1998; Lee et al., 2017) and improved the user performance (Chance et al., 1998; Ruddle & Lessels, 2009). Body movement, not limited to walking, have been reported to increase the engagement of players as well as presence (Bianchi-Berthouze, 2013; Ermi & Mäyrä, 2005; Slater, Steed, McCarthy, & Maringelli, 1998). Studies related with the concept of embodiment also point out that sense of self-location in virtual environments can be enhanced through vestibular and tactile information along with the origin of visual perspective (Kilteni, Groten, & Slater, 2012), although a visual representation of users' body as an avatar in the VE is thought to be a requirement for embodiment.

2.2. VR user experience and measurement methods

The user-oriented studies focus on several aspects of VR. Although presence is integral part for successful VR, VR experience is not limited to it. Cybersickness is also explored as a negative aspect of VR experienced by users. In addition, the VR applications should be evaluated according to their purpose of use; such as a training VE should be explored for its contribution to learning while a game should be explored for its ludic properties.

Presence, simply defined as "sense of being there" within the context of VR, is the perceptual illusion of being in a computer-mediated environment. While cognitive system of the user slowly concludes that the experience is an illusion, the perceptual system was automatically identifying the objects and events leading to users' reactions to the changes in the environment (Slater, 2018).

Several assessment tools have been offered for measuring mediated presence (Laarni et al., 2015). We decided to use a MEC-SPQ (Measurement, Effects, Conditions-Spatial Presence Questionnaire) (Wirth et al., 2007) as it was reported to be more sensitive to different applications explored via HMDs (Yildirim, Bostan, & Berkman, 2019), compared to other multi-dimensional questionnaires for subjective evaluation of presence. MEC-SPQ based on a two level conceptual model. IT includes process dimensions which evaluate the users' subjective responses regarding to the experienced media and trait-like constructs that query users' aspects. Each of its 7 dimensions can be evaluated via 4, 6 or 8 item questionnaires, through a 5-point Likert scale.

Cybersickness, which is also referred as visually induced motion sickness, is an adverse effect of VR, most commonly explained via theories regarding to sensory mismatch or postural instability (Rebenitsch & Owen, 2016). Sensory mismatch is mainly due to the discordance between the visual and the vestibular information, related with tracking, vection, and navigation in VR. Postural instability points out the situation that user is unable to maintain the posture necessary given the stimuli from the outside environment, such as orientation cues and position during immersion. In order to assess cybersickness, the Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilienthal, 1993) is preferred for being sensitive to different VE's (Sevinc & Berkman, 2020), although it is controversial that it is the most appropriate measure of cybersickness. SSQ results are reported as a Total Severity score as well as symptoms could be evaluated to reflect scores for Nausea, Oculomotor and Disorientation.

Game user experience is a multidimensional construct in which "engagement, immersion, presence, and flow are key areas" and the Game User Experience Satisfaction Scale (GUESS) (Phan, Keebler, & Chaparro, 2016) is a psychometrically evaluated measure of gaming experience developed considering former measurement tools that point out the given key areas. GUESS provides 9 dimensions but its developers suggest that Social Connectivity and Narratives dimensions can be excluded in application if the evaluated game does not provide any social connection between players or any story aspects. Usability/Playability refers to the degree that game can be played without any obstructions from the user interface or controls. Play Engrossment is the "degree to which the game can hold the player's attention and interest" while Enjoyment is amount of pleasure and delight. Creative Freedom refers to the ability of the game to foster players' creativity and curiosity as well as letting player to express his individuality. Personal Gratification regards to "motivational aspects that promote the player's sense of accomplishment". Audio Aesthetics query the auditory aspects enriching the gaming experience and Visual Aesthetics examine the appeal of game graphics. These subscales have different number of items that use a 7-point Likert scale.

Several studies on exergaming (e.g. Bock et al., 2015; Malone et al., 2019) evaluate the enjoyment of players in physical activity via Physical Activity Enjoyment Scale (PACES) (Kendzierski & DeCarlo, 1991) which is also employed in our study as the long version.

3. Methodology

3.1. Stimulus : The Dragon Ride VR Game

We developed a ludic VR experience, in which the user rides a dragon which can exhale fire to attack the hot air balloons floating around (Figure 2). The game was developed with Unreal Engine 4 version 4.20. It runs on several consumer VR devices but HTC Vive was chosen for experiments since its movement range is wider than other VR sets. Two different input methods were implemented as game control mechanics. Therefore, we produced two applications, which include the very same content but interacted with different methods. The physically inactive version of the game is developed in a way that it can only be played with a standard gamepad, preferably in a seated position (see Figure 1, left). For the physically active version, we employed the HTC Vive VR controllers, which are a pair of magic wands with several buttons on them (see Figure 1, right). However, we designed a control scheme that is based on the positions of the wands rather than buttons, to provide a gameplay based highly on body movements of the user. Although the game can be played in a seated position or standing, we expected the player to play with the help of an exercise apparatus that is attached to the ceiling, namely 4D Pro (www.4dpro.de). This equipment is basically a swing, with a soft fabric seat hanged to the ceiling with elastic straps. This lets the players to sit on the swing or stand leaning on the swing, and bounce up and down with their feet. The magic wands were also attached to the ceiling with elastic straps. Either in static seated position with game controller or bouncing position with magic wands, participants will play the same game; only difference is that each game will have its own input methods and which demand different physical activities during the gameplay.

Figure 1: Seated joystick contolled condition (on the left) and hanged bouncing condition (on the right)

Riding a dragon, player's goal in the game is to direct the dragon towards the hot air balloons and blast all of the hot air balloons and zeppelins they see with the fire of the dragon. Sitting near the dragon's neck, users can see its full body and the saddle on it, but there is no visual representation of their avatar.

For seated version, players need to use the joystick on the game controller to control the flight direction of dragon, which is naturally mapped to the joystick as back and forth for controlling the dragon's height and sideward to control its direction. Left trigger button on gamepad controls the fire of the dragon.

Figure 2: The Dragon Ride VR gameplay screenshot

For physically active version, controls are a little bit more complicated. Users need to raise both controllers up above the position of their heads (VR headset) to direct the dragon upwards and below their heads for going downwards, adjusting the height of the dragon. The sideward position control depends on the comparison of the position of magic wands. When the magic wand on user's right hand is in a position lower than the other, the dragon turns rightwards; and vice versa. The dragon fire is controlled by the trigger on the left wand.

3.2. Participants

The participant group was formed from young adults between the ages of 18-37, equally distributed as males and females. The number of participants is 40. 30 of them had prior experience with HMD based VR applications for 5 times or less, while other had no experience.

3.3. Procedure

Equal number of participants were randomly assigned to the seated gamepad controlled game sessions and magic wand controlled physically active game sessions of the game, which were counter balanced in order. They were asked to destroy all the zeppelins and balloons as soon as they could and their total time is recorded as an indicator of their performance. Through a within-subjects design, participants played the other version of the game after having a break of 15 minutes or more if they want to and rated their experience again.

After each session, participants rated their experience through a questionnaire which contains MEC-SPQ to measure presence, GUESS to measure game user experience, and PACES to measure enjoyment of physical activity as well as SSQ to measure cybersickness.

MEC-SPQ has 7 subscales originally. One of those subscales, the "Visual Spatial Imagery" measure a trait-like construct that is concerned with the participants' general spatial abilities rather than their subjective experience regarding to their immersion into a specific VE. For this reason, the "Visual Spatial Imagery" dimension is not employed in our study. Another subscale that is addressing to an enduring personality factor, the "Domain Specific Interest" is also a trait-like construct and it is not expected to be affected by our experimental conditions since the same dragon-themed game is experienced by users. The other dimensions of MEC-SPQ employed in the study were "attention allocation, spatial situation model, spatial presence: self-location, spatial presence: possible actions" which are factors related to the process of immersion and dimensions referring to states as "higher cognitive involvement and suspension of disbelief". We used the 8-item per subscale version of MEC-SPQ to enhance its sensitivity.

Of the 9 original dimensions of GUESS, the "Social Connectivity" dimension is excluded since the game does not provide any multi-player gameplay. The "Narratives" dimension was also excluded since the narrative of the game does not differ between the two versions. On the other hand, the metrics that assess the audio and visual aesthetics are employed to determine whether the judgement of players on these dimensions would be affected by the physicality of the gameplay, although these components are identical in both versions of the game.

The SSQ was employed in the study since cybersickness is an adverse effect of being immersed into a VE and the sensory conflict that may cause cybersickness can differ due to the body movements of users. Cybersickness is assessed with three different types of symptoms regarding to motion sickness: Nausea, Oculomotor symptoms and Disorientation, along with a Total Severity (TS) score based on all symptoms. PACES is employed in order to assess the difference between the level of enjoyment due to physical activity.

4. Result and Discussion

A series of paired samples t-tests were executed to identify differences in the virtual reality user experience between the seated condition gamepad controlled interaction and hanged bouncing position with magic wand controls. Results suggest that there are significant differences between the conditions, observed on several measures employed in the study

4.1. Player Performance Observed

Users were asked to eliminate all hot air balloons and zeppelins in the VE and they successfully accomplished the task, but the time on task were significantly different for seated (M=4.48 minutes, SD=1.5) and hanged bouncing (M=5.5 minutes, SD=2.2) conditions, t(39) = 3.39, p < .005.

In our opinion, the difference is not due to the physical activity expected from the users in hanged bouncing conditions, since many of the participants we observed tended to sit on the swing and keep their balance and facing direction with their feet instead of jumping and turning. However, the control scheme provided for magic wands may have been complicated for the participants, while they had limited prior experiences with magic wand controllers. In addition, some of them criticized that the mapping of upwards and downwards controls should be in the opposite way: Move wands downwards to go upwards, and vice versa. We think that users would perform better in accomplishing the task if they have the opportunity of practicing game controls via magic wands.

4.2. Game User Experience Satisfaction Scale

There was a significant difference on Usability/Playability dimension of GUESS (t(39)=-2.77, p<.01), revealing that users' subjective assessment for the seated game controller version of the game (M=5.78, SD=1.12) was higher than the hanged bouncing magic wand controlled version (M=5.44, SD=1.23).

Users rated the usability/playability of the physically active version with a slightly lower mean score due to a similar reason that they spent longer time in order to accomplish the given task: the complex control scheme with the magic wands, rather than for the gameplay demanding to be more physically active.

Results which are given on Table 1, did not reveal a significant difference between the conditions on other dimensions of GUESS. Mean scores are same or very similar in magnitude.

Users rated the both gameplays quite closely in terms of creative freedom, enjoyment, personal gratification and player engrossment, which are defining their subjective experience of playing the game. The dimensions related to game assets' production quality, visual and audio aesthetics dimensions are rated almost with the same mean score.

4.3. Subjective Presence via MEC-SPQ

We observed a significant difference on the Spatial Presence related dimensions of MEC-SPQ: Self-Location and Possible Actions. The effect of different physical conditions was significant for being higher for the magic wand controlled hanged bouncing gameplay condition (M=3.89, SD=.96) compared to seated gamepad controlled (M=3.58, SD=.97) condition, t(39)=3.05, p<.005. The Possible Actions also yielded a higher score in the same way, t(39)=3,37, p<.005; hanged bouncing (M=3.69, SD=.97) is higher than seated (M=3.34, SD=.95).

In addition, the "Involvement" items revealed a significantly higher score for hanged bouncing condition (M=3.31, SD=.99) compared to seated condition (M=3.02, SD=.85), t(39)=2.54,p<.05.

Results reveal that the availability of embodied movements increased the users' "sense of being there" in the virtual environment, although they had difficulties in controlling the game in more physically active version of the game. Participants felt they could interact with the VE more freely when they are physically more active, although the controls yield to same movements in both versions of the game. The increase in sense of spatial presence also leads to a higher level of involvement, i.e. more intense thoughts about the game content.

The hanged bouncing mechanism enhanced the feeling of presence of when riding a dragon, although none of the users had any prior similar real-world experience, obviously not only riding a dragon but also any type of free flight.

GUESS	Hanged		Seated			
	M	SD	M	SD	M Diff	
Usability / Playability	5.44	1.23	5.78	1.12	-0.34	t(39)=-0.09, p=0.01
Creative Freedom	4.64	1.66	4.50	1.47	0.14	t(39)=0.43, p=0.33
Enjoyment	4.92	1.02	4.87	0.89	0.05	t(39)=0.28, p=0.68
Personal Gratification	5.44	1.10	5.33	0.98	0.11	t(39)=0.39, p=0.41
Player Engrossment	4.94	1.39	5.07	1.10	-0.13	t(39)=0.19, p=0.4
Audio Aesthetics	5.15	1.50	5.15	1.42	0.00	t(38)=0.29, p=0.98
Visual Aesthetics	4.75	1.75	4.78	1.65	-0.03	t(39)=0.25, p=0.81
MEC-SPQ	Hanged		Seated			
	M	SD	M	SD	M Diff	
Self Location	3.89	0.96	3.58	0.97	0.31	t(39)=0.51, p=0
Possible Actions	3.69	0.97	3.34	0.95	0.35	t(39)=0.56, p=0
Involvement	3.31	0.99	3.02	0.85	0.30	t(39)=0.53, p=0.02
Attention Allocation	4.32	0.76	4.33	0.71	-0.02	t(39)=0.18, p=0.87
Spatial Situation Model	3.83	0.94	3.87	0.84	-0.05	t(39)=0.13, p=0.6
Suspension of Disbelief	3.04	0.81	3.12	0.75	-0.08	t(39)=0.11, p=0.41
SSQ	Hanged		Seated			
	M	SD	M	SD	M Diff	
Total Score	84.4	24.46	76.8	16.33	7.67	t(39)=14.77, p=0.04
Oculomotor	77.7	25.10	69.5	18.79	8.15	t(39)=15.88, p=0.04
Disorientation	131.9	39.50	126.3	31.74	5.57	t(39)=18.35, p=0.38
Nausea	96.8	32.01	87.3	23.12	9.54	t(39)=19.83, p=0.07
PACES	Hanged		Seated			
	M	SD	M	SD	M Diff	
	3.74	0.40	3.81	0.32	-0.07	t(39)=0.07, p=0.33

Table 1: Standardized questionnaire mean scores comparison for their dimensions employed in the study.

Other dimensions of MEC-SPQ employed in the study did not reveal a significant difference on their mean scores given in Table 1, as the differences between mean values are to close.

Participants declare that they had similarly focused their attentions to both versions of the game, although the controls were more complicated in the physically active version. The environment was completely identical in both versions. Thus they formed a similar spatial model in both conditions as well as the “Suspension of Disbelief” dimension results, which were also very similar. This dimension querying the realism and consistency of the virtual environment.

4.4. Cybersickness as a negative experience via SSQ

Participants provided a significantly higher SSQ TS score (t(39)=2.18, p<.05) for hanged bouncing condition (M=84.4, SD=24.5) compared to seated condition (M=76.8, SD=16.3).

The scores for different symptom factors were also higher for hanged bouncing condition as seen on Table 1, but significant only for Oculomotor symptoms, (t(39)=2.13, p<.05.

Theoretically, we expected to observe difference between scores in terms of Disorientation symptoms, since the sensory mismatch occurs between the vision system and vestibular system and the effect on vision system remains same in both conditions while the embodied movements effect the vestibular system in physically active version. Although both conditions yielded a quite severe scores of Disorientation, the mean difference was the lowest on this set of symptoms.

Some participants, who jumped and turned more than others in the physically active condition, verbally reported that they had very severe symptoms of cybersickness. Although one may think that real-world movement would prevent sensory mismatch, it should be considered that movements in our VE is controlled by the position of magic wand controllers according to position of the headset, which is not directly related with users’ body position. Thus, both sensory mismatch and postural instability approaches explain our results.

Our results suggest that physical activity triggers cybersickness, as it is also reported that complex movements in VR with physically active methods resulted with cybersickness (Suma, Finkelstein, Reid, Ulinski, & Hodges, 2009). “Vection-inducing stimuli” similar to our game “are often nauseogenic, but the relationship is complex” since some studies report positive or negative correlations between vection and cybersickness while others report no association (Weech, Kenny, & Barnett-Cowan, 2019).

4.5. Physical Activity Enjoyment via PACES

Participants overall mean scores regarding to enjoyment of the physical activity is slightly higher for the seated condition (M=3.81, SD=.32) compared to hanged/bouncing condition (M=3.74, SD=.4) but the difference is very small in magnitude and the effect is not significant, t(39)=-.99, p>.05.

Although the elastic band swing lets the users stand, jump, turn and move; many of them did not move more than it is required by the gameplay, which is limited to leaning sideward to adjust the position of magic wands. For this reason, it is not possible to say that the gameplay requires intense physical activity and our assessment of physical activity enjoyment fell short in this study

5. Conclusion

Our study provides evidence that user experience in VR can be enhanced using control schemes that requires embodied physical activities. However, intense physical control schemes increase the sense of presence in terms of self-location, possible actions and involvement in expense of usability/playability and also may yield to cybersickness.

Although the usability/playability related issues can be resolved as the users get used to the novel unfamiliar control mechanisms, cybersickness may continue to adversely affect the user experience in VR. However, several studies revealed that cybersickness symptoms also decreases as the users engage with the VR systems more frequently in a longer term (Duzmanska, Strojny, & Strojny, 2018).

Although the current use of the term “embodiment” in VR studies point out the visual representation of user body or body parts in virtual reality, the sense of embodiment might be occurring not only by visual acquisition of avatar representations, but also the "visual representation of kinesthesia", i.e. the movement of camera in the VE. Based on the indirect evidence that on effect of physical movements, we think that the proprioceptive information enhances users' feeling of their body in the VE, when their real-world bodies move in accordance with the visual representation of kinesthesia in the virtual world. Thus, their sense of self-location and their sense of agency in the VE is altered not only by their avatar representations and egocentric view, but also the proprioceptive senses of their real-world body that matches the visual representation of kinesthesia in the virtual world.

Although our study is not primarily designed for this purpose, it is possible to investigate the effect of proprioception on embodiment using a modified version of our Dragon Ride VR Game which includes an avatar representation of user on the dragon asset.

Our study can also be criticized for ignoring the learning conditions. Through an experimental design that lets the users to adjust with the gameplay and controls via repeated sessions may provide a clearer study of physical activity, isolated from the effects of unfamiliar interaction modes.

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Risks and benefits of Artificial Intelligence for humans: A literature review

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Abstract

Emerging technologies, such as virtual reality, augmented reality and Artificial Intelligence (AI), have benefits but can also present risks for humans. This article focuses on AI. AI nowadays gives rise to many applications. So, there is a rich scientific literature on the evolution and development of AI. Despite this abundant and rather techno-centred literature, little research has focused on the benefits and risks for the user, according to the point of view of the Human and Social Sciences. This article aims at summarizing recent works based on 54 articles from 2013 to 2018. This review enabled not only to take a first look at the disciplines, fields and applications that have dealt with the links between human and AI, but also to detail the benefits and risks of AI for the individual and society. This shows a minor investment in psychology on AI issues. It would seem relevant to increase the visibility of research in psychology on AI or even a reinvestment of this field by psychology. We then conclude with three future research perspectives in psychology.

1. Introduction

Used for the first time mid-20th century during a Dartmouth College summer program by John McCarthy, Marvin Minsky, Nicolas Rochester and Claude Shannon, the word 'Artificial Intelligence' (AI) covers science and technologies that make it possible to reproduce or even enhance human cognitive abilities (reasoning, calculation, perception) by the way of a computer (Ezratty, 2018). Sixty years later, much progress has been made (AI winning chess game, understanding of natural language…) thanks to collaboration between mathematicians, computer scientists and cognitive science specialists, to technological advances (new algorithms, Big Data, tenfold increase of computational power) and to the rise of machine learning (Ganascia, 2017). In this way, AI differs from algorithms that do not evolve and are not based on a quantity of data. While AI has many applications today in fields as diverse as education, health, energy and transport (Jordan & Mitchell, 2015; Ezratty, 2018; Villani, 2018), it remains an emerging technology as defined by Kjeldskov (2003). In that regard and in the same way as other technologies like ICT - Information & Communication Technology (Medzo-M'engone, Bobillier-Chaumon, & Préau, 2018), virtual and augmented realities (Santos Silva, Mol, & Ishitani, 2019) or robots (Gaudiello & Zibetti, 2013; Dinet & Vivian, 2015), it has limits influencing its appropriation, *i.e.* how user invests in these technologies and to what extent it is in line with his values, so he wants to use it (Barcellina & Bastien, 2010). These limits include benefits and risks to the user. However, while technocentric literature is abundant, there are – to our knowledge – only few scientific articles or papers dealing explicitly with AI from an anthropocentric perspective.

The objective of this article is to propose a literature review on benefit and risk of AI for humans. The rest of the article is organized as follows. The next section presents the methodology we used to search, filter and analyze the 54 texts on which our review is based. Then, we present results by assessing status of specialities, fields and applications that have studied connection between humans and AI, and by bringing out benefit and risk for individuals or society. In conclusion, we will sum up the contributions and limitations of our literature review before raising possibilities of research in the human and social science field.

2. Methodology

In order to achieve this state-of-the-art review, we used two databases: PsycINFO and ScienceDirect, to access an international perspective of research. We use the following set of keywords: ‘(Title (artificial intelligence) OR Keywords (artificial intelligence) OR Abstract (artificial intelligence)) AND (benefits OR advantages OR reduce OR positive effects OR risks OR improve OR disadvantage) AND (psychology OR human OR person)’. We rejected articles prior to 2013 to focus only on recent research We have chosen to consider publications from 2013 to 2018 for two main reasons: first, AI is still an emerging technology, which changes quickly due to fast-paced technological advances. Given Moore’s law, these five years represent two and a half leaps of technical complexity doubling, which seems like a relevant threshold. Second, these articles come after the release of Deep Learning Google Brain, in 2012, which motivated a wide public interest for AI. Lastly, we only considered scientific articles by filter: ‘Review articles and Research articles’. With all those filters, we ended up listing 127 articles.

After the abstract of each of the 127 articles had been read by at least two authors of the present article, we rejected 73 publications, deemed to bring no information on risk and benefit of AI to humans. In detail, 33 articles were removed because they were duplicates and 7 were removed because they took a form that did not match our literature review objectives (book summaries, editorials, a retractation announcement and an Italian-written article). 8 references were then withdrawn because their content was not directly related to AI. Finally, 24 articles were excluded from the analysis because instead of focusing out benefit and risks for humans, they approached AI from a technocentered perspective, discussing advantages and drawbacks of algorithms or mathematical models.

Our final corpus is thus made up of 54 articles addressing explicitly benefit and/or risk of AI to human beings from a social science perspective.

3. Results

3.1. Disciplines and kind of articles

From the articles listed for this review and matching the criteria of selection relative to the benefits and risks of AI for humans (see Appendix), relative to the first author's discipline, it appears that 40% of the publications come from the field of computer science, *i.e* more than a third of the articles (see Figure 1). The next discipline most involved in AI is psychology, accounting for 13% of publications by authors from this field. Next comes the medical sciences (grouping the disciplines of health, psychiatry and genetics) with 8% of publications and management & communication also with 8% of published articles. The remaining disciplines, such as philosophy, education or history of sciences, each account for 2 to 6% of publications (making up 32% of publications). This AI topic therefore appears to be a heavily invested research focus in computer science comparatively to other disciplines, although it is emerging in psychology. Moreover, we can notice that authors from the computer science community and those from the field of psychology have contributed to this AI thematic by publishing at least one article per year between 2013 and 2018.

Regarding the nature of published articles addressing the risk and benefit of AI, three categories have been identified: reviews (including commentaries, theoretical discussions, literature reviews, methodological reviews, etc.), experimental studies and empirical studies (including case studies, computer simulations, use cases, etc.). As shown in Figure 2, we can notice that currently, works about AI are mainly reviews with 43% of the relevant publications. Experimental and empirical studies, on the other hand, make up an equivalent proportion of publications with, respectively, 30% and 28%.

We can thus observe that, at this point, articles discussing AI regarding benefit and risk have a tendency to address this subject as a methodological and theoretical discussion before dealing with it empirically or experimentally.

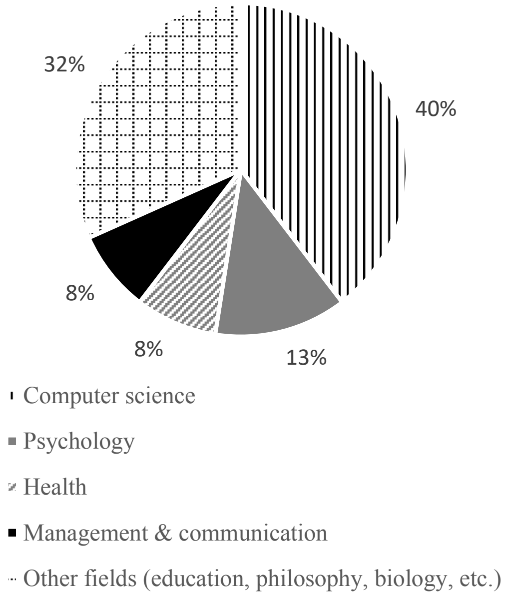

Figure 1: Repartition of fields of first authors of papers addressing AI.

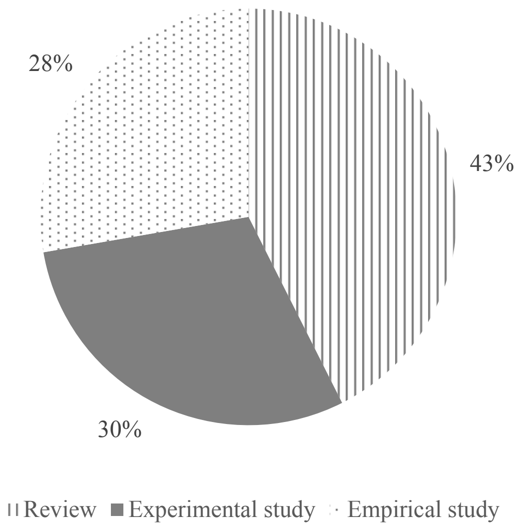

Figure 2: Categories of papers addressing AI.

3.2. Fields of application

Based on the articles selected from this review (see Appendix), an analysis of the applications of studies on the benefits or risks of AI to humans can be conducted. It reveals that three main types of applications stand out (see Figure 3). The first is the field of health, or more specifically medicine, which relates to almost a third of the selected studies (17 articles, or 31%). This is followed by works related to the role of AI in pedagogical topics (13 articles, 24%). The third important field of application relates to AI's contributions to fundamental research in psychology and cognitive science, *i.e.* with the primary aim of a deeper understanding of human functioning (9 articles or 17%).

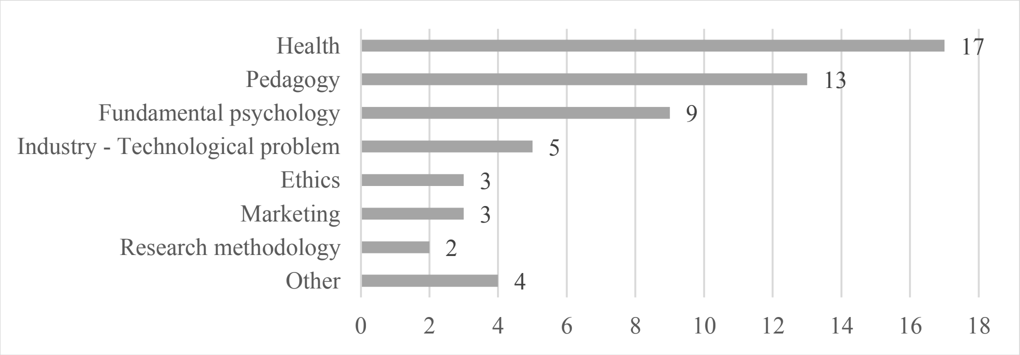

Figure 3: Applications by fields of selected articles.

N.B.: Total count is 56, two articles were related to two fields, they have been counted twice.

The prevalence of applications in these three fields, which thus account for 72% of the selected articles, is an indicator of the uneven development of AI applications in its relationship to humans. Actually, it appears that in relation to the overall development of AI (Jordan & Mitchell, 2015), certain fields (*e.g.* industrial applications, trade, marketing, transportation, etc.) are underrepresented when the analysis is conducted in terms of risk and benefit to humans.

3.3. Benefit to human

3.3.1. Societal benefit

Several authors agree that AI, through its ability to understand what is moral (Müller, 2014), can bring a number of benefits to humanity (Gaggioli, 2017).

A first example is emotional AI, which could help humans to better deal with their emotions (Schutte & Malouff, 2014; Sun, Peng & Ding, 2017), thus having an impact on social behaviour (Cipresso & Riva, 2015).

Gobet, Snyder, Bossomaier and Harré (2014) suggest that a natural or artificial brain with very high cognitive abilities would have tremendous implications for our society. In this sense, AI could facilitate better decisions, especially regarding policies, which could result in solving long-standing issues such as pollution or hunger.

Other authors are convinced that AI could enable us to explore the world (space, beneath the oceans) and thus speed up scientific discovery (Russell, Altman, Veloso & Hauert, 2015).

3.3.2. Individual benefit

AI has definite benefits for physical health (*e.g.* Tarassenko & Watkinson, 2018) or mental health (*e.g.* Trakadis, Sardaar, Chen, Fulginiti & Krishnan, 2018). In practical terms, AI would allow the optimization of prevention (Neuhauser, Kreps, Morrison, Athanasoulis, Kirienko & Van Brunt, 2013), more reliable diagnosis (García-Rodríguez, Martínez-Tomás, Cuadra-Troncoso, Rincón, Fernández-Caballero, 2015) and more appropriate treatments that AI could acquire over time and over situations encountered (Bennett & Hauser, 2013), thus reducing fatality risks. It would also be a tool for e-health that would promote patients' understanding and involvement in their own health (Wolfe, Reyna, Widmer, Cedillos, Fisher, Brust-Renck & Weil, 2015) while improving the efficiency of care systems, reducing the demand on healthcare personnel and costs (Kreps & Neuhauser, 2013) and even improving communication between patients and medical personnel. Some authors also believe that AI will eventually be able to accurately predict the course of a pathology (*e.g.* Fond, Macgregor & Miot, 2013). Finally, AI could improve the living environment of people with special needs by making it safer and more helpful (Guitard, Sveistrup, Fahim & Leonard, 2013). For example, research has demonstrated that interactions with an artificial pet would improve the social behaviour of Alzheimer's patients, bring spiritual comfort to older adults, or could help a child diagnosed with autism (Luh, Li & Kao, 2015).

Furthermore, literature identifies a number of benefits of AI in the area of education (e.g. Brawner & Gonzalez, 2016). At a macroscopic level, educational institutions could use AI to effectively determine the application of suitable learning pathways for given learners (Kurilovas, Zilinskiene & Dagiene, 2014). Some authors go so far as to suggest that AI could improve the educational system by filling the shortage of qualified teachers (Blanchard, 2015). At a more microscopic level, many studies have shown the benefits of using robots in the teaching of scientific disciplines, like mathematics, engineering or technology, based on socioconstructivist theories and modern pedagogical theories based on active pedagogy (Cangelosi & Schlesinger, 2018) through the improvement of students' cognitive abilities (Smart, Madaan & Hall, 2018). Another use of AI in education would be to evaluate students avoiding human error in grading (Grivokostopoulou, Perikos & Hatzilygeroudis, 2017).

Lastly, AI offers benefits in other areas. Among other things, by conferring on non-playing characters a behaviour approaching that of a human being AI sustains the interest of video games (García-Sánchez, Tonda, Mora, Squillero & Merelo, 2018). It also offers significant advantages in text editing support (Green & Stadleren, 2013) by taking over tasks potentially less interesting for an author, such as spell-checking (Thanasuan & Mueller, 2014) or the use of deep learning for machine translation such as the service DeepL, for example.

3.4. Risk to human

3.4.1. Questions about AI capabilities

Many authors agree that AI is still limited and far from the human model. For some, human being can indeed design many more strategies to communicate with AI, which remains limited in its learning (García-Sánchez, Tonda, Mora, Squillero & Merelo, 2018). This limitation seems to be caused by the mechanism differences between AI and humans, including error correction. Although AI-specific models can help in the understanding of human mechanisms, such as memory mechanisms (*e.g.* Thanasuan, Kejkaew, Mueller & Shane, 2014), these models may be overestimated, partly due to a lack of explanatory power (Tarassenko & Watkinson, 2018). Therefore, for them, AI cannot simulate complex behaviours and must thus be controlled by an actual person (Cipresso & Riva, 2015).

Beyond the limitations related to AI learning and its autonomy, it is also the scientific validity associated with the notion of emotional capacities that is highlighted. While many approaches emerge from a variety of disciplines, human emotions are too little considered in these human-machine interactions. For example, the field of education lacks results regarding the emotions mobilized in learning, especially in the way to measure the impact of the emotional context on learners (Porayska-Pomsta, Mavrikis, D'Mello, Conati & Baker, 2013). Emotions are a natural and arguably critical part of learning. Therefore, the study of the affect related to learning poses many challenges, especially if the aim is to promote an AI capable of identifying and dealing with students' emotions in real time (Porayska-Pomsta, Mavrikis, D'Mello, Conati & Baker, 2013).

So, for these authors, AI is more a hope than a reality (Schutte & Malouff, 2016). Even more so as AI research is often culturally centered on Western countries, which could make it less relevant in some emerging countries (Blanchard, 2015). It is therefore still necessary to encourage research to model AI reliably (Trakadis, Sardaar, Chen, Fulginiti & Krishnan, 2018).

3.4.2. Questions about the acceptability

In addition, beyond the limitations inherent to AI, many authors point to the limitations associated with user acceptance. Indeed, in the health field among others, theories and models highlight resistance to changes in behaviour (Green, Rubinelli, Scott & Visser, 2013). To do so, it is necessary to understand and consider the desires, expectations and beliefs of patients that will shape their behaviour and thus explain their resistances.

So, to gain the benefits of AI, patients require a significant level of knowledge and skill in the use of information. Therefore, it is necessary to consider the notion of health literacy (Schulz & Nakamoto, 2013), *i.e.*, understanding the motivation and skills of an individual to access, understand, assess and use information to reach decisions about his or her own health (Sørensen, Van den Broucke, Fullam, Doyle, Pelikan, Slonska & Brand, 2012).

Finally, it is also pointed out that if the communication system is not designed in a participatory approach, interaction with the patient may fail, regardless of the AI's performance (Neuhauser, Kreps, Morrison, Athanasoulis, Kirienko, & Van Brunt, 2013).

3.4.3. Questions about ethics

The concepts of risks related to AI also raise questions of an ethical nature, especially around two major questions: data protection and accountability. Some authors express concerns regarding user data (online data access, data ownership, etc.). Currently, a lot of data is being collected by businesses for specific uses leading to improved profits, with little or no motivation for data sharing (Jordan & Mitchell, 2015).

As for accountability, the examples of the autonomous car and weaponry are particularly relevant. Automatic driving appears to undermine the exercise and allocation of responsibility in several ways. For some authors, these include the replacement of human intervention by machine intervention, but also the evolution of the user's epistemic relationship with the environment, which can be described in terms of human (dis)engagement (Coeckelbergh, 2016). Regarding weaponry, the notion of responsibility is highlighted in the context of autonomous weapons. These autonomous weapons could violate fundamental principles of human dignity by enabling machines to choose who to kill and could also be used by clandestine activists (Altman, Hauert, Russell & Veloso, 2015).

3.4.4. Questions related to loss of control by human

Finally, this concept of risk points to the role of AI in its relationship to humans, and especially to the future of humanity for a large number of authors. Indeed, regarding the role of AI, a first risk involves relationships and communication between humans themselves, if and when it will be increasingly difficult to know whether one is interacting with a human or with an AI in the case of remote communications for example (Adam, Teubner & Gimpel, 2018). According to the authors, obstacles still need to be overcome to enable robots and humans to coexist in a safe and productive way, especially when it comes to communicating with and understanding each other (Altman, Hauert, Russell & Veloso, 2015).

As well, in the idea of loss of control, authors point to the replacement of humans by machines in various fields, such as manual labour or intellectual tasks (Luh, Li & Kao, 2015; Wright, 2018). But it also seems that this loss of control would be psychological in nature, in the human ability to control their destiny on Earth by posing an existential threat to humanity (Müller, 2014).

Finally, apocalyptic end-of-the-world scenarios where humans would be controlled by AI question many scientists (Shermer, 2017). Risks would include total human extinction as a result of super-intelligent and unfriendly AI, which could be mitigated but not avoided by integrating ethical principles into AI systems (Lorenc, 2015). For some, AI could destroy what defines humanity (Gaggioli, 2017).

4. Conclusion

This literature review is intended to highlight the dynamics of publication related to the risks and benefits of AI to humans. The objective is twofold: on the one hand, to provide an overview of disciplines and fields involved with this issue; on the other hand, to describe more accurately the benefits and risks as reported by the authors.

Regarding the first objective, this human-centred literature review on the benefits and risks of AI has shown an existent, but rather minor, involvement of psychology on these topics. Actually, only 13% of the selected articles explicitly deal with research in psychology. Although work on AI in psychology is not limited to the articles surveyed here, the findings support, if not a more extensive investment of the field by psychology, at least a willingness to increase the visibility of works that would be undertaken, but not promoted, on AI in psychology.

Regarding the second point relative to the content of the selected articles, findings show that the benefits and risks associated with AI address each other directly. Thus, based on the same reading of the implementation modalities of AI, some authors will notice benefits while others read risks incurred. For example, Müller (2014) considers AI as an opportunity to better understand what is moral, while Coeckelbergh (2016) emphasizes the risk of a decline in human morality by withdrawing from their responsibilities in favour of AI. In addition, several authors outline the benefits of having AI perform some tasks (e.g. Boyer & Dolamic, 2015) while others point to the risks involved in replacing humans (*e.g.* Luh, Li & Kao, 2015; Müller, 2014; Shermer, 2017; Wright, 2018). This parallelism between the benefits and risks of AI suggests that the questioning on these issues is still young and that scientific consensus on the positive and negative aspects of AI for humans has not yet been established.

These findings point to four research prospects. Firstly, from an initial methodological approach, we have highlighted that the papers questioning AI in terms of benefits and risks are mainly treated from a methodological and theoretical perspective. Therefore, it would be important to initiate empirical and/or experimental research to better understand the mechanisms and processes related to the benefits and risks of AI. Furthermore, we have opted to confine ourselves to a review of the literature limited to the risks and benefits to humans. This choice is based on a willingness to apprehend work that directly answers the questions raised by the emergence of AI. As a result of these restrictions, it is true that most of the literature on the interdependence between AI and humans has been dismissed. Nevertheless, this restricted spectrum enables an overview of the scientific literature defined by this anthropocentric positioning. If we cannot answer the question: ‘How is the relationship between AI and Humans studied? ’, this review proposes an alternative, which is: ‘By whom and how is the impact of the AI emergence scientifically investigated in relation to Humans?’. Therefore, if this analysis of 54 articles sheds light on the scientific positioning of research in human sciences, it would be interesting in the future, *i.e.* when psychology will have investigated this technological field more, to carry out an inventory of specific works in psychology alone without focusing on the risks and benefits of AI to Humans.

A second research approach opened up by this literature review belongs to the disciplinary scope of ergonomic psychology, aiming to yield knowledge about human activity in natural situations in several areas (work, training, daily life, etc.). As an inventory of the risks and benefits of AI to humans, this article is a starting point and should encourage self-questioning prior to the involvement, roles and contributions of psychology and ergonomics researchers who are being increasingly solicited to collaborate in AI research projects such as autonomous vehicles, Smart Grids, E-Health, adaptive learning systems or Industry 4.0.

A third research approach related to this literature review, which would fall rather within the field of social psychology, could focus on integrating the role of the social, cultural and emotional context in AI studies. This is because risk and benefit perspectives are often processes associated with the social perception of affected individuals by the context in which they are embedded, imprinted with social norms, values, and codes.

A final approach, inherently linked to these notions of risks and benefits to humans, is explicitly related to the acceptability of AI. This acceptability issue is all the more interesting in that it would be worth dealing with through at least two complementary scientific assessments promoting a cross-referenced view resulting in particularly rich data: practical acceptability and social acceptability (Nielsen, 1993). From the practical acceptability perspective, the objective would be to improve the ergonomic quality of AI and optimize interactions between it and its user in order to facilitate its adoption, and thus ensure optimal compatibility between the user, his tasks and the emerging technology (Brangier, Hammes-Adelé & Bastien, 2010). In the second sense, and with the objective of optimizing these interactions, it would be about understanding how the social perceptions of individuals in connection with AI and its characteristics, constructed with regard to notably social contexts, promote or discourage the use of technologies (e.g. Davis, 1989). These perceptions and social representations (Moscovici, 1961) should necessarily be linked to the level of expertise of users and their expectations of AI.

Thus, many fields of application of AI seem to be under-represented in this literature review, highlighting the abundance of psychological research perspectives and the urgency of a clear disciplinary positioning on this topic.

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7. Supplementary materials

Table: List of articles dealing with AI.

Authors	**Year**	**Title of the article**	**Journal**	**Discipline of the first author**	**Type of article**	**Scope of AI**

Adam, Teubner & Gimpel	2018	No rage against the machine: How computer agents mitigate human emotional processes in electronic negotiations.	Group Decision and Negotiation	Computer ScienceComputer Science	Experimental	Economics / Social and Behavioural PsychologyPsychology
Bennett & Hauser	2013	Artificial intelligence framework for simulating clinical decision-making: A Markov decision process approach.	Artificial Intelligence in Medicine	Computer ScienceComputer Science	Experimental	Medical
Blanchard	2015	Socio-cultural imbalances in AIED research: Investigations, implications and opportunities.	International Journal of Artificial Intelligence in Education	Computer ScienceComputer Science	ReviewReview	EEducation
Boyer & Dolamic	2015	Automated detection of HONcode website conformity compared to manual detection: An evaluation.	Journal of Medical Internet Research	Management and information system	Experimental	Websites evaluation
Brawner & Gonzalez	2016	Modelling a learner's affective state in real time to improve intelligent tutoring effectiveness.	Theoretical Issues in Ergonomics Science	Computer ScienceComputer Science	ReviewReview	Learning, affect and AILearning
Cangelosi & Schlesinger	2018	From babies to robots: The contribution of developmental robotics to developmental psychology.	Child Development Perspectives	Computer Science	Empirical studies	Developmental PsychologyPsychology
Carenini, Cheung & Pauls	2013	Multi-document summarization of evaluative text.	Computational Intelligence	Computer Science	Experimental	Text analysis
Cipresso & Riva	2015	Virtual Reality for Artificial Intelligence: Human-centered simulation for social science.	Annual Review of CyberTherapy and Telemedicine	Technologies applied to neuropsychologyPsychology	Review	Psychology
Coeckelbergh	2016	Responsibility and the moral phenomenolog	Applied Artificial Intelligence	Philosophy	Review	Autonomous vehicle

		y of using self-driving cars.				
Fatahi & Moradi	2016	A fuzzy cognitive map model to calculate a user's desirability based on personality in e-learning environments.	Computers in Human Behavior	Computer Science	Empirical studies	Psychology (personality, emotion, desirability), e-learningPsychology
Fond, Macgregor & Miot	2013	Nanopsychiatry—The potential role of nanotechnologies in the future of psychiatry: A systematic review.	European Neuropsychopharmacology	Psychiatry	Review	Psychiatry / Pharmacology
Freudenthal, van Stuijvenberg & van Goudoever	2013	A quiet NICU for improved infants' health; development and well-being: A systems approach to reducing noise and auditory alarms.	Cognition, Technology & Work	Industrial design	Review	Medical
Friedman, Forbus & Sherin	2017	Representing; running; and revising mental models: A computational model.	Cognitive Science	Computer Science	Empirical studies	AI
Gaggioli	2017	Bringing more transparency to artificial intelligence.	Cyberpsychology, Behavior, and Social Networking	Psychology	Review	MultidisciplinaryMultidisciplinary
García-Rodríguez, Martínez-Tomás, Cuadra-Troncoso, Rincón & Fernández-Caballero	2015	A simulation tool for monitoring elderly who suffer from disorientation in a smart home.	Expert Systems: International Journal of Knowledge Engineering and Neural Networks	Computer Science	Empirical studies	Homecare
García-Sánchez, Tonda, Mora, Squillero & Merelo	2018	Automated playtesting in collectible card games using evolutionary algorithms: A case study in Hearthstone.	Knowledge-Based Systems	Computer Science	Empirical studies	Videogame
Garnier, Chang, Ormand, Matlen, Tikoff & Shipley	2017	Promoting sketching in introductory geoscience courses: Cogsketch geoscience worksheets.	Topics in Cognitive Science	Geoscience	Empirical studies	Pedagogy

Gobet, Snyder, Bossomaier & Harré	2014	Designing a 'better' brain: Insights from experts and savants.	Frontiers in Psychology	Psychology	Review	Cognition modeling
Green & Stadler	2013	Adding coping-related strategies to biomedical argumentation in computer-generated genetic counseling patient letters.	Patient Education and Counseling	Computer Science	Experimental	HealthHealth
Green, Rubinelli, Scott & Visser	2013	Health communication meets artificial intelligence.	Patient Education and Counseling	Computer Science	Review	HealthHealth
Grillner, Ip, Koch, Koroshetz, Okano, Polachek, Poo & Sejnowski	2016	Worldwide initiatives to advance brain research.	Nature Neuroscience	Neuroscience	Review	Brain function
Grivokostopoulou, Perikos & Hatzilygeroudis	2017	An educational system for learning search algorithms and automatically assessing student performance.	International Journal of Artificial Intelligence in Education	Computer Science	Experimental	Pedagogy
Guitard, Sveistrup, Fahim & Leonard	2013	Smart grab bars: A potential initiative to encourage bath grab bar use in community dwelling older adults.	Assistive Technology	Biomedical	Experimental	Homecare
Ionica & Leba	2015	Human action quality evaluation based on fuzzy logic with application in underground coal mining.	Work: Journal of Prevention, Assessment & Rehabilitation	Management	Empirical studies	Risk Assessment
Jones, Shao & Du	2014	Active learning for human action retrieval using query pool selection.	Neurocomputing: An International Journal	Electronics	Experimental	Pedagogy
Jordan & Mitchell	2015	Machine learning: Trends; perspectives; and prospects.	Science	Statistics	Review	Computer Science
Kotthoff	2014	Reliability of computational experiments on virtualised hardware.	Journal of Experimental & Theoretical Artificial Intelligence	Computer Science	Experimental	Computer Science *(Machine learning)*
Kreps & Neuhauser	2013	Artificial intelligence	Patient Education and Counseling	Communication	Empirical studies	HealthHealth

		and immediacy: Designing health communication to personally engage consumers and providers.				
Kurilovas, Zilinskiene & Dagiene	2014	Recommending suitable learning scenarios according to learners' preferences: An improved swarm based approach.	Computers in Human Behavior	Mathematics	Empirical studies	EEducation
Lendasse, Man, Miche & Huang	2016	Advances in extreme learning machines (ELM2014).	Neurocomputing: An International Journal	Technology	Review	Computer Science *(Machine learning)*
Lieder & Griffiths	2017	Strategy selection as rational metareasoning.	Psychological Review	Neuroscience	Experimental	Psychology
Littman	2015	Reinforcement learning improves behaviour from evaluative feedback.	Nature	Computer Science	Review	Computer Science *(Machine learning)*
Lorenc	2015	Artificial intelligence and the ethics of human extinction.	Journal of Consciousness Studies	/	Review	EthicsEthics
Luh, Li & Kao	2015	The development of a companionship scale for artificial pets.	Interacting with Computers	Industrial design	Empirical studies	Psychology
Müller	2014	Risks of general artificial intelligence.	Journal of Experimental & Theoretical Artificial Intelligence	Philosophy	Review	MultidisciplinaryMultidisciplinary
Neuhauser, Kreps, Morrison, Athanasoulis, Kirienko & Van Brunt	2013	Using design science and artificial intelligence to improve health communication: ChronologyMD case example.	Patient Education and Counseling	Health	Empirical studies	Health
Porayska-Pomsta, Mavrikis, D'Mello, Conati & Baker	2013	Knowledge elicitation methods for affect modelling in education.	International Journal of Artificial Intelligence in Education	Education	Review	Education
Ruffaldi & Filippeschi	2013	Structuring a virtual	Robotics and Autonomous Systems	Computer Science	Empirical studies	Sports Training

		environment for sport training: A case study on rowing technique.				
Russel, Hauert, Altman & Veloso	2015	Robotics: Ethics of artificial intelligence.	Nature	Computer Science	Review	Ethics
Salehi & Kamalabadi	2013	Hybrid recommendation approach for learning material based on sequential pattern of the accessed material and the learner's preference tree.	Knowledge-Based Systems	Computer Science	Empirical studies	Learning
Santos & Boticario	2015	User-centred design and educational data mining support during the recommendations elicitation process in social online learning environments.	Expert Systems: International Journal of Knowledge Engineering and Neural Networks	Computer Science	Empirical studies	Education
Schulz & Nakamoto	2013	Patient behavior and the benefits of artificial intelligence: The perils of 'dangerous' literacy and illusory patient empowerment.	Patient Education and Counseling	Communication	Review	Health
Schutte & Malouff	2016	Comment on developments in trait emotional intelligence research: A broad perspective on trait emotional intelligence.	Emotion Review	Psychology	Review	Psychology
Semmelmann & Weigelt	2018	Online webcam-based eye tracking in cognitive science: A first look.	Behavior Research Methods	Psychology	Experimental	Psychology
Shermer	2017	Apocalypse AI.	Scientific American	History of Science	Review	Multidisciplinary
Smart, Madaan & Hall	2018	Where the smart things are: Social machines and the internet of things.	Phenomenology and the Cognitive Sciences	Computer Science	Review	Multidisciplinary

Sun, Peng & Ding	2017	Emotional human-machine conversation generation based on long short-term memory.	Cognitive Computation	Computer Science	Experimental	Human/machine communication
Tarassenko & Watkinson	2018	Artificial intelligence in health care: Enabling informed care.	The Lancet	Biomedical	Review	Health
Thanasuan & Mueller	2014	Crossword expertise as recognitional decision making: An artificial intelligence approach.	Frontiers in Psychology	Psychology	Experimental	Problem solving
Trakadis, Sardaar, Chen, Fulginiti & Krishnan	2018	Machine learning in schizophrenia genomics; a case-control study using 5;090 exomes.	American Journal of Medical Genetics Part B: Neuropsychiatric Genetics	Genetics	Empirical studies	Genetics
Valenza, Gentili, Lanatà & Scilingo	2013	Mood recognition in bipolar patients through the PSYCHE platform: Preliminary evaluations and perspectives.	Artificial Intelligence in Medicine	Bioengineering	Experimental	Psychopathology
Wolfe, Reyna, Widmer, Cedillos, Fisher, Brust-Renck & Weil	2015	Efficacy of a web-based intelligent tutoring system for communicating genetic risk of breast cancer: A fuzzy-trace theory approach.	Medical Decision Making	Psychology	Experimental	Health
Wright	2018	The Changing Nature of Work.	American Journal of Public Health	Health	Review	Changes in the work
Zipitria, Arruarte & Elorriaga	2013	Discourse measures for Basque summary grading.	Interactive Learning Environments	Psychology	Experimental	Education

Shaken, not Stirred: Visualizing Vibrotactile Feedback in Virtual Reality

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Keywords: Vibrotactile feedback – Visualization – Virtual Reality – Immersion – Presence

Abstract

This paper proposes three different methods of visualizing vibrotactile feedback in Virtual Reality (VR) by developing a multimodal system that simulates the turbulence felt during a commercial airline flight. The system consisted of a physical apparatus (wooden platform with integrated subwoofers) and a digital virtual environment of the interior of an airplane. The goal of the system was to enhance the participants' level of immersion by adding a visualization of vibrotactile feedback. An experiment was conducted to evaluate whether the proposed solution achieved its purpose. A statistical test was performed on the collected data, and the results indicated that when compared to no visualization of the perceived vibrotactile feedback, the method of shaking objects in the virtual environment has the potential to increase immersion in VR. In particular, the aspects of sensory and visual engagement, involvement and focus on the virtual environment, and lastly real-world consistency and consistency between senses, demonstrated a significant increase.

1. Introduction

Virtual Reality (VR) has seen a resurgence the last few years (Jerald, 2016) and is now applied in a vast number of fields, such as education (Freina & Ott, 2015), training (Boud, Haniff, Baber, & Steiner, 1999), therapy (Reger & Gahm, 2008), entertainment (Beat Games, 2018), among others. This is largely due to advancements in technology, resulting in more user friendly and economically accessible devices, while also allowing for the virtual world to be experienced with a higher fidelity.

One technology that has seen an increase in attention, due to its ability to increase immersion by "transforming a simulation from a world of ghosts to a world of solid forms" (Swapp, Pawar, & Loscos, 2006, p. 1), is haptic feedback technology. This feedback groups the modalities of force feedback, tactile feedback, and proprioceptive feedback (Burdea, 1996). Force feedback, in the context of VR, provides information on the weight and inertia of a virtual object. Tactile feedback indicates the texture, pressure and geometry of an object, and proprioceptive feedback is the sense of body position and movement. While Head Mounted Displays (HMDs) allow a user to visually experience the VR world, and a pair of good headphones aid in the compelling simulation of 3D sound, haptic technology adds yet another dimension to VR by letting users feel the Virtual Environment (VE) via the sense of touch. This is usually accomplished by using external devices such as gloves, controllers, suits etc., where users receive feedback in the form of vibrations. This haptic feedback, in conjunction with VR, has seen uses in e.g. the field of entertainment for amusement parks (Formica & Olsen, 1998), exposure therapy for treating fear of flying (Wiederhold & Wiederhold, 2000), or medical education for surgery training (Larsen et al., 2009).

Evidently, a lot of research explores the different application areas for the utilization of haptic feedback, yet investigation is lacking on how this haptic feedback could be visually represented in the VR environment as to further increase immersion. In the context of digital media, immersion is described as an affordance that enables the reproduction of realistic experiences by surrounding the users with sensory information, allowing them to temporarily forget the fact that they are in a mediated environment (Ahn & Bailenson, 2011). Witmer and Singer (1998, p. 3) define immersion as "a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences”. They argue that immersion is affected by users’ isolation from the physical environment, their perception of self-inclusion in the VE, whether they have natural modes of interaction and control, and a perception of self-movement.

When users perceive haptic feedback from an external device, without seeing any effect of this sensation in the VE, they might be reminded about their real-world physical environment in which they are located, thus breaking the psychological state of perceiving themselves as being included in and enveloped by the environment. If, instead, there is a visual event within the VE that complements the haptic stimulus, perhaps the feeling of immersion is enhanced, as the sensory information then matches some of the expectations users might have from reality, prompting them to relate the physical sensation to the visual representation, thereby reintroducing the perception of self-inclusion in the VE.

In this paper, we present the results of a comparative study of user immersion when experiencing different visual representations of vibrotactile feedback in a simulated flight turbulence in VR. These representations are introduced to users as four nearly identical conditions that only differ in the way they visualize the vibrotactile stimuli. The following section reviews work relating to the current paper. Section 3 describes the materials and methods used in the evaluation. Section 4 presents the results and a discussion of the findings, and Section 5 concludes the paper.

2. Related Work

In a recent study, Egeberg and Lind (2016) investigated the effect of vibrotactile feedback on the sense of illusory self-motion (vection) in VR. The purpose of the study was to determine how the various properties of vibration affect the perception of vection, with the intention of achieving a realistic impression of the phenomena. This is of importance when wanting to realize an immersive experience in VR, especially when it is a simulation of an event from the real world. These properties are the frequency of the vibration, its amplitude and waveform, as well as the way it is placed on the user’s body and the type of stimulus it is supposed to trigger based on the skin receptors.

Shionoiri, Sakuragi, Kodama, & Kajimoto (2018) emphasized the significance of deciding on the vibration parameters of frequency, amplitude, and decay rate that are suitable for the type of haptic feedback the VR system aims to provide. In their system, they added vibrotactile feedback through transducers to the physical apparatus of the VR system. The purpose of the system was to produce a wider range of frequencies to improve the experience of using a VR motion platform. A specific focus was to match collision with different materials in VR with the participants’ subjective impression of real collisions with the same material.

Riecke, Schulte-Pelkum, & Bülthoff (2004) carried out a study to investigate the influence of vibrational cues on the perception of vection. While the results showed that the addition of vibrations made the experience more convincing, some participants expressed that experiencing a mismatch between the perceived modalities resulted in the experience being more unrealistic. The authors of the research attributed such occurrences to a cognitive conflict between the visual and vibrational cues. Egeberg and Lind suggested that vibrotactile feedback that is congruent with the visual and/or auditory elements can enhance vection. While vection, specifically, is not the focus of the present paper, the findings from Riecke, Schulte-Pelkum & Bülthoff support the notion of a visual representation complementing any perceived vibrational sensations. Furthermore, these sensations should be designed with the parameters of frequency, amplitude and waveform in mind, as suggested by the first two reviewed studies.

As for the apparatus providing the vibrations, an example can be seen in a study by Rothbaum et al. (2000), which investigated the effects of VR as a method for exposure therapy. Previous studies have shown that VR has been proven a successful aid in treating people who suffer from various anxiety disorders. A common fear that received extensive research in terms of virtual exposure therapy is aviophobia, i.e. the fear of flying. The study by Rothbaum et al. concluded that both real exposure and the virtual exposure therapy can produce equivalent results in terms of curing aviophobia. The apparatus used by Rothbaum et al. consisted of a computer, capable of simulating a virtual airplane environment, and a Thunderseat; a specially designed seat with an embedded 100-watt subwoofer to both emit vibrotactile feedback encountered in a real airplane and play sounds such as flight attendants speaking, and takeoff and landing sounds.

Rothbaum et al. (2006) recreated their original study six years later with a more recent apparatus, capable of handling a more complex VE. Furthermore, the apparatus provided the vibrotactile feedback through a chair that was placed on a vibrating plate. The study yielded identical results. Albeit the results of Rothbaum et al. indicate a successful design of apparatus, the choice of the chosen vibrotactile feedback is not clearly presented in the literature.

A recent study by Lovreglio et al. (2018) investigated VEs as means to prepare for evacuations during earthquakes. The employed apparatus utilized a vibrating plate to provide vibrotactile feedback in the VE alongside a “ButtKicker Gamer”. This device is mounted to the chair and translates low frequencies sounds into small bursts that are felt by the user as vibrations. Tarnanas and Manos (2001) addressed a similar topic in their research, with their target group being pre-school children and Down syndrome kids. The apparatus of this study conveyed vibrotactile feedback of the virtual earthquake environment via a vibrating plate. The choice of vibrotactile feedback and visualization of such remained briefly addressed in both studies. However, as can be seen from several of these studies, a plate capable of producing vibrations could be utilized as an apparatus for experimenting with different ways of visually representing the stimulus.

3. Material and Methods

We designed an experiment to test the effects of visual representations of vibrotactile feedback on the sensation of immersion in VR. The developed system was a multimodal design that provided the users with vibrotactile stimuli through a physical apparatus, and visual and auditory stimuli through a digital VE. While the experimental design focuses on the visual and vibrotactile aspects of the system, the auditory modality is still integrated in the system, considering its importance when creating a coherent multimodal interface. The components of the system are explained in further detail in Section 3.1.

The system simulated the potential vibration (turbulence) experienced during a commercial airline flight, as most people have experience with this and are thereby capable of relating to in-flight events caused by turbulence.

As mentioned in Section 2, the inclusion of vibration in VR requires determining its frequency and amplitude in order to replicate and match the sensation of the real-world scenario. According to a report by Boeing (Carbaugh, Carriker, Huber, & Ryneveld, 2001), there are mainly two different types of vibrations, which flight crew members observe and report during flights of commercial airplanes. The first one is a high-frequency tactile vibration that is above the 25 Hz mark, while the second type of vibration is of lower frequency which is often less than 20 Hz. Based on this report, the frequency of the vibrotactile feedback needs to range from less than 20 Hz to more than 25 Hz. A lo-fi test was conducted early in the development process, through which we discovered that the range of the vibrotactile frequency to be used in the system was from 25 - 80 Hz.

3.1. Apparatus and Simulation

The system consists of a physical apparatus and a digital VE. The VE was produced using the Unity 3D engine, and it depicts the interior of an airplane flying in the sky. The environment was rendered on a computer equipped with an i7-4770 CPU, a Nvidia Geforce GTX980Ti GPU, and 16 gigabytes of RAM. The rendered environment was displayed to the user, who takes on the role of a passenger in the plane, by an HTC VIVE HMD with a 1920 x 1080 resolution and a 60° field of view. The user’s view is the same across all evaluated conditions. The SteamVR Plugin was utilized to create a virtual representation of the user, which is placed on a seat in the back of the airplane model. The context and the design of the experiment allow the user to have little interaction with the surrounding environment, therefore it was deemed sufficient to limit the virtual body to only a right hand, the movement of which corresponded to the user’s physical motion. The virtual hand was controlled through the use of the matching VIVE controller. This makes it possible to interact with three virtual objects (mobile phone, soda can and plates) that are placed on a tray in front of the user, as well as starting the experiment by triggering a "Start" button that is situated above the objects. Figure 1 shows the VE of the plane.

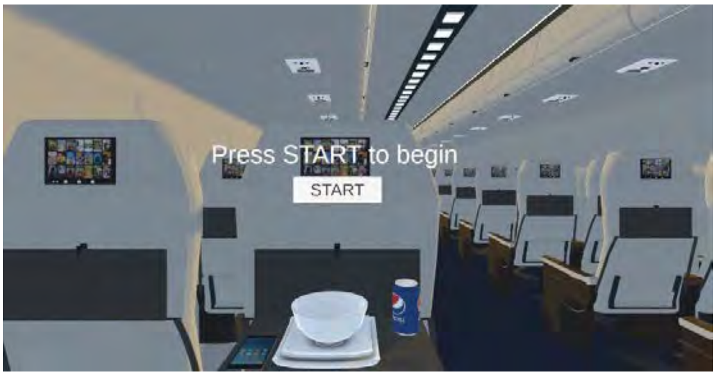


Figure 1: Virtual environment of the prototype

The VE is complemented with a few visual and auditory elements that aim to improve the aspect of realism when experiencing the environment in VR.
As for the physical apparatus, users were seated in a chair placed on a wooden platform (120 cm x 77 cm x 12 cm) that has two 50-watt subwoofers positioned at an equal distance from each end of it. The subwoofers were used to apply vibrations through the platform after having the signal amplified by a Thomson DPL 550HT amplifier. A pair of JBL Synchros S700 headphones were used to provide audio output to the user, while also partly canceling out the noise emitted from the vibrating wooden platform. The audio was mainly background and engine noise that is usually heard on a plane, complemented by the sounds of rumbling luggage during the simulated turbulence. The design of the apparatus can be seen in Figure 2.

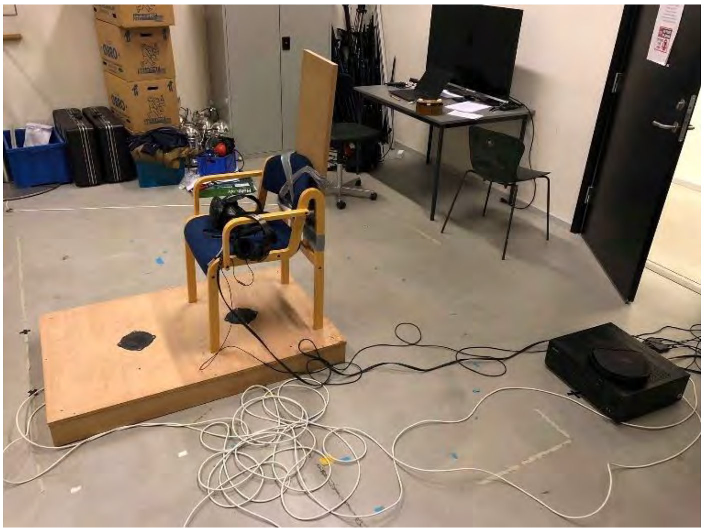


Figure 2: Physical apparatus of the prototype

The turbulence felt during the experience was composited in the Audacity software by using a Narrowband Noise generator (Daulton, 2019). The length of the generated noise is 40 seconds, where the first 15 seconds has a center frequency of 75 Hz with a bandwidth of 10 Hz. From 15-35 seconds, noise from two center frequencies, 30 Hz and 40 Hz, was generated separately, with both having a bandwidth of 10 Hz. Thereafter, the frequency spikes from the 30 Hz range-noise were amplified and cut out, then combined with the already generated 40 Hz rangenoise. The noise generated for the last five seconds has the same properties as the initial 15 seconds. At the end of this process, an external audio file was produced and saved to be played through the amplifier and sent to the subwoofers, whenever the user triggered the start button during any condition.

When an experimental condition was started, a timeline sequence, of equal length to the generated audio file, was initiated in Unity. From the 15-35 seconds mark of the sequence, there were events that trigger the visualization method of either shaking the virtual objects in front of the user, or the screen that is displaying the environment or a combination of both. These events matched the same timestamps when a spike in the vibration frequency occurred. The visualization used the same frequency and duration in the process of applying the shaking effect on the screen or the objects in the scene. This was achieved by utilizing Perlin noise to generate a random pattern that affects the orientation of the axes of the camera viewing the VE. As for the objects, the shaking effect stems from shaking the tray in front of the user with a different pattern of Perlin noise that only alters the orientation of its z-axis. This produced the visual event of the objects lightly bouncing around on the tray, making the coke can fall over and sometimes roll off the tray in a standard downward gravitational acceleration of 9.81 m/s^2. The pattern changed every time a visualization was triggered; however, it remained within the range of the specified parameters.

3.2. Procedure

Prior to carrying out the experiment, a qualitative assessment with five participants was conducted to evaluate the performance of the vibrotactile feedback provided in the VE through the apparatus, by comparing it to a scenario where the VE was not enhanced by any vibrations. Each participant was asked to test both conditions and express their opinion on which condition felt more immersive. All five participants echoed the same sentiment that the inclusion of vibrotactile feedback resulted in a more immersive experience.

The experiment of the developed system was conducted as a within-subject design, and it consisted of four different conditions. The order of the conditions was randomized amongst the participants in order to protect against order effect, practice effect and context effect. This was achieved by applying Balanced Latin Square to the conditions. All four conditions shared an identical level of vibrotactile feedback, but they differed in the way it was visually represented in the VE. The conditions were the following:

- The first condition had no visual representation of the vibrotactile feedback, which is referred to as “No Visual Representation" (NVR).
- The second condition had the vibrotactile feedback be visually represented through the shaking of specific objects in the VE. This condition is referred to as “Object Shake" (OS).
- For the third condition, the visual representation was applied in the form of shaking the screen through which the VE was experienced. This condition is referred to as “Screen Shake" (SS).
- The fourth condition is referred to as “Combined Shake" (CS), as it combined the visual representation of both the second and third conditions.

A total of 20 participants (15 males and 5 females) recruited from CREATE campus at Aalborg University, aged between 22 and 28 years old, with various educational and occupational backgrounds, took part in the experiment. Prior to the start of the test, each participant was asked to fill out a consent form that included questions about their age and education/occupation. Thereafter, they filled out a pre-test questionnaire consisting of two questions regarding their experience in VR and how frequently they fly on a yearly basis. A facilitator explained the procedure of the experiment to the participant and informed them that the experimental condition is initiated by triggering the start button through the controller. The participant was advised against interacting with the objects during OS and CS conditions to prevent interference with the method of visualization. After testing each condition, the participant was asked to take a break from the VR experience to answer a corresponding immersion questionnaire (see Table 1) which the facilitator had prepared beforehand on a laptop. Upon progressing with the conditions, they were allowed to go back to previously answered questionnaires to review their ratings, as well as change them if they saw fit. The experiment concluded once the participant finished testing all conditions.

3.3. Hypotheses and Data Collection

The aim of the experiment was to obtain data on the level of immersion experienced by participants during each condition. The general intention was to achieve higher levels of immersion when a visual representation of the vibrotactile feedback was introduced to the environment in the OS, SS, and CS conditions, compared to the NVR condition. This was investigated by forming a questionnaire that had a total of 10 questions, answered through a 7-point Likert scale, ranging from 1: ”Not at all” to 7: ”Completely”. The questionnaire, seen in Table 1, was a combination of established VR presence questionnaires acquired from different sources (Witmer & Singer, 1998) (Witmer, Jerome, & Singer, 2005) (Slater, Usoh, & Steed, 1994) (Hendrix, 1994) (Chertoff, Goldiez, & LaViola, 2010). Deciding on which questions to include from each questionnaire was based on the following criteria: the question had to be concerned with immersion and measure aspects that focus on the modalities involved in the experience, with a likelihood of experiencing a difference between the conditions.

Q1	How completely were all your senses engaged? (Witmer & Singer, 1998)
Q2	How much did the visual aspects of the environment involve you? (Witmer & Singer, 1998)
Q3	How aware were you of your display? (Witmer & Singer, 1998)
Q4	How much did your experiences in the virtual environment seem consistent with your real-world experiences? (Witmer & Singer, 1998)
Q5	How involved were you in the virtual environment experience? (Witmer & Singer, 1998)
Q6	Were there moments during the virtual environment experience when you felt completely focused on the environment? (Witmer et al., 2005)
Q7	Was the information provided through different senses in the virtual environment (e.g., vision, hearing, touch) consistent? (Witmer et al., 2005)
Q8	In the computer-generated world, I had a sense of “being there” (Slater et al., 1994)
Q9	How real did the virtual world seem to you? (Hendrix, 1994)
Q10	I found the tactile content of the environment to be of high quality. (Chertoff et al., 2010)

Table 1: Immersion Questionnaire

Expectations were drawn for the comparisons between conditions for each question. Besides having an increase in the level of immersion for the OS, SS and CS conditions, the visual representation through OS was expected to produce better results than that of SS. The visualization of vibrotactile feedback through SS was evaluated in the lo-fi test, mentioned in Section 3, with four participants to determine its effects on the participants, as it might cause physical discomfort, i.e. cybersickness, when experienced in VR. While the participants expressed no issue with the condition during the lo-fi test, the effect of SS was only tested to be applied for a maximum of five seconds at a time. The current iteration of the study does not account for the possible implications of applying SS for a longer duration of time in a VR experience. Additionally, since manipulating objects in the scene is a more established method of visual engagement within VR, rather than shaking the screen, it is expected that the OS condition fares better as an immersion increasing visualization method.

Multiple hypotheses were formulated for the condition comparisons per questionnaire question. For some of the comparisons, there were clear expectations about the outcome of the experiment, but for others, it was more uncertain what the results would yield. The following 15 hypotheses were expected to show a significant difference between comparisons:

- Hypothesis 1 (Question 1): Introducing visual representation of the vibrotactile feedback in the form of OS, SS, or CS increases the feeling of sensory engagement.
- Hypothesis 2 (Question 1): OS causes a higher level of engagement when compared to SS.
- Hypothesis 3 (Question 2): Introducing visual representation of the vibrotactile feedback in the form of OS, SS, or CS increases the feeling of visual involvement.

- Hypothesis 4 (Question 2): OS causes a higher level of involvement when compared to SS.
- Hypothesis 5 (Question 3): Introducing SS increases the user's display awareness.
- Hypothesis 6 (Question 4): Introducing visual representation of the vibrotactile feedback in the form of OS, SS, or CS increases the consistency of experiences between the virtual world and the real world.
- Hypothesis 7 (Question 4): OS causes the highest level of consistency between the virtual and the real worlds when compared to SS.
- Hypothesis 8 (Question 5): Introducing visual representation of the vibrotactile feedback in the form of OS, SS, or CS increases the user's involvement with the virtual world.
- Hypothesis 9 (Question 5): OS causes a higher level of user involvement with the virtual world when compared to SS.
- Hypothesis 10 (Question 6): Visually representing vibrotactile feedback through OS heightens the user's focus on the virtual environment.
- Hypothesis 11 (Question 7): When the vibrotactile feedback is visually represented through OS, SS, or CS, the consistency of the information provided through different senses is increased.
- Hypothesis 12 (Question 8): Introducing a visual representation of the vibrotactile feedback in the form of OS, SS, or CS increases the feeling of being in the virtual environment.
- Hypothesis 13 (Question 8): The feeling of being in the virtual environment is higher during the condition of OS when compared to SS.
- Hypothesis 14 (Question 9): Introducing visual representation of the vibrotactile feedback in the form of OS, SS, or CS increases the feeling of realness.
- Hypothesis 15 (Question 9): The feeling of realness is higher during the condition of OS when compared to SS.

In addition to the 15 hypotheses above, another 21 were formed to test the differences between the comparisons with an unclear outcome. Some of the immersion questionnaire questions shared the same uncertainties regarding comparisons.

3.4. Statistical Analysis

The measurements of the immersion questionnaire were taken under four conditions for each participant, which makes the experimental design a repeated measures design. It was decided to perform a Wilcoxon signed-rank test to evaluate the differences between the dependent samples.

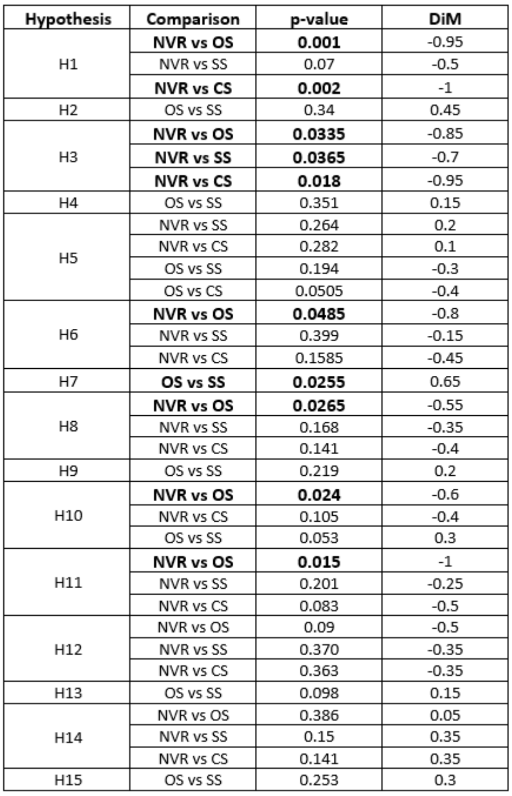
Initially, the Wilcoxon signed-rank test was applied with a significance level of 5%, $\alpha = 0.05$. However, as there is no clear expectation for 21 of the total 36 hypotheses, the problem of multiple comparisons occurs, reducing the power of these results. This is accounted for by applying the Bonferroni method. This means that, for a statistical result to be considered significant, the p-value of any of the 21 hypotheses must now be less than 0.00238.

In addition to the Wilcoxon test, a Pearson correlation coefficient test was carried out on the data from the pre-test questionnaire to determine if there was a correlation between prior experience of using VR or frequency of flying per year, and the level of immersion.

4. Results and Discussion

The p-values and difference in means for the comparisons in hypotheses 1 to 15 are presented in Table 2. Three box plots illustrating the distribution of answers for the four conditions in Q3, Q9 and Q10 of the immersion questionnaire are presented in Figure 3.

The Pearson correlation test indicated that whether a participant was a frequent flyer, experienced with VR, or the opposite, their answers to the immersion questionnaires did not significantly vary.



Hypothesis	Comparison	p-value	DiM
H1	**NVR vs OS**	**0.001**	-0.95
	NVR vs SS	0.07	-0.5
	NVR vs CS	**0.002**	-1
H2	OS vs SS	0.34	0.45
H3	**NVR vs OS**	**0.0335**	-0.85
	NVR vs SS	**0.0365**	-0.7
	NVR vs CS	**0.018**	-0.95
H4	OS vs SS	0.351	0.15
H5	NVR vs SS	0.264	0.2
	NVR vs CS	0.282	0.1
	OS vs SS	0.194	-0.3
	OS vs CS	0.0505	-0.4
H6	**NVR vs OS**	**0.0485**	-0.8
	NVR vs SS	0.399	-0.15
	NVR vs CS	0.1585	-0.45
H7	**OS vs SS**	**0.0255**	0.65
H8	**NVR vs OS**	**0.0265**	-0.55
	NVR vs SS	0.168	-0.35
	NVR vs CS	0.141	-0.4
H9	OS vs SS	0.219	0.2
H10	**NVR vs OS**	**0.024**	-0.6
	NVR vs CS	0.105	-0.4
	OS vs SS	0.053	0.3
H11	**NVR vs OS**	**0.015**	-1
	NVR vs SS	0.201	-0.25
	NVR vs CS	0.083	-0.5
H12	NVR vs OS	0.09	-0.5
	NVR vs SS	0.370	-0.35
	NVR vs CS	0.363	-0.35
H13	OS vs SS	0.098	0.15
H14	NVR vs OS	0.386	0.05
	NVR vs SS	0.15	0.35
	NVR vs CS	0.141	0.35
H15	OS vs SS	0.253	0.3

Table 2: The p-values and Difference in Means (DiM) for comparisons between conditions for hypotheses 1 to 15

4.1. Hypotheses with Expected Outcome

The results from the Wilcoxon signed-rank test performed on hypotheses 1 to 15, with an α of 0.05, indicated a significant difference for 10 of the 34 comparisons. Specifically, participants tended to feel more sensory engagement (H1) from the conditions with OS and CS compared to NVR. This could indicate that introducing shaking objects, both on its own and in combination with shaking the screen, was more visually noticeable, thereby more engaging for the visual modality, resulting in an increase in overall sensory engagement. While the three conditions all scored higher, on average, than NVR, OS was not significantly greater than SS (H2).

Visual involvement (H3) was significantly increased by the three conditions with visual representation when compared to NVR, yet OS did not show any significance when compared with SS (H4). This pairs fairly well with the results from both H1 and H2, yet it seems that SS contributed less to the overall feeling of sensory engagement than it did to the visual modality specifically.

Apparently, display awareness was not significantly affected by shaking the screen (H5), even though this was suspected to have an effect. Had this been the case, the level of immersion might have been affected, as the user would not have been entirely isolated from their physical environment. While SS did not increase display awareness, which is a positive discovery, it did not increase the consistency of experiences between the virtual world and the real world (H6) either. In fact, only OS showed a significant increase when compared to NVR, and when compared to SS (H7). This indicates that, even if SS increased visual involvement, the effect was not something participants associated with real life events, whereas they seemed to relate more to the visual experience of OS.

Regarding user involvement with the virtual world (H8), a significant increase was observed in the OS condition when compared to NVR, though not when compared with SS (H9). With objects shaking, moving around, or falling on the floor, it is to be expected that participants felt more involvement with the virtual environment, as they could react to these events by trying to catch the objects or move them back into position. Surprisingly, this did not seem to carry over to the CS condition. A possible explanation to this, and the fact that OS and CS did not generally score higher, could be that during the experiment, a confounding

variable was observed for five of the participants. These participants did not notice the objects shaking, as they were either looking straight ahead or looking out the windows of the airplane. This made the experience similar to the NVR condition, which could have resulted in lower scores for OS and CS. The decision of having the objects in front of the participant be the only ones affected by any shaking, resulted in the entire event being overlooked. A possible solution would be to add more objects in the plane followed by implementing the shaking effect on these as well, making it relatively difficult not to notice.
The user's focus on the VE (H10) was observed as significantly greater for OS when compared to NVR. Again, this probably stems from the participants seeing something in the environment move around, thus resulting in an increase of focus on the virtual world and its contents. For the consistency of information provided through different senses (H11), OS showed a significant positive difference when compared to NVR. The sensory information that participants received from their visual modality during the OS condition, appeared to be more consistent with the tactile feedback provided from the vibrating board, which also ties in with H6.
The comparisons in H12 and H13 showed no significance, resulting in the retainment of their null hypotheses. This could be due to the relatively high scores that all the conditions received for this question, as the differences between them were then only minor and thereby not significant. Lastly, H14 and H15 showed no significant increase in questionnaire scores either. This is possibly caused by the generalness of the question, as participants could take the design of the entire VE into consideration here. Since the focus of this paper was not concerned with the overall realness of the VR experience, time was saved on implementation details, such as adding and animating other passengers in the plane, gradually changing the lighting, or turning on and off the seat belt sign whenever the sound cue was played, etc. This is also evident when examining the average scores for Question 9 (see Figure 3, top right), as these were the lowest compared to the rest of the questions, apart from Question 3 (see Figure 3, top left).

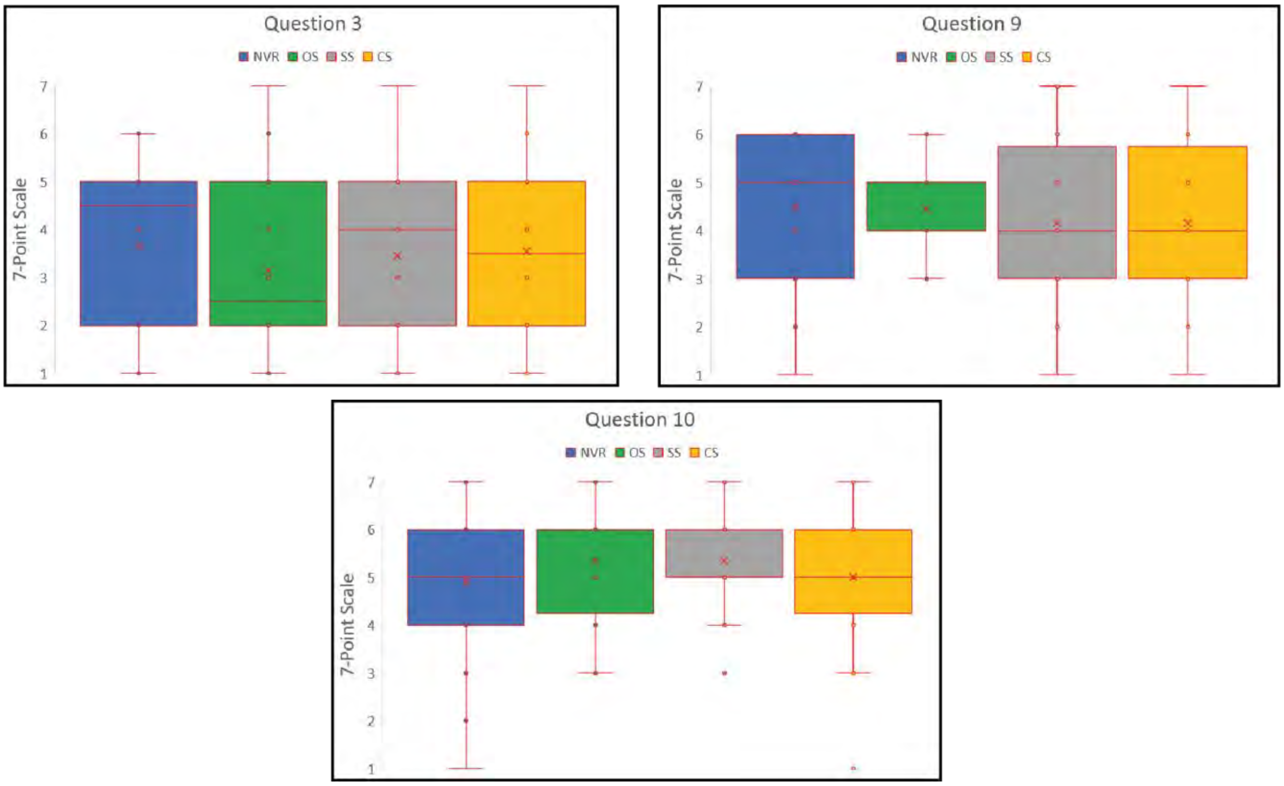


Figure 3: Box plot of answers to Questions 3, 9, and 10 of the Immersion Questionnaire for the four conditions. The ”X” signifies the mean.

In summary, the condition of OS increased sensory engagement, visual involvement, real-world consistency, VE involvement and focus, and consistency between senses, when compared to NVR. While SS and CS generally seemed to increase the scores in the same categories, only CS did so significantly in terms of visual involvement. These results indicate that, if appropriate for the design of the VE; then shaking objects to visually represent vibrotactile feedback in VR, has the potential to increase immersion.

4.2. Hypotheses without Expected Outcome

While the Wilcoxon signed-rank test was also performed on the 21 hypotheses with unclear expectations, their p-value had to be below $\alpha = 0.00238$ due to the Bonferroni correction. Even without this new threshold, none of their null hypotheses were rejected, however, some interesting tendencies and answers were still observed.

For questions 1 to 9 in Table 1, the expectations were that there would be a difference between SS and CS, though it was unclear which of the conditions the difference would favor. While there was no indication of significant differences, CS seemed to slightly outperform SS in eight of nine hypotheses, thereby somewhat demonstrating that adding OS to the visual representation further increased immersion. This was additionally supported by the relatively high p-values (ranging from 0.175 to 0.453) between OS and CS, which indicated a smaller difference between these two conditions.

Question 10 focused on the quality of the perceived tactile feedback, and there were no obvious expectations regarding changes in the participants' answers, as the tactile feedback was identical throughout all four conditions, yet the quality was still perceived differently. This perception was not significant, but as can be seen from the average scores (See Figure 3, bottom), their answers varied between the different conditions, and were generally higher for conditions with visual representation. This could be due to the visual representations increasing consistency between sensory information, thus creating a better match and therefore a notion of better quality.

A final general thought regarding the execution of the experiment is that some of the issues discovered during the experiment and the subsequent statistical analysis could have emerged from how it was conducted, since participants experienced all four conditions in the same experiment. This could potentially have made it difficult for them to reflect on previous conditions to make a valid comparison. Perhaps the experiment should be designed such that the participants only have to compare the condition with no visual representation against that of shaking objects. By doing this, the conditions are more clearly remembered, and participants are less likely to become bored or uninterested. Then, if one of these conditions were to demonstrate to be significantly more immersive, this condition could be compared to another one, e.g. screen shake, and so forth. Furthermore, this would eliminate the problem of multiple comparisons, allowing for a less strict threshold of the alpha value. This is undoubtedly a more time-consuming process, which the time restrictions this study was carried out under, did not allow for.

5. Conclusion

Based on the deployed experimental method of this paper, it can be concluded that visualized vibrotactile feedback in the form of shaking objects has the potential to increase immersion in virtual environments. While this potential is evident, further research is needed to report a definitive increase in level of immersion. Retrospective analysis of the conducted experiment concluded that this could be achieved by conducting a different experimental approach of iteratively exposing participants to different visualization methods, rather than exposing participants to multiple methods in a single experiment.

The revealed potential that visualized vibrotactile feedback can have on immersion level, should be considered by other VR applications, such as games or edutainment software, when designing VR environments. Future work should investigate the proposed revised experimental approach of this paper. Furthermore, a more accurate representation of the physical apparatus to add more realism to the investigated context, along with a more noticeable implementation of moving objects in the virtual environment, is worth exploring. To supplement this last point, eye-tracking could be utilized in the evaluation to examine the participants’ gaze in the environment.

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PERCEPTION & COGNITION

Session Chairs: Sylvain FLEURY, Arts et Métiers, LAMPA
Abdelmajid KADRI, Arts et Métiers, LAMPA

Using virtual reality to represent space: a quick survey of promising methods to investigate spatial knowledge

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Abstract

With recent technological advances and easier availability of computer equipment, virtual reality has been widely adopted in various fields among which basic research is no exception. However using VR to design experimental protocols requires a good knowledge of several central concepts to the interaction between human and virtual. In this paper, we will discuss definitions of VR and its various cognitive components to look at a particular field in which VR has allowed important advances: spatial cognition. We will first examine the limits of VR as a tool for basic research in spatial cognition. Then we will highlight a particularly interesting use of VR related to the introduction of local transgressions of the laws of physics. The aim of this work is to encourage the use of such methods as well as to call for a rigorous use of virtual reality as a valid research tool in spatial cognition.

1. Virtual reality for research in human behaviours

The term "virtual reality" (VR) is an oxymoron: it describes an entity that is simultaneously "real" and "fictional" (Viaud-Delmon, 2007). Early definitions state however that VR is "an alternate world" or a collection of "simulated environments" (Greenbaum, 1992), emphasizing the fact that VR aims to create an artificial situation that is not the reality, but looks a lot like it. As VR was first used to describe an ensemble of computer-related tools by J. Lanier, this domain is strongly rooted in technologies and marketing (Krueger, 1991; Steuer, 1992), thus aiming at recreating a reality specifically depicted on a computer interface (McGovern, 1994). It is important to note that precursors of virtual reality existed long before the advent of computer sciences: applied domains used artificial simulations such as interactive vehicle simulators for pilot formation or evaluation (Lahy, 1927), and even for leisure purposes (see Gigante, 1993; Ringham & Cutler, 1954). These tools used multimodal stimulations synchronized with optic flow (videos) to reproduce real-like situations. In the present report/ article, we will only consider VR as its modern computerized iteration.

With the growing interest of cognitive sciences for VR, more human-focused definitions appeared: VR has become a tool for a better understanding of cognitive mechanisms (Sharma et al., 2016). First, VR is a scientific and technical domain using computer sciences and behavioural interfaces to simulate in a virtual environment the behaviour of tri-dimensional entities, that interact in real-time with each other's and with the users (Fuchs & Moreau, 2006). This definition supposes that adequately simulating reality requires a sufficient degree of real-time interaction. Second, VR requires inducing in the user the illusion of participation in a synthetic environment (Gigante, 1993). The success (or failure) of the induction of such an illusion rests on two distinct psychological states: the feeling of presence and the state of immersion.

Immersion can be described as the state experienced by a participant when one or more of its perceptual entries are isolated from the outside (real) world, and only receive information sent from the computerized simulation (Pimentel & Texeira, 1993). Immersion is seen as an objective level of fidelity between real-world sensory experiences and system delivered sensory experiences (Slater, 2003; Slater & Wilbur, 2004). It strongly depends on the interfacing, which is the collection of technical devices used to display the sensory information: VR systems can be considered as more or less immersive according to the variety and quality of multisensory displays (Bowman & McMahan, 2007). However, immersion also depends on individual characteristics. Some people can experience the illusion of an immersive state while simply watching a video (Robertson et al., 1997) whereas others need to use more immersive technologies such as head-mounted displays. Additionally, higher levels of immersion are correlated with better performances, for example during the execution of a complex memory task (Slater et al., 1996) or complex planning (Gruchalla, 2004). Note that immersion can also be reduced by the interfacing itself which can often be slightly invasive because of its weight or shape, thus causing attention switching from the virtual environment or the task to the device (Dede et al., 1997; Krueger, 1991).

As for presence, it is traditionally defined as the feeling of actually “being there” (Slater & Wilbur, 2004), of being physically part of a world (Sheridan, 1992). Presence is a state of consciousness about existing in an environment that captures attention, appeals to senses and stimulates active involvement (Witmer et al., 2005). To that extent, the higher the number of action possibilities offered by the environment, the better the feeling of presence (Sanchez-vives & Slater, 2005; Schubert et al., 2001). Note that it is possible to measure presence through the use of questionnaires (Slater et al., 1994; Witmer et al., 2005). This method allowed observing that levels of presence can fluctuate in virtual environments as well as real environments depending on the involvement of individuals (Usoh et al., 2000). Experiencing a strong feeling of presence in virtual environments requires a high level of immersion (Held & Durlach, 1992), but also relies on realistic situations that convey perceptual fidelity (Stoffregen et al., 2003) and psychological fidelity (Burkhardt et al., 2003). This means that in order to favour the inducing of presence, virtual environments must emulate realistic graphical aspects, physics, social interactions and spatial arrangements.

Hence, presence is composed by a subjective component (the feeling itself) and an objective component: the likelihood of succeeding at the task (Schloerb, 1995) by adopting a naturalistic behaviour (Slater, 2003, 2009). The possibility that offers VR to observe realistic behaviours in realistic situations has been a major focus in cognitive sciences because it can represent a better way to generalize results in basic research (Rogers et al., 2005). Indeed, traditional experimental protocols have been criticized for their lack of ecological validity, implying that results gathered from artificial tasks performed in the lab do not necessarily reflect actual behaviours in real-world situations (Araújo et al., 2007; Conway, 1991). Immersive virtual reality that furthers high presence levels seems to provide an opportunity to increase ecological validity in experimental contexts (Mestre, 2006; Slater, 2002) while maintaining high experimental control (Pan & Hamilton, 2018) and reproducibility (Aarts & Lin, 2015). However, raising the ecological validity of VR (through higher realism, immersion and presence) comes generally at the expense of experimental control, since this requires the inclusion of potential sources of cognitive bias in virtual environments (Loomis et al., 1999).

Despite the idea that VR can provide accurate emulations of reality, several authors have thus considered that the conception of virtual environment for research should not aim at copying every aspect of reality but rather trying to reach an ideal balance/trade-off between ecological validity and experimental control (Burkhardt et al., 2003; Loomis et al., 1999; Parsons, 2015). In this paper, we will defend the idea that VR is a useful tool for basic research, not because it allows to copy reality with high fidelity while increasing safety compared to field experimentation (Pan & Hamilton, 2018), but because it is possible, conversely, to selectively distort some selected aspects of reality. We will provide recent examples of how researchers can use local transgressions of reality in VR to gather new insights on human thinking, by focusing on a particular field of study which greatly benefits from this tool: spatial cognition.

2. VR for the study of spatial cognition: limits and challenges

Research in the field of spatial cognition seeks for how individuals acquire, store, retrieve and manipulate knowledge about spatial properties of objects and events (Montello, 2015). In this context, VR has been a fantastic tool to gather new results: for example, it allowed the use of brain imagery techniques during real-time navigation (Maguire et al., 1998) and provided new methodologies for the investigation of multimedia learning and retrieval (Chrastil & Warren, 2012; Mallot et al., 1998). This use has been validated by a converging body of literature showing that performances and behaviour observed during VR spatial learning is not significantly different from learning in the real environment (Mellet et al., 2010; Ruddle et al., 1997). Spatial cognition also benefits from VR because it allows the observation of large-scale spatial processing (Ruddle, Volkova, & Bülthoff, 2011) while giving access to high precision measures in real-time such as body position, route recording and pointing direction (Hardiess et al., 2015). VR can also be used to visualize spatial learning methods associated with mental imagery (e.g. *method of loci*, Legge et al., 2012; Reggente et al., 2019).

However, despite these significant advantages, this method also comes with particularly restrictive drawbacks in the specific field of spatial cognition. First, spatial processing requires navigation in the environment, but a large number of studies that allowed participants to move freely only used symbolic walking interfaces such as a joystick or a keyboard (mostly due to technical limitations). This notably led to incongruent results between active learning studies performed using non-immersive technology (see Gaunet et al., 2001; Péruch et al., 1995; Wilson, 1999). Moreover, various works showed that immersive walking technology that simulate aspects of actual walking (such as a treadmill) could improve spatial performances in VR (Chrastil & Warren, 2013; Ruddle & Lessels, 2009), particularly for complex large-scale environments (Ruddle & Péruch, 2004; Ruddle, Volkova, & Bülthoff, 2011) and both for translational and rotational components of walking (Ruddle, Volkova, Mohler, et al., 2011). These ambulatory studies advocate for the systematic use of walking treadmills for studying spatial cognition in VR, compared to symbolic interfaces. For a review of real locomotion techniques for immersive walking in VR, see Cardoso and Perrotta (2019).

Second, immersive VR is likely to cause motion sickness-like symptoms commonly referred to as cybersickness (Rebenitsch & Owen, 2014), including physiological manifestations such as gastrointestinal upset, general fatigue and anxiety (Keshavarz & Hecht, 2011). Cybersickness is usually associated with the experience of locomotion in VR (McCauley & Sharkey, 1992) because it comes from sensory conflicts between visual and vestibular information (LaViola, 2000). However, the risk of experiencing cybersickness can be reduced by using better technologies to avoid frequent causes of sensory conflicts (lags, flicker, poor graphical quality…), which can be achieved more easily nowadays. It is also important to note that many individual factors favouring the occurrence of cybersickness have been identified (Rebenitsch & Owen, 2014), which suggests that preliminary sampling of participants could be possible on the basis of questionnaires (Golding, 2006) or using physiological measures (Dennison et al., 2016). For reviews on cybersickness and recommendations, see Mousavi et al. (2013), or Rebenitsch and Owen (2016).

Lastly, perceptual experience in VR is degraded by nature, in particular with regard to the visual perception of depth. Several studies showed that all distances were systematically underestimated in VR (Kenyon et al., 2008; Loomis & Knapp, 2003), regardless of the interfaces used for display and the distance measurement methods (see Renner et al., 2013 for an extensive review). Identified factors contributing to this phenomena include field of view width (Kellner et al., 2012) or tilt (Leyrer et al., 2011), graphical resolution and sharpness of the image (Kunz et al., 2009), or physical and optical parameters of the ambient light (Tai, 2012). Technical limitations in correctly reproducing the sensation of visual depth cause even greater distance underestimation effects for large-scale environments, because extra-personal distances are more difficult to model and lead to higher variance in participants' estimates (Armbrüster et al., 2008). Thus comparisons of VR performances to real-world observations can be misleading, even though several studies suggested a reliable transferability between VR and actual distances estimations (Mellet et al., 2010). This advocates for protocols comparing spatial learning for different conditions all experienced in VR. In summary, the current state of technologies does not allow to achieve perfect realism yet. Researchers can only achieve a sufficient level of ecological validity to get closer to the fact that behaviours observed in VR are similar to real-life behaviours. However, VR offers a wide range of new possibilities other than the "mere" simulation of a realistic environment, which may turn out to be extremely useful for future research. Among these novel uses of VR for research, we will now focus on the ability to introduce local transgressions of physical properties of reality.

3. Distorting space in controlled ways: local transgressions

VR makes it possible to create new situations, which have never been observed before because their parameters are theoretically impossible to occur in reality. It is then possible to induce precise variations of selected physical invariants in VR in order to observe the effects of these local transgressions on cognitive processes and performances. An illustrative example can be taken from studies investigating how objects acceleration caused by gravity is anticipated during visual perception. Senot et al. (2005) adapted a classical time-to-contact task in VR, during which participants had to observe a ball thrown by a virtual cannon in straight line above their head or below themselves, and hit the ball at the right time with a virtual racket. VR permitted not only to create perfectly repeatable and controlled situations (distances between the cannon and the racket, etc.), but it allowed to manipulate the effects of gravity by setting different ball kinematics (fall durations and ball accelerations). Results of this study showed a significant influence of movement direction on response times, consistent with the hypothesis that effects of gravity on objects motion are automatically computed from visual perception. Similarly, this method can be used to study the influence of gravitational reference frames on various perceptual measures by confronting astronauts in weightlessness to virtual situations simulating the earth reference frame (e.g. Bourrelly et al., 2015; Cheron et al., 2014).

The method of local transgressions is a very insightful tool for spatial cognition, as was shown lately by providing new elements to very important debates such as the one dealing with the nature of spatial representations. Classical views on spatial memory state that spatial knowledge is structured under the form of cognitive maps (Tolman, 1948), which depicts spatial positions on a cartesian system of coordinates (Gallistel, 1990) in a survey perspective (Newcombe, 1985). Cognitive maps are supposed to be isomorphic and use Euclidean geometry (O'Keefe & Nadel, 1978; Thorndyke & Hayes-Roth, 1982). Recently, VR has been used to test these hypotheses and disentangle classical theories from more recent spatial representation models, in particular about the Euclidean and isomorphic structure of spatial knowledge in memory. For example, Warren et al. (2017) compared spatial learning performances for a Euclidean and a non-Euclidean virtual maze. The non-Euclidean virtual maze featured two "wormholes" that instantly and seamlessly teleported and rotated participants from one place to another as if they had crossed a shortcut through space and time. Participants then had to plan and navigate routes between different landmarks. Results showed that non-Euclidean virtual environments were leading to the same performances as Euclidean environments. More interestingly, routes with wormholes were mainly selected by the participants. In a second study, comparing map drawing for participants who performed the task in a Euclidean or in a non-Euclidean environment unveiled automatic integration of the geometry violations in the second case. The participants who studied the non-Euclidean environment seem to integrate metric violations analogous to "folds" or "tears" in their spatial representations, in an automatic and unconscious way (Warren et al., 2017). These results question the assumption that individuals construct Euclidean and isomorphic representations of space, and are in line with early works showing that "hyperlinks" (spatial discontinuities analog to wormholes) in

VR could be exploited by participants to obtain good performances to a variety of spatial tasks such as route planning or map drawing (Ruddle et al., 2000). Additionally, using “hyperlinks” in VR has also been used to gather new insight on the relation between temporal and spatial representations in the brain using fMRI (Deuker, Bellmund, Schröder & Doeller, 2017).

In these studies, VR was used to introduce local transgressions of physical spatial properties by creating impossible spatial objects (wormholes or hyperlinks). Several studies also used VR to violate global metric properties in order to observe how individuals could gather and use spatial information in these impossible places. Zetzsche et al. (2009) created impossible indoor environments by exaggerating relative sizes of corridor segments and angles. Although all environments were enclosed and navigable (from the participant perspective), they were not possible in the real world. For example, a triangular shaped spatial layout could contain angles whose sum exceeded the 180° of a normal Euclidean triangle. After learning Euclidean or non-Euclidean geometry environments, participants were asked to plan and navigate different routes between several landmarks. As for Warren et al. (2017), results showed that Euclidean geometry transgressions did not prevent participants from solving the tasks by choosing the shortest possible routes. Since metric properties linked with horizontal spatial choices (e.g. “second path on your left”) are more easily/accurately encoded and retrieved from memory (Poucet, 1993), the authors replicated this protocol in a second experiment dealing with another type of transgression: violations of planar topology. Topologic inconsistencies in irregular environments resulted in a “disruption of their inside/outside regional structure”, where paths entering the inside region from the outside were not intersecting with boundaries and other paths as they should in a Euclidean space (Zetzsche et al., 2009). Again, results show that planar topology transgressions did not affect navigational performances, what the authors interpret as evidence that internal spatial representations are not Euclidean. These results have been replicated in several studies, showing that impossible spaces did not need to be translated into Euclidean representations to be properly used (Kluss et al., 2015). It seems that a dissociation exists between perceptual information which looks Euclidean-like for immediate distances, and spatial representations, which might dispense with Euclidean-like structure. However, it should be noted that introducing local transgression should not prevent researchers from trying to minimize distance biases previously discussed, because violations of Euclidian geometry do not affect perceived distances in themselves: it impacts spatial relations and the consistency of spatial structure.

Through these examples, we showed that VR could represent a useful tool to present participants with distorted spaces and observe to what extent spatial knowledge was altered by these local transgressions of geometry. Nevertheless, space is not only defined by geometry: ecological views of perception state that space is perceived as a venue for action, where action possibilities and anticipated physical effort is automatically computed from vision (Gibson, 1979; Proffitt, 2006). Following these ideas, embodied and situated views of cognition emphasized the importance of bodily states during the construction of multimodal representations, with the assumption that sensorimotor processes are re-enacted in order to bring out concepts from memory (Barsalou, 2008; Gibbs, 2006). As we pointed before, immersive VR can make use of sensorimotor interfaces to let users perform a wide range of actions and receive sensorial feedbacks from the simulation. Thereby, VR has been used to study various postulates of embodied and situated cognition by introducing sensorimotor transgressions during spatial processing: if sensorimotor processes participates to the construction of representations, then artificially distorting selected aspects of the perception-action loop should lead to observe differences compared to non-distorted situations. In that vein, Creem-Regehr et al. (2004) used a force feedback walking treadmill to observe how visual slant and walking effort interact while estimating slant angles. In this experiment, participants were actively walking in a virtual environment simulating various degrees of slopes. A force apparatus allowed experimenters to manipulate the degree of effort needed to walk (with or without appropriate slope force). Participants were then tested on verbal estimations of slopes and motoric estimations (using a tilting device which inclination had to be matched with the travelled slope). Results showed that walking with an appropriate effort with regards to the slant led to greater verbal overestimations of slant than walking without appropriate slope force, while motoric judgments remained precise and unbiased in all conditions (Creem-Regehr et al., 2004).

Using a different approach, Lhuillier (2019) recently used an omnidirectional treadmill to maintain walking effort constant while having participants learning uphill and downhill slanted routes. The goal of this study was to investigate how slant visual perception influenced the metric properties of spatial representations in memory, and how body-related information participates to this process. After learning virtual environments by travelling uphill or downhill routes, participants were tested on their global spatial representation by positioning landmarks on a map. Unlike previous classical works (Creem-Regehr et al., 2004; Stefanucci et al., 2005), results showed greater underestimation of all distances from memory (global compression of the metric representation) after uphill learning compared to downhill learning. As this effect was attributed to the proprioceptive feedback transgression of walking uphill without additional effort (made possible by VR), a second experiment replicated this protocol by fixing this transgression applying additional effort for all conditions using loaded ankle weights. Spatial learning without proprioceptive transgression then yielded no significant metric distortion between uphill and downhill routes. In summary, sensorimotor local transgressions induced by VR allowed to gather new results by studying novel situations that could not be observed without this tool. Interestingly, the use of local sensorimotor transgression in the study by Lhuillier (2019) was not accompanied by a decrease in the subjective feeling of presence measured by questionnaire (Witmer et al., 2005). This was true for all sub-scales of the questionnaire including those dealing with the possibility of acting and the interfacing with the environment, even if the synchrony between walking physical effort and visual information was violated in this study. This suggests that the behaviours of participants were naturalistic, but also that the sensorimotor transgression was not large enough to be consciously affecting the ecological validity of the task. Unfortunately, previous cited works using geometry transgressions did not asked participants to fill presence questionnaires, but they assessed by the means of other questionnaires that participants were not explicitly aware of the non-Euclidean nature of the environments (Kluss et al., 2015; Warren et al., 2017; Zetzsche et al., 2009). It is important to note that all works described in this paragraph suggest that sufficient levels of presence can be elicited by impossible environments using local transgressions. Thus, the use of this method should not rule out the search for ecological validity. One of the possible ways to conciliate local transgressions and ecological validity could include the use of inconspicuous distortions so that participants remain unaware of these transgressions. Nonetheless, the question of whether violations of Euclidean geometry affect the feeling of presence (and therefore the validity of behaviour) remains to be systematically explored in future works.

Lastly, interesting examples of this use of VR can be found in the studies dealing with body schemas. For example, the classical paradigm of the rubber hand illusion (Botvinick & Cohen, 1998) has been adapted in VR in order to disentangle possible causes of this effect between proprioceptive, visual and motor information (Sanchez-Vives et al., 2010; Slater et al., 2008). These studies are based on VR's ability to induce a sense of embodiment (Kilteni et al., 2012), which explains why participants easily perceive avatars as their own body. Sense of embodiment can then be used to observe how one's body constraints can shape space perception: for example using various heights of the avatar (Leyrer et al., 2011; Lin et al., 2012) or simulating various arm lengths (Linkenauger et al., 2015), according to embodied views on spatial cognition. Other works even showed that embodying an articulated avatar in VR improved distances estimations compared to a non-articulated one or no avatar (Mohler et al., 2010), emphasizing the importance of fostering embodiment to favour performances and presence, even when artificial distortion are included in virtual environment for the needs of research.

4. Conclusion

In this work, we provided a brief overview of important notions to consider when using VR as a methodological tool for basic research. We then presented a short overview of how VR can be used to gather novel findings in the field of spatial cognition. It is manifest that technical and psychological progresses in the use of VR during the last fifteen years largely benefitted to our state of knowledge regarding spatial perception and spatial representations. We advocated that, even though VR lets us improve (to some extent) several identified pitfalls of experimental research in spatial cognition such as the lack of ecological validity, its primary interest for future research does not lie in this point. Many insightful protocols used VR to observe the effect of physical, geometrical or sensorimotor transgressions on cognitive functioning, often providing novel results. We support the idea that using VR for this kind of controlled local transgression method is likely to lead us to important advances in this research field, because it will allow us to observe humans evolving in situations that were hitherto impossible to create. However, this does not free us from having to overcome the methodological challenges that are currently facing cognitive sciences, such as reducing risks of cybersickness, improving immersive displays and interfaces, or more importantly trying to minimize the distance biases inherent to VR.

5. References

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Reliability of virtual reality for user experience in spatial cognition: an exploratory approach.

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Abstract

Immersive virtual reality technologies have proven multiple experimental benefits for the study of spatial cognition in large-scale environments, such as a high control over variables and safe travels. However, in navigation tasks, the user orients himself thanks to an integrated, unconscious and complex mechanism combining the use of locomotion and cognition. The constraints linked to the use of a motor interface and a virtual environment for navigation raise questions about the possible generalization of the data collected in these digital experiments. Our long-term objective is to evaluate the reliability of virtual reality to assess the user experience in the specific dimension of spatial cognition. However, user experience in virtual reality is complex to evaluate, and navigation tasks are often evaluated with isolated subjective data.

In this paper, we describe the design of a comparative study dedicated to spatial cognition and involving a multidisciplinary approach (neurosciences, psychology, and engineering). We present the development of a protocol suited for virtual and real environments, combining the collection of subjective and objective data (behavioral, biomechanical and physiological measurements), then the modelling of a virtual environment dedicated to spatial cognition is described. To finish, the constraints met during an experimental test and the feedback of the participants are presented.

1. INTRODUCTION

Immersive virtual reality technologies is a very dynamic field, where innovation follows a very high pace of renewal (Anthes, García Hernandez, Wiedemann, & Kranzlmüller, 2016). One of the areas where the development of new immersive virtual technologies has given new impetus is the study of spatial cognition in large-scale environments, including navigation. Navigation combines both a locomotor dimension, i.e. a coordinated movement in the surrounding environment, and a cognitive component (including orientation, planning and decision-making, necessary to reach a destination) (Montello, 2005). Its study in Virtual Environments (VE) allows different experimental benefits, such as a high control over variables, safe travels and the possibility to access various environments. However, the design of these experimental materials is complex and rely on the good understanding of the human's cognitive behavior in order to create an adapted model and interface. Moreover, questions remain about the user experience in these virtual experiences, notably about the possible generalization of these results in the real environment, also known as the ecological or external validity: does the simulation of a displacement in a VE have a similar impact on spatial cognition as the one caused by a displacement in a real environment?

The evaluation of the user experience can be done by collecting subjective and objective data (cognitive, behavioral, biomechanical and physiological). Most studies have used isolated data. Our goal is to combine these methods in order to make a more in-depth evaluation of the user experience, in order to assess the reliability of VE in the field of spatial cognition. However, this methodology is a real challenge, which requires a multidisciplinary approach. Indeed, we believe that studying the issues raised by immersive technologies development with the expertise of both neuroscience and engineering fields could lead to a better understanding of the user experience and a more efficient and adapted design of virtual reality technologies.

In this paper, we present the design of a comparative and descriptive cross-sectional study, including the development of a protocol suited for virtual and real environments, and the modelling of a VE dedicated to spatial cognition. We also present the first conclusions of an experimental pre-test, realized to identify possible technical constraints, and the future works considered.

2. RELATED WORKS

This section will focus on describing the main methods for evaluating the user experience in the context of navigation, adapted to both the real and virtual environment.

The evaluation of the user experience can be done by collecting subjective data, most of the time by using self-report questionnaires. This type of questionnaire can be useful to get specific information on the user after the experiment to understand how the person felt while performing, or before the experiment, such as a competency self-evaluation. One of the first scale is the "Santa Barbara Sense-of-Direction Scale" (Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002). Validity studies have shown that this scale is correlated with tasks evaluating navigation, based on a spatial strategy. "The Familiarity and Spatial Cognitive Style Scale" (Piccardi, Risetti, & Nori, 2011) takes into account the spatial cognitive style (route type or spatial type) and familiarity with the environment, internal factors that would influence the sense of direction. The "Wayfinding Questionnaire" (van der Ham, Kant, Postma, & Visser-Meily, 2013a) has the advantage of integrating 3 dimensions (with its own score) concerning spatial navigation capacities, distance estimation and a psychological measure of spatial anxiety.

To be independent from the user's subjective interpretation and evaluate his behavior objectively, it is also possible to use physiological sensors, to measure muscle activity, heart rate or electrodermal activity for example (Kroes, Dunsmoor, Mackey, McClay, & Phelps, 2017; Meehan, Razzaque, Insko, Whitton, & Brooks, 2005). The use of objective indicators is essential to study phenomena that are not always conscious, as is the case in spatial cognition. However, the use of sensors also adds constraints to the experimentation field, because of their implementation, the possible discomfort they can cause to the participant, and the difficulty there may be in interpreting the data. Navigation based experiments are particularly demanding because the device must not be too invasive as to not distract or hinder the user's gestures, and it should provide the clearest possible measure despite the risk of artefacts linked to the movements.

Biomechanical measurements such as eye tracker are also widely used in the field of navigation, and particularly in wayfinding tasks. Wayfinding refers to the ability to go to a given destination, in a new or complex environment. It is similar to a spatial problem-solving task and strongly mobilizes information search strategies in order to be able to plan and then execute the route. Although all of the senses can be mobilized, sighted individuals are essentially based on visual cues. The selection of visual cues in the environment, or selective attention, can be guided endogenously (involving a top-down process) or exogenously (bottom-up process). Studying the visual sense has several advantages, because it collects spatial information at a much greater distance and at a higher resolution than the other senses, and because humans actively direct their visual sense (unlike, for example, the vestibular sense or hearing) (Kiefer, Giannopulos, Raubal, & Duchowski, 2017). In addition, the use of eyetracker is a particularly interesting tool for studying the strategies used to select this information.

Cognitive measurements are used to assess spatial memory. Tasks are generally distinguished according to the type of spatial knowledge they assess: the most basic, landmarks knowledge, can be evaluated via a task of recognizing or evoking landmarks present in the environment. Route knowledge is classically evaluated by a task of route-learning, where the subject must reproduce a route, learned either by direct navigation in the environment, or via a medium such as a map or a GPS, or even by a task of classifying the landmarks in chronological order of the route. Finally, survey knowledge, the most elaborate, is based on a cognitive map type representation, comprising the metric relationships between the landmarks, in a coordinate space. This knowledge is assessed by tasks such as locating landmarks on an environmental map, by map drawing, by pointing tasks, or even by estimating distance.

Distance perception is a much-debated topic in literature. In a real environment, the different mechanisms involved in an accurate distance perception are not yet fully understood, which of course complicates the design of an ecologically valid VE. Indeed, egocentric distances tend to be underestimated to 74% of the modeled distances in VE (Renner, Velichkovsky, & Helmert, 2013). In a review of the literature, Montello (1997) suggested that knowledge of the route distance can be based on three sources of information: the number of environmental landmarks, the duration of the route and the effort produced by displacement. Van Asselen, Fritschy, & Postma (2006) suggested that effort can be divided into physical and cognitive efforts, i.e. the requirement in terms of attentional and memory resources. Distance estimation is also influenced by the learning mode of the route (incident versus intentional). Thus, these authors (van Asselen et al., 2006) showed that participants who intentionally learned the route overestimated the walking distance, while the incident group underestimated it, suggesting that acquiring knowledge of the survey is effortful. These factors are thus to be taken into consideration for comparative studies of navigation in real and virtual environment.

Depth perception is known to rely on pictorial and nonpictorial cues. Pictorial cues are found on a static scene, where we use information of relative position to estimate the distance between an object and us. For example, if an object hides another then we will assume it is closer to us. If two similar objects are different in size, we will assume the biggest one is the closest, etc… (Cutting & Vishton, 1995) Consequently, increasing the number of nonpictorial cue and creating a well-furnished, complex VE has shown positive impact (Kenyon, Sandin, Smith, Pawlicki, & Defanti, 2007). A common and homogeneous ground surface has also been identified as a key element to improve distance perception, the texture-gradient information being used as a depth cue (He, Wu, Ooi, Yarbrough, & Wu, 2004; Wu, Ooi, & He, 2004). Nonpictorial cues rely on the oculomotor system of the individual and its adaptation to motion. It includes for example convergence and accommodation, but also binocular disparity, which led to the development of stereoscopic presentation of virtual environments.

The study of navigation requires interaction with the VE, allowing or giving the illusion to the individual to move. However, its realistic implementation is also one of the most difficult tasks in the development of virtual reality (Steinicke, Visell, Campos, & Lécuyer, 2013). The best locomotion interface highlighted in literature involve translational and rotational body-based information, meaning the user needs the proprioceptive information generated while walking and turning or looking around, just as in a natural displacement. The use of an omnidirectional treadmill to address the need for natural walking in large-scale environment is also becoming more widespread (Ruddle, Volkova, & Bülthoff, 2011).

Regarding the VE itself, visual realism has been shown to improve spatial cognition (Meijer, Geudeke, & van den Broek, 2009).

Evaluating the user experience in a global manner thus pushes us to take into account a set of factors, at the same time physiological, psychological, cognitive and biomechanical, in order to be able to evaluate the validity of a VE in the study of spatial cognition. The previous review shows that given the complexity and diversity of the parameters to be taken into account, comprehensive methodologies need to be further developed. As a consequence, the objective of this exploratory research is to develop an experimental protocol aimed at assessing the impact of the environment media (real situation versus virtual one) on navigation performance, the navigation strategies to reach a determined destination, the spatial memory of the environment, the emotions (physiological reaction to surprising events), and the gap between subjective and objective evaluation.

3. METHODOLOGY

Our protocol proposes the combination of different tasks and type of measurements explored in the previous overview (figure 1).

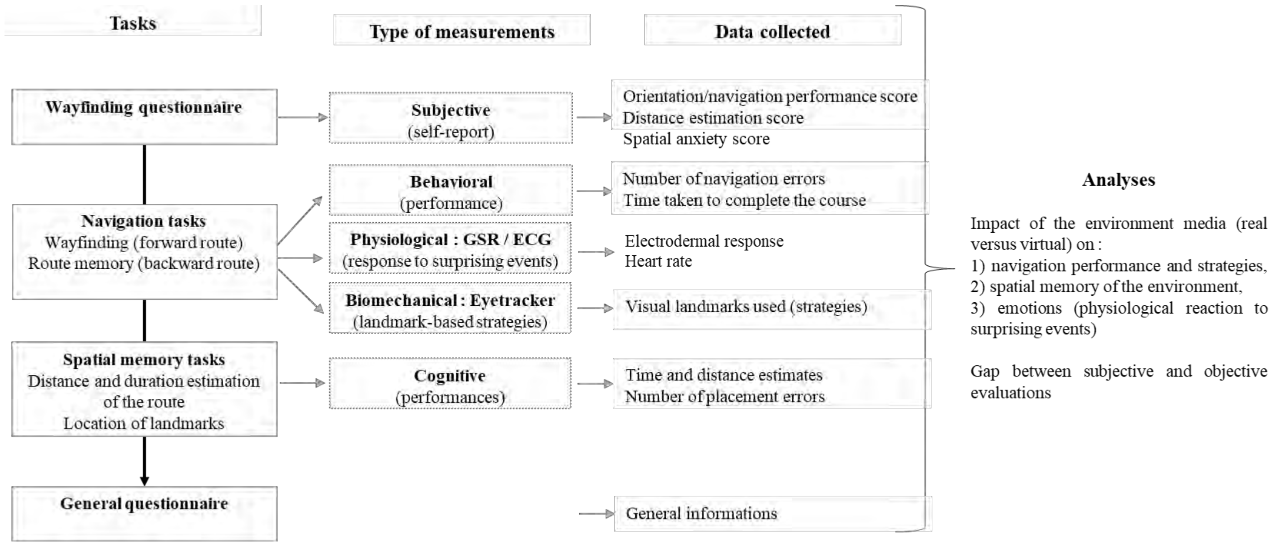

Figure 1: Experimental protocol summary
GSR = galvanic skin response; ECG = electrocardiogram

3.1. Tasks and Procedure

The navigation task was designed covering a path on two floors of the building of two French engineering schools. A similar environment was developed in virtual reality, which we will detail later. The protocol described below is designed in order to compare directly spatial cognition between the real and virtual setting without any knowledge transfer.

3.1.1.Subjective assessment: Wayfinding Questionnaire

First, participants were asked to fill a spatial orientation questionnaire (van der Ham, Kant, Postma, & Visser-Meily, 2013) before the beginning of the navigation task. This questionnaire evaluates navigation capacity, distance estimation and spatial anxiety. Results will be used in order to apprehend the gap between the objective and subjective data collected, and possibly anticipate it.

3.1.2.Navigation tasks: wayfinding and route learning

After answering the questionnaire and equipping the different sensors (see figure 2), participants were informed of the instructions: to go from the ground floor of the school to the underground parking lot of the school and bring back directly a lost set of keys located at a numbered parking space. The first part of the travel is a wayfinding task, requiring the user to search for navigational aids in the environment such as signs, and make multiple decisions. The second part, on the way back from picking up the keys, focuses on the evaluation of spatial memory (backward route).

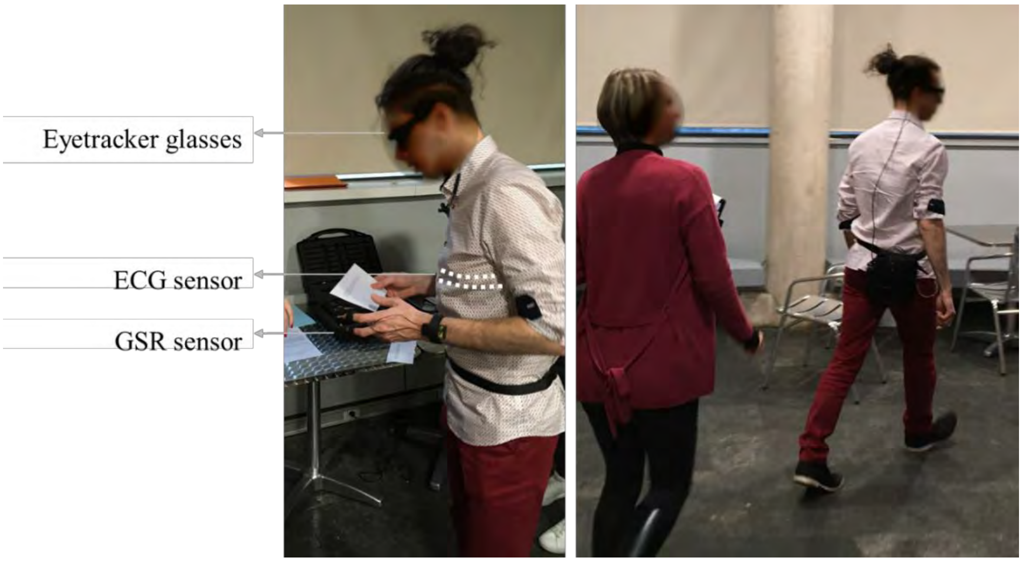

Figure 2: Sensor equipment
On the left, participant equipped with the three sensors (ECG sensor is worn under clothing directly on the skin). On the right, the participant moves with the bag containing the receiver case behind his back, an experimenter follows him during the navigation task. ECG = Electrocardiogram; GSR = Galvanic skin response

3.1.3.Spatial memory tasks

The participants were asked to estimate the duration of their travel and the distance they covered. Then, they had to reposition encountered landmarks of the ground floor on a map.

3.1.4.General questionnaire

Demographic information was collected such as age, sex, number of years of study.

3.2. Measures

We collected both objective and subjective data.

3.2.1.Subjective (self-report navigation skills)

In order to assess the subjective skills of spatial navigation and distance estimation, as well as spatial anxiety, the participants completed the Wayfinding Questionnaire (van der Ham, Kant, Postma, & Visser-Meily, 2013). This scale has 22 items to rate on a Lickert scale from 1 to 7, giving a total score for each of the 3 dimensions assessed.

3.2.2.Behavioral (navigation performances)

To evaluate the navigation performances, we chose to analyze the number of orientation errors and the time taken to complete the route during the wayfinding task (forward) and the route learning (backward).

3.2.3.Physiological (GSR / ECG)

To measure emotional reactions we chose to collect physiological data using an electrocardiogram and a Galvanic skin response sensor.

The study of heart rate and its variability is used as an indicator of psychological stress. The heart rate variability is dependent on the autonomic nervous system and activation of the parasympathetic of sympathetic system. The last one is responsible for the stress-related physiological response by preparing the body to respond with action, thereby causing an increase in heart rate and a decrease in the heart rate variability. Physical and cognitive activity can naturally affect heart rate (Fallahi, Motamedzade, Heidarimoghadam, Soltanian, & Miyake, 2016). In this experiment, the participant is required to move around and use stairs to change floor, which can cause unwanted artefact of physical exercise. Therefore, we decided to consider heart rate only for the first part of the experiment, where the participant go from the ground floor of the school to the parking lot. The physical exercise being limited to walking and going down the stairs (Appelhans & Luecken, 2006; Azam, Ritvo, Fashler, & Katz, 2018; Kim, Cheon, Bai, Hwan Lee, & Koo, 2018; Rieger, Stoll, Kreuzfeld, Behrens, & Weippert, 2014).

The electrodermal activity, or galvanic skin response, is also used to measure an individual's physiological response. In the literature a link is often made with the individual's emotional state (Armougum, Orriols, Gaston-Bellegarde, Marle, & Piolino, 2019; Nourbakhsh, Wang, Chen, & Calvo, 2012). The electrodermal activity is based on the skin conductance variations, which are caused by the activation of sweat glands located on the palmar or plantar surfaces (Sequeira, Hot, Silvert, & Delplanque, 2009). As it is a direct reflection of the sympathetic system activity, this response can be the result of various causes (physical stress, emotional state, mental load, etc.) It is therefore difficult to associate this measure with a specific psychological or emotional state (Dawson, Schell, & Filion, 2000). In our protocol, we use the electrodermal activity sensor in order to evaluate the physiological reaction of the individual confronted to specific visual or auditory events, in the real situation and the modeling. Within the framework of a VE, many parameters are controlled, which limits interpretation biases.

Moreover, concerning both the analysis of the ECG and GSR measurements, we are interested in observing the physiological reaction to a very precise and timed event. Therefore, we are looking for a sudden variation following the trigger of said event, and not the general evolution of a mean, which limits the risk of interpretive bias due to artifacts or uncontrolled parameters.

3.2.4.Biomechanical (landmark-based strategies)

In order to apprehend the navigation strategies of the individual an oculometric measurement is carried out with eyetracker glasses to identify the various landmarks used by the participant during the navigation task in the building. The objective is to compare the observation and landmark finding patterns in both real and virtual situations.

The same data will be collected in the real environment and its digital equivalent. We used T-sens sensors to collect the electrodermal activity and the heart rate. People navigating in the real environment wore Pupil Labs eyetracker glasses, whereas participants exploring the VE wore a HTC Vive Pro EYE head mounted display (HMD) equipped with a built-in eyetracker system.

3.2.5.Cognitive (spatial memory)

We asked the participants to estimate the duration of their travel and the distance they covered. Then, they had to reposition encountered landmarks of the ground floor on a map.

The survey knowledge or the "cognitive map" is assessed through two tasks: an assessment of the distance of the backward route, (in meters), i.e. between the moment the subject takes the keys to the starting point and an estimate of its duration (in seconds). This distance was compared to the actual distance and duration.

To assess whether the subjective assessment of distance estimate was predictive of actual performance, the score of the questionnaire was compared to the objective estimate of the actual distance of the route.

Finally, the subject is asked, from a map, to replace 7 landmarks present in the hall in the right place. A score out of 7 was calculated.

4. IMMERSIVE ENVIRONMENT DESIGN

To investigate these questions, we designed a VE similar to one of the building of the engineering school used as experimental field (figure 3). To focus on the key elements essential to navigation and spatial perception, we used the design method developed by P. Fuchs, G. Moreau and J-M. Burkhardt (2006) (Richir, Fuchs, Lourdeaux, Millet, Buche & Querrec, 2015). They distinguish three levels of immersion and interaction: the functional, cognitive, and sensorimotor levels. The functional level states what we will ask the user to do in the future environment. The cognitive level clarifies the behavior schemes the user will have to use in order to realize these tasks. Finally, the sensorimotor level specifies the interface and technological devices needed.

4.1. Functional level

The design should allow users to travel and orient themselves naturally. It should display the underground parking lot and the ground floor of the school in a realistic manner and show the same visual landmarks, in order for the user to be able to create a mental map of the environment while navigating. The user should be able to read the different indicative signs to find his way and reach the given objective. Interactions should also be possible with elements hindering exploration, such as doors to open. The design should allow the user to assist to different surprising events and react to it.

This suggest:

- The possibility to travel in all direction of the immersive environment: change direction, retrace one's steps, or take the stairs to another floor.
- To have a global vision of the environment: being able to read close signs or see landmarks from afar.
- To watch an event and associate the sound with the visual effect.
- To manipulate door handles in rotation to open a door or to push it open.

4.2. Cognitive level

To answer the different tasks asked from the user in the previous level, he will have to use behavioral schemes linked to:

- Movement and navigation in a space
- Global observation of an environment
- Sound and visual observation toward a determined direction
- Gripping and spatial handling of a handle or a door.

To design our environment we used Unity game engine, which already parameters the physics between the objects of an environment (pictorial cues) and the sound localization, important for noticing and observing an event which takes place at a specific location. Several items (cars, chairs, coffee machine, plants…) were placed in the environment in order to display a rich cues environment, and particular attention has been paid to the different textures. They were developed using the software Blender to look as close as possible to the real surfaces of the building.

We did not make any changes to modify the parameters influencing the nonpictorial cues. They are linked to the hardware used, which will be specified later in this paper.

4.3. Sensory-motor level

The major point in the design of the interface is how the user will move in the environment.

In our case, the VE is too big to consider a free walk (it would require a very large empty hall, which we do not have) and the need to use stairs to change floor was a constraint. The use of an omnidirectional treadmill was not an option since we do not have this kind of technology in the laboratory yet.

To keep part of the proprioceptive information we chose to let the user rotate freely in the environment in order to change direction or look around. This was made possible thanks to the HMD built-in tracking system. For this pilot study, translational movements were controlled via the controller's joystick. To use the stairs and change floor we chose to teleport the user as he approaches the steps. We know that setups with a linear speed of translation can cause a feeling of dizziness, therefore we were extremely cautious towards the participants during the experiment (McCauley & Sharkey, 1992).

The interactions with objects of the environment are performed with the controller. The user has to reach for the object and trigger a button to cause the action.

In our final environment, the user needs to manage a motor interface to move in the virtual building and interact with different objects. Learning how to use the controller and interact with the environment can take time and might complicate the beginning of the experiment, notably for users who are not familiar with the use of immersive virtual reality technologies. In order to lower the attention needed to use the interface and limit a possible additional cognitive load, we designed a learning phase involving a simple environment, displayed just before entering the main environment of the school building. In this first contact with the virtual world, the user can become familiar with each interaction necessary later in the experiment: how to open doors, to pick up an object, how to navigate in the environment and how to teleport up or down the stairs. The next step of the experiment is only started when the participant feels ready.

Concerning the hardware dedicated to the display of the VE, each participant will wear a Vive Pro Eye head mounted display with a Dual OLED 3.5" diagonal screen and a resolution of 1440x1600 pixels per eye (2880x1600 pixels combined). This device offers a field of view of 110° and a refresh rate of 90Hz. It is also equipped with an audio headset. The environment is rendered on an Intel Core i7-7700HQ processor computer, with a GeForce GTX 1070 graphics card and 16Gbytes of RAM.

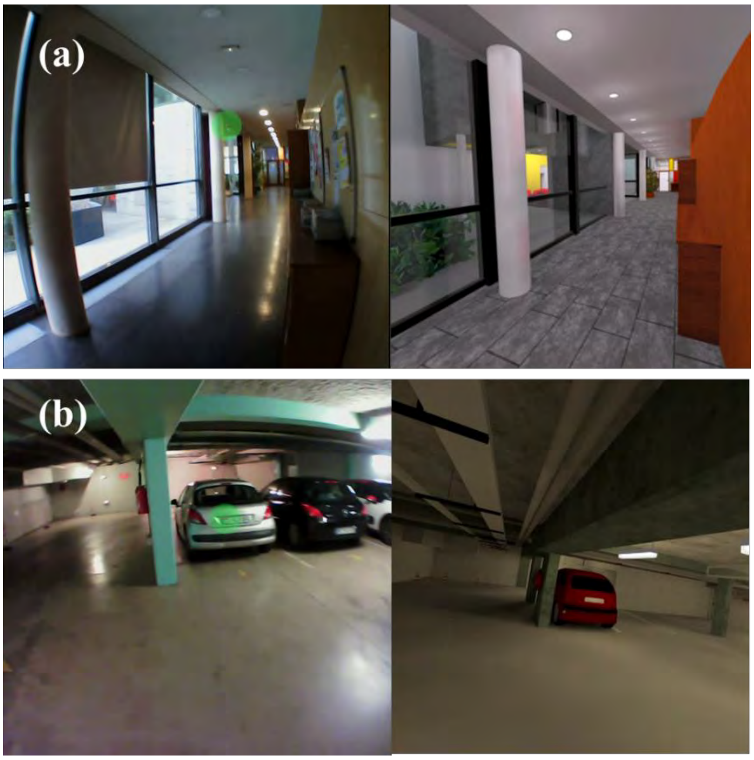

Figure 3: real environment and its modeling

The ground floor of the school (a) and the underground parking lot (b), with the real environment on the left and the modeling on the right. On the left the eyetracker measure is pictured with a green circle (the green mark is also present in the VE but less visible)

5. PRELIMINARY RESULTS

A real condition experimental test was realized in order to identify the possible technical constraints and identify areas for improvement of user experience assessment in a mixed approach comparing reality and VE. We proposed this study to a group of 21 participants (10 females; 11 males; mean age: 24.3, min18-max31). After giving their written consent, they were assigned in two groups: the real environment (RE) group, or the VE group. In the RE group the user wore eyetracker glasses, which was not compatible with the wear of corrective glasses. Therefore, all participants wearing corrective glasses were automatically included in the VE group. Those wearing corrective lenses or without correction were randomly assigned. 13 participants were included in the RE group and 8 in the VE group. It took eight hours to perform these experiments with 2 researchers and 1 engineer to accompany the passage of the participants for each situation VE and RE.

First results revealed frequent data loss in RE group, on both the ECG and the eyetracker measurements. During the experiment, the receiver of the ECG and the one used to record the oculometric data were placed on different location depending on the participants, in order for them to feel comfortable with the sensors and the cables. Our hypothesis concerning the ECG loss is that when the receiver was placed in a back pocket, the body caused too big an obstacle to collect the signal of the ECG sensor, placed on the chest. Considering the eyetracker issues, the fact that the participants were dynamic and walking during the experiment caused the cable to disconnect multiple times. In order to resolve these issues, the ECG receiver was upgraded and we plan to equip future participants with an adapted bag to place the receivers at the same location during the experiment, to favor an ergonomic setup and a better signal reception. A 3D printed part is being designed to secure the eyetracker cable to the socket. Future tests will validate the implementation of these solutions.

During the feedback sessions, participants expressed a discomfort concerning the sensors they wore. At the beginning of the experiment, while equipping the sensors, the experimenter notified them not to touch them or move them once they were in place. Participants told us that this instruction led them to be very focused on this particular point during the experiment and worried about doing something wrong. It may have impeded their movements and distracted them.

Considering the VE group, no technical constraints linked to the ECG, GSR or eyetracker acquisition were met. We observed that participants sometimes had difficulties to navigate in the environment. However, everyone agreed that the learning task in which one could try the interface and test the different interactions was enough to feel prepared for the navigating task. Those who may have felt difficulties perceived the virtual experience as anxiety inducing, and said that they felt pressured by the modelling because everything felt too close to them. We assume that this could be linked to a poor understanding of how the controller works. Some participants had issues pressing the button correctly in order to move in the environment, which may lead to a feeling of not being in control of the distance between them and the environment. This might be resolved by training the participants on the controller prior to wearing the HMD, so that they can properly see the controller while using it before beginning the learning phase.

On the opposite, certain participants reported that they felt the VE was very safe because they knew nothing could happen to them. All participants agreed that the sound environment felt too empty and that moving with the joystick resulted in a feeling of dizziness. These feedbacks will be used to improve the VE for future use.

6. CONCLUSION AND FUTURE WORKS

In this paper, we present the design of an original experimental protocol, based on the combined collection and analysis of subjective and objective data (behavioral, biomechanical and physiological measurements), to evaluate the reliability of virtual reality to perform experiments involving spatial cognition of potential users. We also present the design of the VE and the results of a first experimental test involving students.

First results showed technical constraints due to the movement of the participants during this navigation task, and improvements have been identified for the VE. We plan to improve the sensor robustness and ergonomics, and implement the modelling according to the feedback of the participants in order to plan a second measurement campaign on a larger scale under better conditions.

The use of a joystick to control the translation in the environment is an important limitation of this pilot study. In future works we would like to explore the possibilities of the redirected walking technique, which seems promising to answer the physical constraints we met in the design of this protocol (Langbehn, Lubos, & Steinicke, 2018; Langbehn & Steinicke, 2018).

This study shows further comparison between RE and VE is improved by a multidisciplinary approach to user experience. The use of physiological data is reliable to have an objective evaluation of the user's behavior and its interpretation should help determine for what kind of application we can use VE effectively. The understanding of complex cognitive mechanism such as spatial cognition requires a holistic approach in the type of data collected during the experimentation and the underlying technological means, as well as in the expertise of the analyses. In this new exploratory approach, research team involved psychologists, neuroscientists, 3D designer, technicians, etc. Substantial material and human resources were required for results that need to be strengthened before a real implementation. If the results of a larger scale experiment prove to be relevant, a future development path could focus on optimizing the cost effectiveness of such a process.

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Development of an IMU-based ergonomics assessment tool for virtual reality

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Abstract

Human workers are confronted to an increased level of interaction with machines on work settings and manufacturing environments. The design of adaptative production systems that further enhance human's physical, sensorial and cognitive capabilities requires a thorough understanding of their capacities and a deep analysis of their interactions. This highlights the need for tools that facilitate the study of human-machine interactions on the early design phases. Virtual reality technologies provide a great opportunity to simulate and let users interact with the system during the design process. Some existing tools for motion capture enable the ergonomic analysis during this use simulations. However, current solutions lack a dedicated tool to facilitate the analysis by decomposing the different parameters by task. In this paper, we present the development of a tool for preventive ergonomic assessment in virtual reality environments. The proposed tool is based on inertial motion units for motion capture and builds upon an ergonomic analysis software for activity analysis. A warehouse item storage task analysis is presented to illustrate the use of the tool.

1. Introduction

The Industry 4.0 enabling technologies (e.g. Internet of Things (IoT), Cyber Physical Systems (CPS), data mining and cloud computing) (Hofmann & Rüsch, 2017; Lu, 2017; Oztemel & Gursev, 2020; Zhong et al., 2017) are based on automation and data exchange in manufacturing technologies. These technologies will bring significant improvements in effectiveness and efficiency of the industry (Hofmann & Rüsch, 2017; Lu, 2017), but also provide an increased number of interactions between machines and operators. Authors suggest that this interaction should be characterized by the cooperation of machines with humans in work settings in a more "human-centered automation symbiosis" (Longo et al., 2017) where the operator of the skills and capabilities of the operator of the future are nor replace by machines but enhanced and supported by them (Romero et al., 2016).

To support the design of machine interfaces and work settings that enhance and support the human operator there is a need of tools to analyze and measure their interactions. In order to, in a preventive manner, to include this analysis into in the design of the manufacturing systems.

While simulation and virtualization technologies might provide a first part of the answer by allowing to analyze the behavior of the future system (El Saddik, 2018). The second part could be covered by a preventive (or even prospective) analysis of human factors during the design phase which might provide ergonomists and designers with information regarding tasks acceptability, long before it moves to the assembly line or workplace (Robert & Brangier, 2009).

This highlights the need for a system capable of assessing human factors and ergonomics in virtual environment simulations. Current ergonomic analysis are performed through observations and interviews which could end up in an evaluation that differs from specialist to specialist or in measurement mistakes (Carayon et al., 2014; Khandan et al., 2013). These limitations can be partially avoided with the help of some technologies of Industry 4.0 (e.g. sensors). Indeed, some researchers have proposed a few systems that could respond to this need by allowing to perform prospective ergonomic analysis using motion capture (mocap) systems (Battini et al., 2018). However, most of the existing solutions lack of a link with a tool that allows to perform the ergonomic analysis by task. What's more, the use of optical-based motion capture solutions seems to be generalized while their use is restricted to a lab setting or dedicated room, limiting the possibility to perform on-site analysis. This is a limit if the intent is to assess the simulated environment and the real environment once the solution is deployed. For these reasons in this paper we propose an inertial motion unit (IMU) based ergonomics assessment tool for virtual reality which allows to perform ergonomic analysis of simulated solutions and facilitate the test on the real environment once the solution is deployed.

The rest of the paper is structured as follows. Section 2 presents a brief review of similar systems. Section 3 presents the development of the proposed system. Section 4 illustrates a use situation of the proposed system by the analysis of a warehouse organization task. Finaly, conclusions and perspectives are presented.

2. Related work

Integrating motion capture systems for ergonomics assessment has attracted attention on researchers due to recent advances on head-mounted displays (HMD) and immersive technologies. (Battini et al., 2018) summarized some of the recent systems for ergonomic analysis and motion capture, table 1 develops on their review. From table 1 we can observe that the use of optical based systems has been a major trend for ergonomic assessment. However, recent developments show that the use of inertial measurement units seems to be more appropriate for the use in workplace and manufacturing sites given their ability to do real-time assessment on-site while avoiding the need for a dedicated motion capture room or laboratory (Peeters et al., 2019). This gives the assessment system the advantage of being able to be used on the simulation during the design phase and on the real manufacturing site once it is built.

While optical based motion systems tend to have higher precision, recent research has shown that the performance of IMU can be as good as optical systems. Depending on the activity to be assessed (like in the manufacturing floor) their differences are on acceptable ranges (Peeters et al., 2019).

Additionally, to the motion sensors some of the proposed systems provide the possibility to integrate other biometrical measures (e.g. heart-rate, skin conductance, EMG) that could provide more information about the behavior and state of the human operator while performing a given task (Balters & Steinert, 2017; Battini et al., 2018; Peruzzini et al., 2019; Peruzzini, Grandi, et al., 2017).

Moreover, Table 1 shows that from the existing systems only three of them facilitate the ergonomic analysis task. However, from those tools only the solution proposed by (Battini et al., 2018) facilitates a time-based analysis of position and joint angles of the operator that performs the task. One useful feature on this type of system could be the possibility to have those measurement values synthesized by task performed. In order to identify the problematic areas like in a Hierarchical Task Analysis (Brinck et al., 2010). This feature is, however, lacking the existing solutions.

Table 1: Existing and proposed ergonomic analysis system comparison, based on (Battini et al., 2018)

References	Motion capture	VR	Ergonomic analysis	Characteristics
(Chagué & Charbonnier, 2016)	Optical	x		Optical motion tracking, lack of ergonomic analysis
(Podkosova et al., 2016)	Optical	x		Optical motion capture, lack of ergonomic analysis
(Rincon et al., 2016)	Optical	x		Optical motion capture, use of EMG for controlling muscle contraction
(Peruzzini, Carassai, et al., 2017)	Optical	x		Optical motion capture
(Vosniakos et al., 2017)	Optical	x	x	Optical motion capture
(Caputo et al., 2018)	Inertial	x	x	Ergonomic analysis in parallel with the use of simulation of workstation, numerical feedback, difficult for analysis
(Battini et al., 2018)	inertial	x	x	Numerical analysis of ergonomics values to be performed after the simulation,

Even though, there are some existing systems to perform ergonomic analysis of task in simulated and virtual environments. They are missing some important features, there is still a need for a system that facilitates the ergonomic analysis by providing a way to synthesize measured values by task in order to facilitate the identification of problematic areas and that could be used both during the design phase and the deployment phase to compare the performance of the designed solution. For this reason, we propose in the next section such a system.

3. Tool design and development

Through the analysis of existing systems and a need analysis, the required features to be developed in the tool were defined. Among others, the following features were defined: Ability to integrate additional biometrical sensors to the motion sensors, integration with virtual environments for simulation, integration of tools to facilitate the ergonomically analysis, facilitate the analysis of the activity at the task level.

3.1. System architecture design

The proposed Captiv-VR motion system was designed with the company TEA based on their ergonomic analysis software Captiv L-7000 (TEA-ergo, France). The proposed system architecture is presented in Figure 1 and its composed by the following elements.

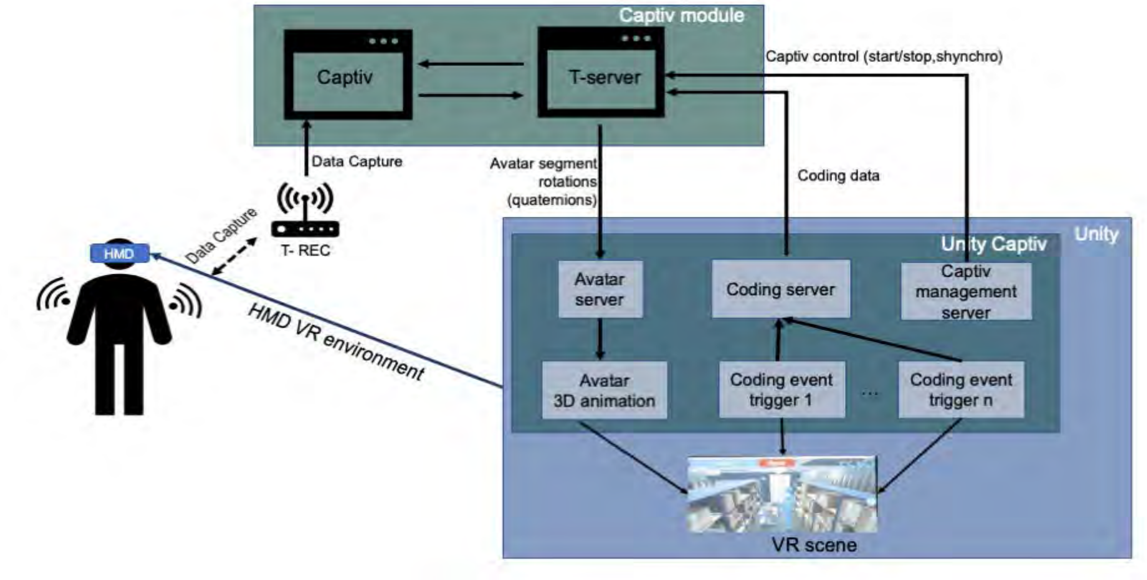


Figure 1: CAPTIV VR system architecture.

3.1.1. Inertial motion capture system

The motion capture is performed through 15 IMU (TEA-ergo) with a sampling frequency of 64 Hz placed around the body and joints of the user. The IMUs has being previously tested for their accuracy against optic-based systems (Peeters et al., 2019). The sensor information is transmitted through RF to a receptor unit (T-REC) that is connected (USB) to the main computer, where the VR scene and the Captiv software are running. The IMU information is first received by Captiv. The data provide by the sensors are the body 3D joint angles, and segment rotations.

3.1.2. HMD device

In this system we used the HTC VIVE system (HTC and Valve corporation) as the head mounted display (HMD). The system uses two base stations that emits pulsed IR laser to track the position of the HMD and the two wireless controllers. The positioning system allows the user to move in the 3D environment and interact with its elements. Steam VR running on a windows computer is used to communicate with the device through a USB connection. The HMD allows the user to “see” the virtual scene proposed. The virtual scene was designed in Unity and it communicates with the Captiv module software as will be explained next.

3.1.3. Software components (Captiv module and Unity plugin)

Several software components communicate in the system. The IMU data is received by the Captiv-VR software through the connection with the T-REC receiver. The information about joints and angles of the body are sent to a Unity scene to have an animated avatar that corresponds to the body of the user and its movements. The unity scene communicates through a Captiv plugin in Unity with a T-Server (TCP/IP server) that establish the connection with the Captiv software. Besides the graphical content and activities that can be performed in the virtual Unity scene, some other information is shared with the Captiv software. First when the scene is started or stopped the information is synchronized with the Captiv software to record the actions and keep all data synchronized (this allows to perform the time-based analysis later). Second, to allow the ergonomic analysis on a task level it is possible to set-up in the Unity scene a coding scheme of actions performed and send them to the Captiv software. Each time the user starts, and finish a given action on the VR scene it sends that information to the Captiv software. This allows for instance, to synchronize what actions and for how long these actions are performed by the user and to synchronize all the positions, angle information with the action performed.

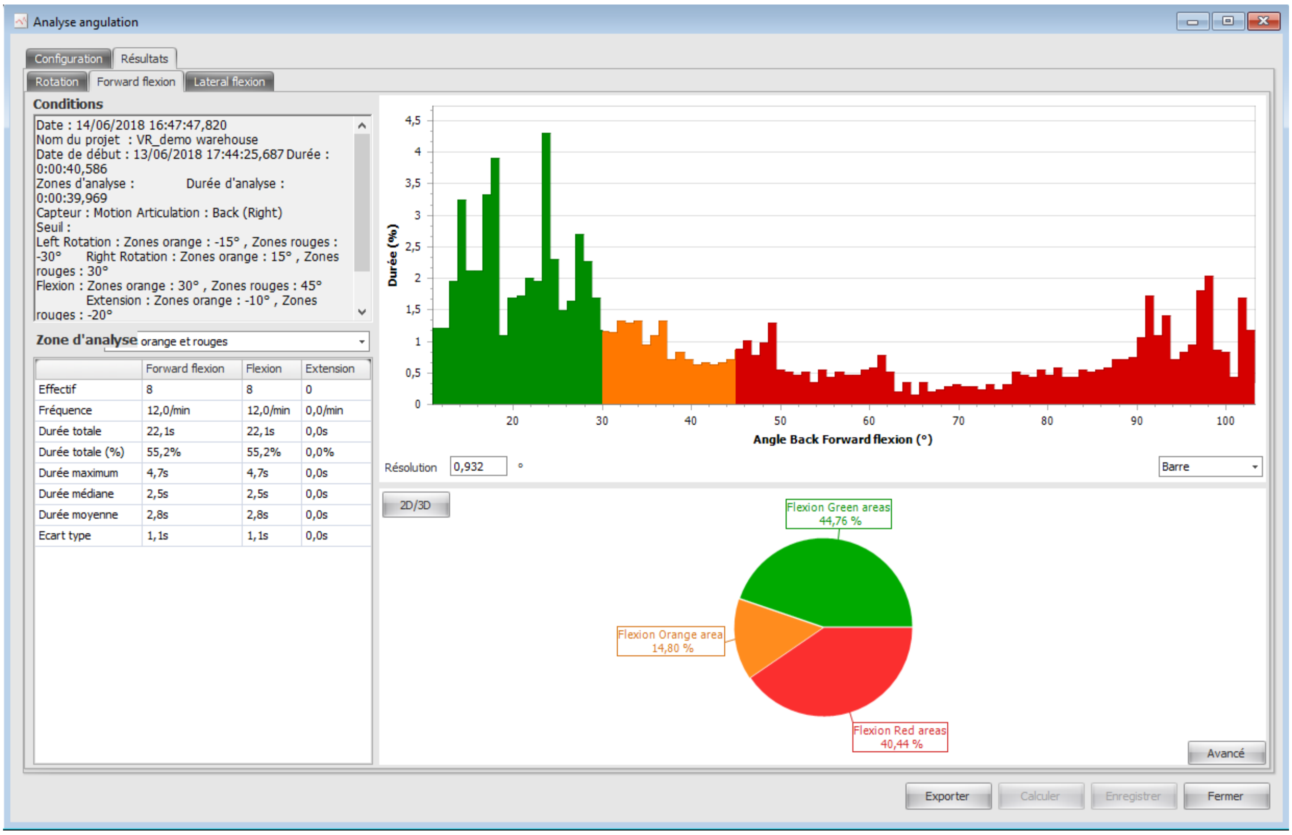
The main component is the Captiv module software where all the data is synch and the analysis are performed. Figure 2 presents the interface of the Captiv software after a test session. In the left pane all the video sources are displayed, the 3D avatar that was recorded during the session, a synched video (external source) of the participant with the IMUs and the HMD, and a view of the VR scene. The right pane shows the different sensors and their angles, the bottom image shows the different activities and performed and the time the participant is performing them. All the measures are synched so one can play the video and observe exactly what the participant is doing, and the red marker will move (time-based analysis) in synch to show the corresponding measured values (angles, positions, activity).

Figure 2: CAPTIV system interface.

4. Experimental use case: logistic warehouse

In order to better explain the interest of such a system, we tested a use case scenario. The example developed is the assessment of a warehouse setting where an operator has to place boxes on their corresponding space (shelves). The operator would transport the boxes to be stored with the help of a trolley to move them around the warehouse. Once he has found the corresponding shelf, he would use his hands (through the VIVE controller) to interact pick-up the box and placed it on the corresponding space. The operator will repeat the procedure until all the boxes on the trolley are stored. The storing places on the shelves have different heights in order to test different positions while placing the items.

From figure 2, we can observe that a first feedback is available for the analysis. Indeed, the joints on the avatar can be set up so to take a color depending if the joint angle is higher than a certain value. In the figure most of the joints are green which indicates to be in a “right” position but the hip is orange which indicates it’s on a zone of attention, a red color indicates that the angle on a joint is in a dangerous value and a position should not be sustained for a long time. These parameters can be set up to correspond to analysis of RULA, OCRA, OWAS and Lifting Index for instance. Figure 3 shows an example of the detailed report for the angle back forward flexion.



Date : 14/06/2018 16:47:47,820
Nom du projet : VR_demo warehouse
Date de début : 13/06/2018 17:44:25,687 Durée : 0:00:40,586
Zones d'analyse : Durée d'analyse : 0:00:39,969
Capteur : Motion Articulation : Back (Right)
Seuil :
Left Rotation : Zones orange : -15° , Zones rouges : -30° Right Rotation : Zones orange : 15° , Zones rouges : 30°
Flexion : Zones orange : 30° , Zones rouges : 45° Extension : Zones orange : -10° , Zones rouges : -20°

Zone d'analyse orange et rouges

	Forward flexion	Flexion	Extension
Effectif	8	8	0
Fréquence	12,0/min	12,0/min	0,0/min
Durée totale	22,1s	22,1s	0,0s
Durée totale (%)	55,2%	55,2%	0,0%
Durée maximum	4,7s	4,7s	0,0s
Durée médiane	2,5s	2,5s	0,0s
Durée moyenne	2,8s	2,8s	0,0s
Ecart type	1,1s	1,1s	0,0s

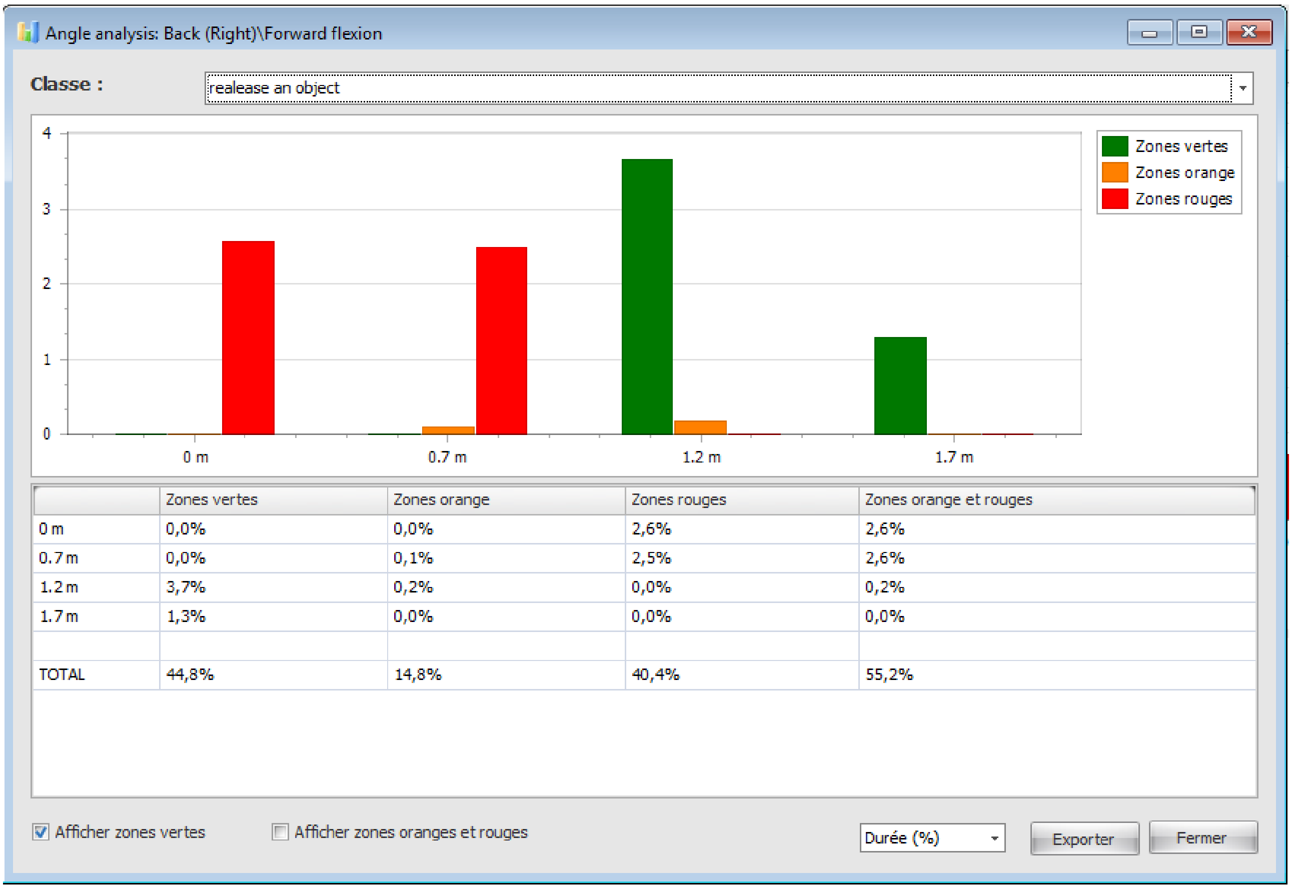
Résolution 0,932 °

Barre

Figure 3: Detailed example report.

In the expected features, it was highlighted in the interest of having a detailed analysis of angles going higher than a certain value on a given task. Take for instance the placing of a box in a shelf. For this task it is interesting to know at what height (or positions on the shelf) the operator is confronted to a “bad” position. In figure 4 for the back/forward flexion we can have a detail of during the entire procedure how many times (or in what frequency) he took the “bad” position (according to the different levels: green, orange, red) and the corresponding heights. Figure 4 shows that in our case the operator took more bad positions (red zone) while placing objects on the tow bottom shelves (0 m and 0.7m). While having a comfortable position (green zone) when the shelves where at its height.

This example shows that the tool can serve as a preventive ergonomics design tool if the warehouse doesn’t exist yet and allows ergonomists and designers to test different layouts and designs. But it could also serve a corrective approach if the layout is the one of an existing setting that is tested and improved.



Classe : realease an object

	Zones vertes	Zones orange	Zones rouges	Zones orange et rouges
0 m	0,0%	0,0%	2,6%	2,6%
0.7 m	0,0%	0,1%	2,5%	2,6%
1.2 m	3,7%	0,2%	0,0%	0,2%
1.7 m	1,3%	0,0%	0,0%	0,0%
TOTAL	44,8%	14,8%	40,4%	55,2%

☑ Afficher zones vertes ☐ Afficher zones oranges et rouges Durée (%)

Figure 4: Example analysis by placement height.

5. Conclusion and perspectives

In this short paper, we presented the development of a tool to improve the ergonomics assessment of activities. This tool can improve the design process of workplace or manufacturing setups by facilitating the inclusion and real assessment of human factors with a real assessment of the "future" performed task. For this we used a simulation of the future setup configuration through a virtual reality scene. This assessment facilitates and allows the improvement of the future scenarios by allowing to assess problematic situations during the design process before the job is performed on the real workplace. The use of IMU for motion capture and the use of the Captiv-VR platform allow to perform the same analysis once the workplace is built.

Furthermore, through the integration of other biometrical measures (such as a heart rate monitor), some indicators of fatigue or stress level can be integrated. Finally, the proposed system is still in development to include useful new features and as such a more detailed experimental testing could be performed.

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Physiological assessment of User eXprience supported by Immersive Environments: First input from a literature review

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Keywords: Immersive environments – physiological devices – virtual reality – literature review

Abstract

Immersive virtual environments can support the co-design process during the early innovation stages. For these technologies to be used as a support tool researchers and designers need to better understand users' behaviors and experiences in these environments. While most of the existing literature proposes to assess immersive experiences using self-reported assessments such as questionnaires, some alternatives propose the use of physiological data. In this sense, biometric and physiological measures can be useful indicators to study human behavior and performance in immersive virtual environments in order to highlight what physiological data monitoring can bring to the understanding of user experience. Based on an analysis of 1850 papers retrieved from the main bibliographical databases, our paper is aiming to propose a systematic review of the scientific literature interested in the use of biometric evaluation of human behavior interaction in an immersive environment. Through this review, the different uses of the technologies and their perspectives as tools for the assessment of user experience in immersive environments are presented and discussed.

1. Introduction

Immersive or virtual environments can play an important role as tools to support the design and development of innovation projects. They have been used in multiple disciplines such as health (Vogt et al., 2015), entertainment (Parker et al., 2011), psychology (Wood et al., 2007), human behavior (Slater et al., 2006) and user experience (Silva et al., 2009). This shows a high potential for the technology as a tool in diverse applications. However, research on co-creation process involving user experience supported by immersive environment still needs more development (Dupont et al., 2018). Indeed, if the Immersive Collaborative Environment (ICE) tree describes the properties of collaborative experience and immersive experience (Dupont et al., 2017), we need to better understand how users interact with those technologies. Research methods in human-computer interaction have been developed to analyze user behavior and other human factors (Rubio-Tamayo et al., 2017). While most of the reported methods use self-assessment measures (i.e. questionnaires and survey), another part is based on the use of physiological measures (Rubio-Tamayo et al., 2017). However, the literature shows that these technologies have been used in many different ways to study immersive environment experiences and there is a plethora of methods and approaches. For this reason, it is important to make a synthesis on how biometric and physiological assessment have been applied to study immersive virtual environment experience for researchers to better use this approach. The aim of this study is therefore to propose a systematic literature review of Biometric assessment (or physiological assessment) in Immersive Environments (or virtual environment).

In this review, 1850 research articles published between 2000 and 2020 extracted from Scopus database were analyzed using a co-occurrence approach conducted with VOSviewer software. Next, from those articles 153 significant references in terms of biometric devices uses for assessment were selected and sorted. After this, 26 publications were analyzed to determine which parameters have been studied to evaluate virtual immersion. Finally, we summarized the biometric devices technologies found in the literature in three groups: Common Technologies, Original biometrics technologies and Non-typical biometric technologies.

The principal contribution of this work is to summarize relevant aspects of Biometric assessment in Immersive Environments: Which factors have been studied and which technologies have been employed.

The rest of this paper is structured as follows. In section 2, previous works on Immersive Virtual Environment (IVE) and a general background about the Biometrics devices used to measure IVE is developed. In section 3, Material and Methods are described. Sections 3 and 4 synthesizes the results and conclusions.

2. Previous works and general background

2.1. Immersive virtual environment experience assessment

While there are several tools (questionnaires) and models to study user experience on immersive environments (Tcha-Tokey et al., 2016), to our knowledge there are no other frameworks to analyze co-creation in virtual environments. For this reason, in this research we use the Immersive Collaborative Environments (ICE) tree structure developed by (Pallot et al., 2017). This model identifies the most relevant elements to assess immersive co-creation in virtual environments. These elements have been summarized in the Immersive Collaborative Environments (ICE) tree structure (cf. Figure 1).

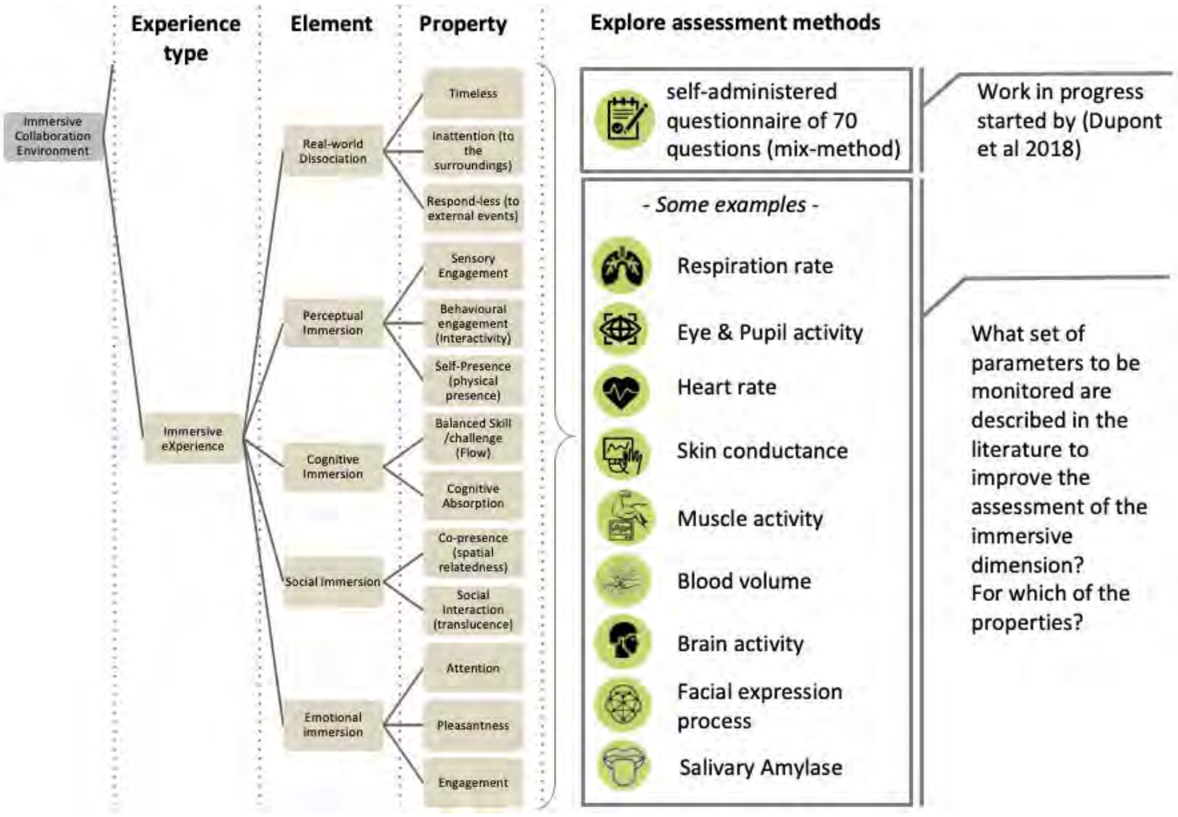

Figure 1. Exploration of assessment of immersive properties of the ICE structure based on (Dupont et al., 2017)

The ICE structure includes cognitive, social, perceptual and emotional facets. It is divided in two experience types: Immersive Experience and Collaborative Experience, both include their own elements and properties. The ICE tree has been applied by means of a questionnaire (self-reported measure) and survey instrument to assess the participants experience in immersive environments (Dupont et al., 2017). While the use of the ICE tree structure and the questionnaire instruments seems to give a complete picture of all the factors affecting the participants experience in immersive environments, self-assessment measurements present some limits because they rely on the ability and willingness of the respondent to accurately report their attitudes and prior behaviors (Lee et al., 2007). First experiments show the questionnaire is long and tedious for users. The participants are questioned after the experience. How could we collect their feedback at the time of the action, or even automate part of the collection? There seems to be some part of the answer in physiological responses as they can be collected when respondents are directly participating in the behavior and are difficult to control. For this reason, in this research we are interested to study how some of the ICE tree structure properties can be observed by means of biometrical devices as an alternative (or complement) to the existing instruments. For example, can respiration rate or eye pupil activity be used to assess one or several of the model properties. Figure 1 presents the tree structure and some of the possible devices to be explored. Furthermore, as the collaborative and immersive dimensions are complex and attached to different fields of research in this initial literature review, we will focus solely on the Immersive dimension (Figure 1). The collaborative dimension will be explored in further research.

2.2. Physiological devices for experience assessment

As seen from the ICE tree the immersive experience is affected by cognitive, social, perceptual and emotional facets. There has been extensive research in the fields of human behavior and decision-making processes. This research has shown that emotion plays a critical role guiding decision-making and behaviors in response to stimuli (Damasio, 1994), and also plays a crucial role regulating the interactions between humans and their environment (Dalgleish, & Power, 2013; Eimer, Holmes, & McGlone, 2003; Naqvi, Shiv, & Bechara, 2006). The processing of emotions is predominant in the limbic system (Shalev et al., 2017) located in the brain's medial temporal lobe. This system is responsible for processing emotional stimuli and regulating the expression of emotional responses to integrate them into complex brain functions. This process integrates the Central Nervous System (CNS) and the dynamics of the Autonomic Nervous System (ANS) (Marín-Morales et al., 2019). Because of this, emotion has a great impact on body responses. This is the working principle exploited by many of existing biometric devices that relies physiological responses to assess emotional and cognitive impact, states or types.

One of the impacts of emotion in body responses is expressed through facial expressions: helped by some neuronal groups called Central Pattern Generator (CPG), it initiates and controls facial muscle activities (López Mejía et al., 2009). Thus, some emotions can be recognized by the means of facial expressions (Winkielman et al., 2008). In terms of user experience this measure is related with social interaction and intention of participants, willingness to interact (Sacco & Hugenberg, 2012), empathy (Lundqvist & Öhman, 2005; Ruggiero et al., 2017), and as a confidence or trust indicator (Van IJzendoorn & Bakermans-Kranenburg, 2012; Weber & Brewer, 2006).

There are other patterns of physiological activation present in emotional states, such as: heart rate, respiratory rate, brain activity or galvanic activation of the skin (Hagemann et al., 2003). These can be used to measure the impact or relevance of a certain stimulus. However, it is difficult to identify with these biometric data alone to which of the six basic emotions the activation corresponds (Dawson et al., 2007). For this reason, it is often necessary to combine several of these measures (e.g. skin response and facial expressions).

Human emotional processing, interpretation of the facial expression process (Wicker et al., 2003), empathy (Jackson et al., 2005) and perception all involve the activity of the cerebral cortex and the CNS to automatically classify emotions and monitor the attentional meaning of emotions. Because of this, electroencephalogram (EEG) and FMRi are the most commonly used techniques to measure CNS responses (Valenza et al., 2016). In addition, EEG has been used to measure engagement (Castellar, E Voigt A., Jan N. & Marinazzo, D.& Looy, 2016; Cirett Galán & Beal, 2012; Shestyuk et al., 2019) and it can detect the perceived cognitive absorption (Conrad & Bliemel, 2016; Léger et al., 2014).

Changes on cardiovascular dynamics by specific emotional states (Marín-Morales et al., 2019) can be measured using electrocardiogram devices (ECG). Heart rate variability (HRV) has been used as an indicator of presence and pleasantness (Greenfeld et al., 2019; Jonathan et al., 2013; Meehan et al., 2002; Wood et al., 2007).

As a person becomes more or less stressed, the conductance of the skin increases or decreases proportionally (Slater et al., 2006). Galvanic Skin Response (GSR), is commonly used to establish the user's emotional states and it is used to measure sensory stimuli (e.g., pain, pressure, touch). In virtual reality settings it has been used as a presence indicator (Slater et al., 2006).

Finally, eye monitoring data, such as pupil dilation, fixations and saccadic eye movements, can determine pleasant or unpleasant emotions or reactions. Eye movement is measured by the mean of eye tracking devices.

The provision of information on the position of the eye is also related with a measure of joint-presence between two people (Špakov et al., 2019), attention (Wang et al., 2015), and it has been used as an indicator of context awareness (Bulling et al., 2008).

As seen from this brief literature background, some of the properties included in the ICE tree for immersive experience assessment have been assessed with the use of physiological measures. In particular presence attention, engagement and pleasantness. However, we need to better understand how authors have assessed those particular properties with physiological devices and if the other properties have been assessed. For this reason, we performed a systematic literature review on the use of physiological devices for the assessment of immersive environments experience.

3. Materials and methods

The objective of this study was to propose a systematic literature review of the use of biometric devices for assessment in Immersive Environment (or virtual environment) experiences. We performed a qualitative and systematic literature analysis using VOSviewer software (www.vosviewer.com). In this process, five filters were applied to narrow the number of publications found.

Table 1: Search parameters.

Field	Option
Keywords	TITLE-ABS-KEY ("immersive environment" OR "virtual environment" OR "immersive" OR "mixed reality" OR "virtual reality" OR "augmented reality") AND ("Biometric" OR "Physiological")
Search in	Title, abstract, keywords
Period explored	From 2000 to 2020
Type of documents	Articles and conference papers
Database	Scopus®

Filter 1. First, we searched in the Scopus database articles and conference papers from 2000 to 2020, using the title, abstract and keywords fields. The 20 years period was chosen because as analyzed from the (Dupont et al., 2018) research it was appeared that before 2000 there are few research works on the immersive experience assessment question. The search parameters are presented in Table 1, the search equation used the keywords: Immersive environment (or Virtual) and Biometrics (or Physiological).

With this first filter a total of 1850 publications were found.

Filter 2. The second step was to use the proximity operator "W/50" between the same keywords. This tip is provided by Scopus to make sure all terms appear in the same paragraph. Applying this filter 530 publications were found.

Filter 3. Using exclusion criteria of English publications and excluding duplicates, a total number of 513 publication result.

Filter 4. Then on this step, we read and analyzed the abstracts of the 513 selected articles, for a quantitative analysis. After the screening 153 publications were chosen as the most relevant, because there were several works unrelated to immersive environment from the previous filter. In addition, we excluded papers performing literature reviews, using languages different from English and we maintained application studies using biometrical devices in Virtual environments. Those 153 selected papers were carefully reviewed and classified to the category of biometric devices used (common technology, original technology and non-typical technology), classified by their study objectives and classified according to the properties of the ICE structure (cf. Appendix B).

Filter 5. This filter based on reading and analyzing the abstracts of those 153 selected articles, for a quantitative analysis, 26 publications were chosen. This filter consisted in the analysis of the topics to select which of those were focused exclusively in immersion study and not for other types of applications, we identified among them the parameters to be monitored used in the immersion research.

4. Findings

4.1. Data analysis through visualization

A total of 1850 studies from the first filter were analyzed with the VOSviewer software. Using co-occurrence links, a network of keywords was developed and mapped (cf. Figure 2). The circle represents the keywords and its diameter represents the frequency of occurrence. The distance between words means the relatedness, so, the closer two words are located the stronger their relatedness.

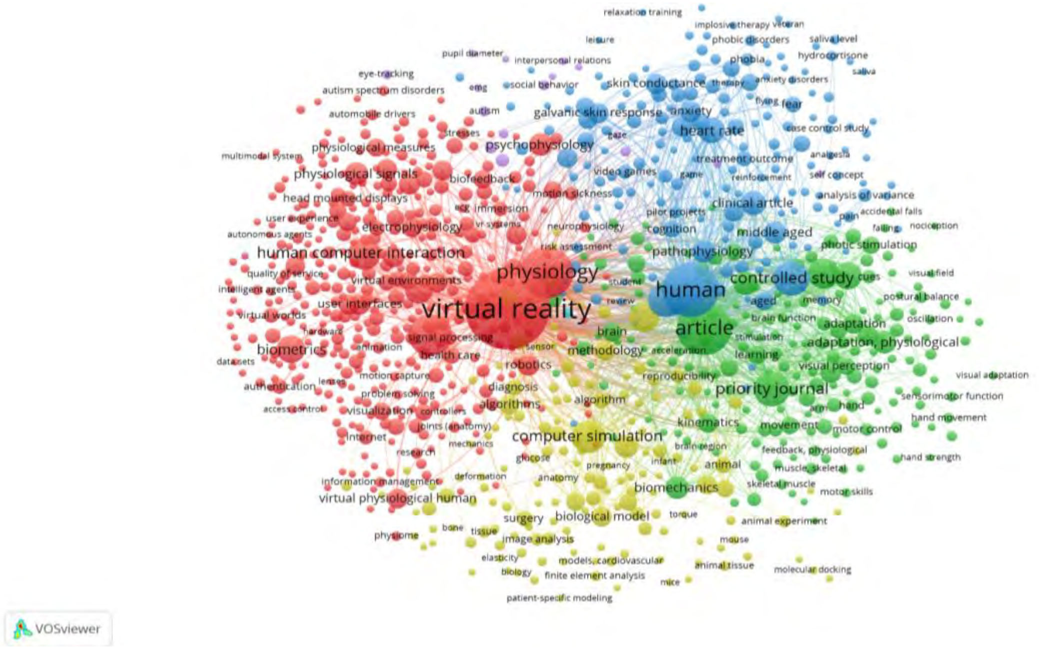

Figure 2. Network analysis of 1850 publications by VOSviewer software

In figure 2, a collection of keywords having strong relationship creates a cluster, each represented by a different color. A total of four main clusters were identified by VOSviewer. Table 2 details each cluster, color, main keywords and others related words. Form table 2 we observe that each cluster might be associated with a certain research trend. The first trend represents the use of virtual environments as a tool for simulation and as an interface for simulators. The second trend shows that there is a stream of research that deals with the use of physiological responses for the study of human computer interaction. The third trend is the use of some specific commonly used variables in these studies, as heart rate, emotion, anxiety. The fourth cluster links some of the aims of the studies that were found (e.g. memory, learning or adaptation studies).

This initial analysis allows us to identify what type of studies have been performed and which types of technologies have been commonly used.

Table 2. Network analysis of 1850 publication with VOSviewer software

Cluster	Color	Main Keywords	Other related words	Research Trend
1	Yellow	Computer interface, simulation, article	Computer simulation, algorithm adaptation, software	Computer interface, simulation and article as a tool of virtual environment studies
2	Red	Virtual Reality	Human computer interaction, physiology, physiological response, biometrics	Virtual reality and human computer interaction use physiology and physiological responses
3	Blue	Heart Rate, Emotion	Psychophysiology, anxiety, attention, questionnaires, stress, arousal, self-report	Variables as hear rate, emotion, anxiety and others are variables used in virtual reality environments
4	Green	Vision, Biomechanics, adaptation, human experiment	Movement, memory, learning, adaptation	Those keywords may reflect aims or objectives of the researches

4.2. Document analysis

Based on the Filter 4 the 153 selected publications were first categorized by the application domain and aim of study. Then we performed a detailed analysis on the different technologies that were used.

In an initial analysis we identified five main categories of the aim of the studies. Most of the studies intended to understand and Improve effectiveness of virtual environment (71), a second stream was concerned with Psychological purposes (51), then studies related to Simulation to measure performance (13), then studies related to Health (12) in general and studies related to Education and training purposes (6).

4.2.1. Biometric devices used to measure Immersive Virtual Environments

On the analyzed papers biometric devices were used to measure the emotions and assess the experience of the participants in immersive virtual environments. We summarized them in three categories according to the frequency in which they have been found in the literature: common, original and non-typical technologies. Common technologies are devices that were found on at least 5 studies, original technologies are technologies that were developed for a specific purpose of the study, and non-typical technologies are technologies that were used by less than 5 studies. In particular, we observe that they correspond to existing devices or technologies but are rarely used in the context of immersion studies. Among the studies 82% of the papers used common technologies, 14% used non-typical technologies and 4% developed their own original technologies.

4.2.2.Common Technologies

In common technologies, the most used technology or physiological response to measure virtual environment was heat rate measure (89 studies), followed by skin conductance (67 studies). Other common technologies are less frequently used as respiration rate (20 studies), EEG (30 studies), EMG (9), Blood Flow Velocity (9) and Salivary Aplha Amylase or Cortisol (10). The eye tracking technology that is common in user experience studies was less common on the immersive experience studies found (8 studies).

In the case of Heart rate measures with ECG it has been commonly used with EEG to assess emotional responses and the sense of presence (Marín-Morales et al., 2019; Vogt et al., 2015). In addition, GSR and Respiration Rate measurement devices were used to evaluate emotional (Silva et al., 2009) states and as a measure of stress levels (Hägni et al., 2008; Tinga et al., 2019; Wood et al., 2007). GSR have been used in cognitive rehabilitation as an indicator of presence (Lo Priore et al., 2003; Slater et al., 2006).

Jackson et al. (2015) developed the Evolutive Virtual Environment for Empathy Improvement (EEVEE). It is based on three main components: (1) different avatars capable of expressing feelings and emotions in various levels based on the Facial Action Coding System (FACS); (2) systems to measure the observer's physiological responses (heart and respiratory rate, skin conductance, eye and eye movements, facial expression); and (3) a multimodal interface that links the behavior of the avatar with the neurophysiological response of the observer. EEVEE consists of a series of devices that will allow real-time measurement of the behavioral and physiological responses of the participants, using biometric devices such as: Face Reader (Nolduls) as an emotional face recognition tool to create avatars. In addition, they used measures of heart activity, respiration rate, and skin conductance, as well as eye-tracking and pupillometry.

In the case of eye movements they have been used as a predictor of emotional states and to assess the effects in virtual reality context (Cebeci et al., 2019). Other authors, have used eye tracking as a tool to improve the collaborative immersion experience. Murray et al., (2009) studied how the gaze is of paramount for subjects to correctly identify what a person is looking at in an immersive virtual environment. For this, they tested the differences observed when a subject tried to distinguish which objects in a scene looked at the avatar in the environment. As a result, they find that Eye-gaze has proven to be a key resource for collaborative interaction. In addition, eye-trackers were commonly used as attention, visual search and visual memory indicators in Immersive Experience (Kit et al., 2014).

4.2.3. Original Biometrics Technologies

In the case of original technologies different types were found. GNeuroPathy, Deep Long Short-Term memory (LSTM) and Multimodal Biofeedback System. GNeuroPhaty was a technology developed to measure electrodermal response in virtual reality (Quaresma et al., 2019). LSTM was developed to record state postural signal (Hofmann et al., 2018). Multimodal Biofeedback was designed to capture up to six biomedical signals: EMG, EEG, GSR, temperature, heart rate and respiratory rate simultaneously. Other developed technologies were found: Virtual Reality Medical Center (VRMC), Integrative system, Foveal Eye movements, eyeblink potentiation, Ear-Eye Pitch (E2P), PhysioVR, OpenViBe.

Quesnel & Riecke (2018) studied interactive virtual reality as a positive technology that can generate astonishment and how the scale of beauty / aesthetics, familiarity and personalization characteristics (self-selection of travel destinations) can induce astonishment. To measure the physiological response related to the incredible emotional experience, they created a "chicken-skin camera" that consisted of a webcam to capture changes in skin texture. The person uses the device on his non-dominant arm and was designed to accommodate virtual reality manual controllers. The video of the camera was analyzed to determine the presence of goosebumps on the skin.

It is still complex to measure facial expressions in the virtual environment, because the use of HMDs covers the person face. However, Burn (2017) has developed a device called MASK, a base in foam sensitive to neurons that comprises a ring of sensors that can be inserted in the front plate of any VR headset. This biometric technology allows to detect the user's facial expressions and translate the emotion expressed through virtual avatars in real time.

4.2.4.Non typical biometric technologies in VR

In this category we identified existing technologies that are uncommon to be found in virtual or immersive environment studies. However, they are common in other fields of study such as medicine, biology, neuroscience or others. These were used in these virtual studies mainly because the variable studies were very specific, so they integrated different tools from other areas of knowledge, such as neuroscience (Alcañiz et al., 2018). We found the use of oxygen consumption (VO 2) was used in 3 studies, accelerometers (2 papers), mean ventilation responses (1 paper), body forces (1 paper), transcranial Doppler (1 paper).

Blood flow and oxygen consumption was used in anxiety studies while salivary measures to cortisol (Stress) studies. Among the studies that used a non-typical measures (Yu et al., 2018) created a health application that uses VR and biometric measurements. The objective was to examine the influence of forest and urban environments of virtual reality on health. To measure the impact of the VR environment three biometric measures were used: heart rate frequency, salivary α amylase activity, to quantify stress levels. It was measured using a salivary amylase monitor DM-3.1. Additionally, participants Blood Pressure was used to detect the right position of participants' arm or movement it was measured by blood pressure monitor (HEM-1000).

Other studies focused on comparing the immersive environment and the real environment based on other physiological responses. Yeom et al., (2019) focused their study on determining whether a thermal quality component and a component built in a built environment could generate some physiological problems, compared to the real-world environmental condition. For this, they used a biometric temperature sensor (STS-BTA).

4.3. Use of properties from the ICE structure

Based on the 153 publications from Scopus we classified the properties studied in each publication quantitatively in the ICE structure (cf. figure 3 and appendix B).

From the 153 publications, only 39 of these studies used at least one of the properties proposed by the ICE structure. Most of the properties from the ICE structure that were used by the studies are those related to emotional immersion facet, being Attention and Presence the most studied properties.

A final filter (Filter 5) was applied to select twenty-six studies that exclusively focused on immersion research. We found that 20 (77%) articles from the 26 used at least one of the properties proposed in the ICE tree structure. From the 26 analyzed studies 58% used only properties found in the ICE structure, 23% used some of the properties in the ICE structure but combined them with other properties, and 19% used only properties that are not included in the ICE structure. Among the other variables included in immersion studies researchers used anxiety (in 3 studies) and stress (2 studies). In terms of parameters to be monitored to assess the different properties that affects the immersive experience figure 3 synthesis the results related to the technologies and properties of the ICE model. Appendix B presents the technologies used for parameter monitoring in all the papers. As presented previously it is shown that heart rate, respiration rate and skin conductance measure are the most used technologies. The Self-presence property of is the one that has benefited from a higher development and use of parameter monitoring technologies followed by Attention property. It would be interesting to see further development of technologies to assess the other properties.

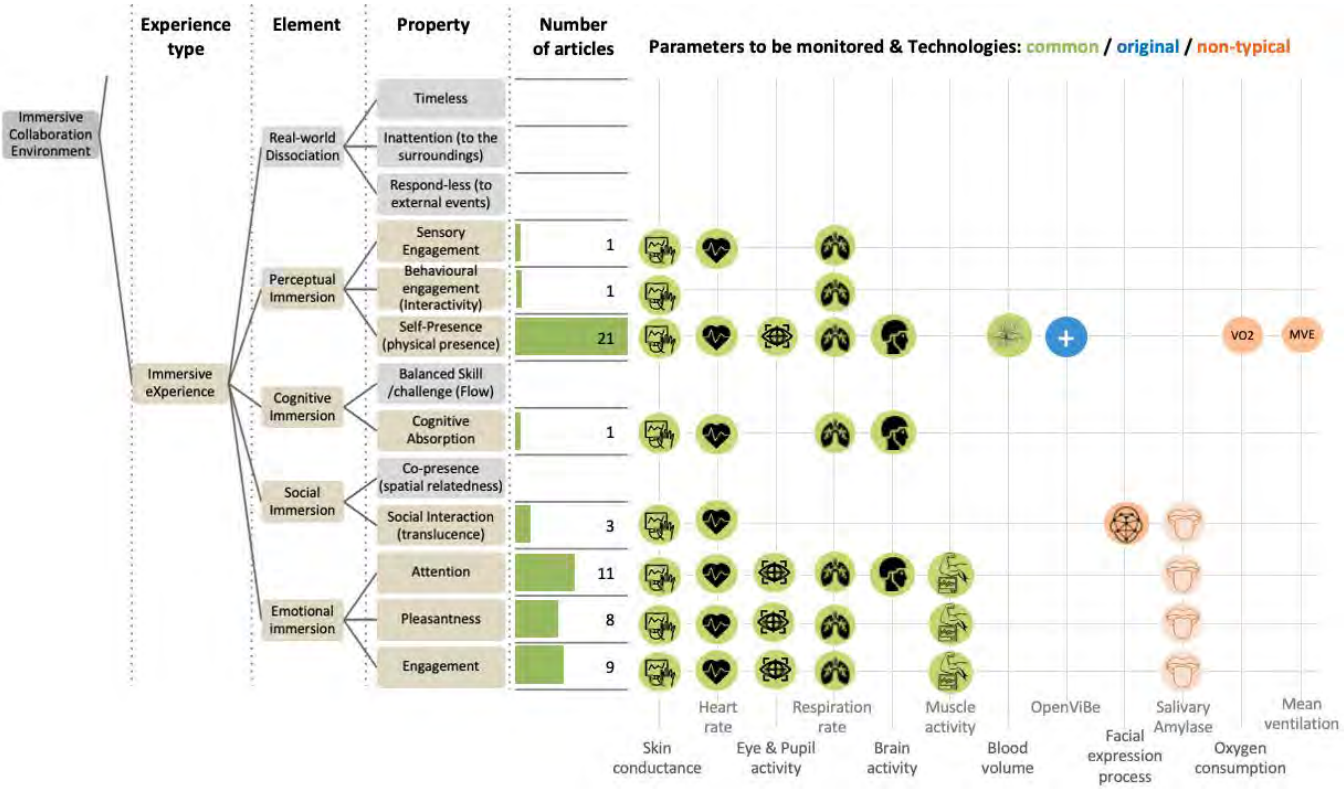

Figure 3. IX Properties and technologies found in the analyzed studies

5. Conclusion

For this study, a systematic literature review methodology with five filters was used to narrow down the number of potential articles collected from the Scopus database. An initial search presented 1850 publications for uses of biometric/physiological devices to measure virtual environment that were briefly explored. In an additional filter we narrowed them down to 153 to develop a qualitative analysis. This literature review contributes to mapping links and connection of the uses of biometric devices in Virtual Environments and some categories of their uses.

To measure immersive environment's experience many studies used biometric or physiological approaches. Their aim was mainly on improving the efficiency of the developed platforms.

Regarding technologies, heart rate and skin conductance were the most used physiological assessment devices used in virtual environments. However, in this review we presented some other non-typical and original technologies to evaluate virtual environments such as blood flow and salivary measures.

Our initial aim was to understand how the physiological technologies have been used for assessing properties and facets of the immersive dimension of ICE tree structure, in order to facilitate the use of the ICE tree model in assessing immersive experiences in complementarity of the already employed questionnaire and survey instruments. From the analyzed studies we observe that 8 of the properties included in the model have been evaluated by a biometrical approach. The most commonly assessed property is presence, as an indicator of immersion. Additionally, it was found that previous research in immersion studies have used Anxiety and Stress properties as an indicator of immersion. These two properties are not part of the ICE tree model, but this shows that further research should explore the inclusion or not of these properties for example to consider them in the Emotional aspect facet.

Additionally, we found that the availability of biometric tools coincides with the most studied properties or explained in another way, those that have been studied the least are the ones that have less biometric tools available according to what we saw in the review. This represents a great opportunity not only to study the variables proposed in the ICE but also to develop or propose physiological tools that will allow them to be studied.

This review is not without some limitations, it is only a partial view of the existing literature the presented annexes and list of papers are the base that need to be enriched by a deeper qualitative analysis on the uses of the physiological devices and their use constraints. To operationalize the uses of the devices to assess the different properties we need to consider the multifactorial dimension of the parameters monitored, the interpretation of the potential collected data will be a challenge.

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Appendix A. List of papers from the literature review

Ref	Detail
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3	Wiederhold, B. K., Gao, K., Sulea, C., & Wiederhold, M. D. (2014). Virtual reality as a distraction technique in chronic pain patients. *Cyberpsychology, Behavior, and Social Networking*. https://doi.org/10.1089/cyber.2014.0207
4	Zimmons, P., & Panter, A. (2003). The influence of rendering quality on presence and task performance in a virtual environment. *Proceedings - IEEE Virtual Reality*. https://doi.org/10.1109/VR.2003.1191170
5	Meehan, M., Razzaque, S., Insko, B., Whitton, M., & Brooks, F. P. (2005). Review of four studies on the use of physiological reaction as a measure of presence in stressful virtual environments. *Applied Psychophysiology Biofeedback*. https://doi.org/10.1007/s10484-005-6381-3
6	Orman, E. K. (2004). Effect of virtual reality graded exposure on anxiety levels of performing musicians: A case study. In *Journal of Music Therapy*. https://doi.org/10.1093/jmt/41.1.70
7	Herbelin, B., Benzaki, P., Renault, O., Grillon, H., Thalmann, D., & Riquier, F. (2005). Using physiological measures for emotional assessment: A computer-aided tool for cognitive and behavioral therapy. *International Journal on Disability and Human Development*. https://doi.org/10.1515/IJDHD.2005.4.4.269
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13	Slater, M., Guger, C., Edlinger, G., Leeb, R., Pfurtscheller, G., Antley, A., Garau, M., Brogni, A., & Friedman, D. (2006). Analysis of physiological responses to a social situation in an immersive virtual environment. *Presence: Teleoperators and Virtual Environments*. https://doi.org/10.1162/pres.15.5.553
14	Slater, M., Antley, A., Davison, A., Swapp, D., Guger, C., Barker, C., Pistrang, N., & Sanchez-Vives, M. V. (2006). A virtual reprise of the Stanley Milgram obedience experiments. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0000038
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16	Dotsch, R., & Wigboldus, D. H. J. (2008). Virtual prejudice. *Journal of Experimental Social Psychology*. https://doi.org/10.1016/j.jesp.2008.03.003
17	Yamamoto S., Miyashita H., Miyata A., Hayashi M., O. K. (2008). *Basic experiment for switching difficulty in virtual environment*.
18	Alcañiz, M., Rey, B., Tembl, J., & Parkhutik, V. (2009). A neuroscience approach to virtual reality experience using transcranial Doppler monitoring. *Presence: Teleoperators and Virtual Environments*. https://doi.org/10.1162/pres.18.2.97
19	Jordan, J., & Slater, M. (2009). An analysis of eye scanpath entropy in a progressively forming virtual environment. *Presence: Teleoperators and Virtual Environments*. https://doi.org/10.1162/pres.18.3.185
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25	Ranky, R., Sivak, M., Lewis, J., Gade, V., Deutsch, J. E., & Mavroidis, C. (2010). VRACK - Virtual Reality Augmented Cycling Kit: Design and validation. *Proceedings - IEEE Virtual Reality*. https://doi.org/10.1109/VR.2010.5444798
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Appendix B. ICE structure properties present in the literature papers.

SkC	HR	RR	EyeT	EEG	SkT	BFV	EMG	SAA	GNP	VR MC	INTS	FE	EBP	PVR	PP	OVIBE	BF	VO 2	MV E	FR	ACC	TCD
Skin conductance	Heart Rate	Respiration Rate	Eyetracker / ocular exploration	EEG	Skin temperature	blood flow velocity (BFV)	EMG	salivary alpha amylase or cortisol	GNeuro Pathy	VRMC	INTS	Foveal Eye	Eyeblink potentiatio	PhysioVR	Photoplethysmography	OpenViBe	Body forces	oxygen consumption	Mean ventilation responses	Facereader	Accelerometers	transcranial Doppler

	Immersive eXperience													Common Technology									Original Technologies											Non-Typical Technologies					
	RwD			PI			CI		SI		EI																											
Ref	RwDT	RwDI	RwDRI	PISE	PIBE	PISP	CIF	CICA	SICp	SISI	EIA	EIP	EIE	SkC	HR	RR	EyeT	EEG	SkT	BFV	EMG	SAA	GNP	VRMC	INTS	FE	EBPn	E2P	PVR	PP	OViBe	LSTM	MBS	BF	VO2	MVE	FR	ACC	TCD
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INTERACTION

Session Chairs: Simon RICHIR, Arts et Métiers, LAMPA

Jean-Yves DIDIER, Université d'Evry Val d'Essonne, IBISC

Interaction by gesture recognition: a tool to virtually revive the automata of the Antiquity[1]

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Keywords: Automata – Antiquity – Virtual Reality – Gesture Recognition – Interaction

Abstract

This article presents research works devoted to the virtual reconstruction of automata of the antiquity along with associated user interaction. This work is divided in two distinct parts: the virtual reconstruction of ancient automata and the development of an interaction method by gesture recognition. The final application links both the automata with gesture recognition to revive the astonishment feeling generated by the Greeks and Romans automata mechanisms. First the paper focuses on the analysis of ancient sources required to virtually restore some ancient automata (designed during a period ranging from the 3rd century BC to the 1st century AD). Virtual reconstructions make it possible to understand how a mechanism works and to study different hypotheses. In a second step, we introduce gesture recognition as a tool to virtually interact with automata. The construction of an interactive immersive application allows then the user to interact virtually with automata of the Antiquity.

1. Introduction

In the modern world, an automaton is defined as a machine "which, by means of mechanical, pneumatic, hydraulic, electrical or electronic devices, is capable of acts imitating those of animated bodies". This brief definition can also be applied to machines in Antiquity. In this paper, we present a virtual reconstruction of two automata of the Antiquity. This has been made possible after a study of the remaining ancient source materials that describe how they function. If the virtual reconstruction is interesting in itself, enabling a user to directly interact with an automaton can be beneficial in terms of user experience. In addition, it can bring to the user the astonishment that these automata were supposed to produce. This however supposes that the user can interact with the automata. This virtual interaction adds another dimension to the immersive application and the user becomes an actor for the manipulation of objects in real time. Indeed, the common everyday life gestures allow a natural interaction with automata in 3D environments (catching, releasing, pouring, etc.). This interaction also offers the possibility of checking the ergonomics of the object in order to know if the object can be easily manipulated. The union of both virtual reconstruction and virtual interaction makes it possible to understand how these automata worked and to reproduce the astonishment caused by these machines.

2. Automata in Antiquity

In Antiquity, many engineers worked on the study and design of automatic mechanisms (Chapuis, 1949) (Fayol, 1962). However, few real automata artefacts as well as descriptive texts have survived until today (Drachmann, 1948). Our study is based on automata conceived during a period that ranges between the 3rd century BC and the 1st century AD. In that time span, three surviving treatises on the subject can be considered. They were written by Philo of Byzantium (250 BC) and Hero of Alexandria (1st century AD).

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2.1. Available sources

Before any reconstruction can take place and in order to know both the exact dimensions and the shapes and materials of each automaton machine, it is essential to perform what is called an analysis of ancient source materials. This analysis usually takes place in three stages: i) the study of Latin and Greek literary sources, ii) the study of iconographic sources, and iii) the study of archaeological sources. Within the framework of ancient automata, only literary sources are available such as the treatise on *Pneumatics* by Philo and Hero (Hero of Alexandria, 1997) (Philo of Byzantium, 1974) and the one of the *Automata* by Hero (Hero of Alexandria, 1903a). Unfortunately, neither iconographic or archaeological sources are currently available.

2.2. The automated models

The study of both these treatises makes it possible to draw up a list of five automata that can be virtually reconstructed. Each automaton has a specific mechanical system and all five automata provide a representative catalog of the different ancient techniques used (pneumatic, hydraulic, weight system, counterweight, etc.). Thus, we have modeled: 1) The miniature game of Heracles and Ladon (Hero of Alexandria), 2) The automatic maidservant distributing water and wine (Philo of Byzantium), 3) The intermittent fountain of the owl and songbirds (Hero of Alexandria) (Carrer, 2016), 4) The automatic doors of a miniature temple (Hero of Alexandria), 5) The mobile-based automatic theater (Hero of Alexandria) (Prou, 1881). In the next sections, due to space constraints, we present only two virtual reconstructions of these ancient automata: the automatic maidservant and the miniature game of Heracles and Ladon.

3. Virtual reconstruction

3.1. The maidservant of Philo of Byzantium

The automaton of the automatic maidservant distributing water and wine is described in paragraph 30 of the *Pneumatics* by Philo of Byzantium. However, no Greek texts are available today for this treaty, only Arabic versions are available. Before one can understand the functioning of the mechanism, it is useful to specify that it is hidden inside the maidservant's body to be invisible to the public. The text tells us that the automaton is entirely made of copper or silver, and that the maidservant is represented standing, with a jug in the right hand (see Figure 1). It also tells us that the bowl is weighed down by a ballast at its base and that the distributed mixture is two thirds of wine and one third of water. Indeed, during Antiquity, wine was stored in a very concentrated state and it had to be diluted with water to be drinkable. This explains the presence of the two tanks in the maidservant since the mixture is not prepared in advance in the tank but made by the automaton. When the bowl is placed on the servant's left hand, the left arm is lowered. This arm is connected to a butt by two trunnions. In mechanics, a trunnion is a cylindrical part around which a part receives a rotational movement. One of the trunnions (A) is fixed and serves as an axis of rotation for the butt. The other (B) connects the arm to the butt (C) with a rod (D). This butt is weighed down at its base, thus serving as a counterweight to the mechanism to hold the arm in place. When the arm is lowered, it pulls on the end of the butt, the trunnion which is not fixed acts as a lever and the mechanism starts. Two pipes (E, F) come out of the tank, one for wine and the other for water. Two solid rods (H, G) form the end of the butt and are nested in these two pipes. When the mechanism is activated, the rods slide in the pipes using leather seals. These allow silent operation of the machine, so guests using the maidservant do not suspect the presence of a mechanism inside. A slot is present on each solid rod. The rod that comes into contact with the wine hose (G) is the longer The slot at the end is twice as long as the one on the other rod (H). When the slit is at the level of the pipe, it allows air to enter it for a certain period of time. When the slit has completed its passage through the pipe, the solid rod blocks the entry and the passage of air. The tank, dimensioned from head to chest, is divided into two equal parts serving as a reserve for wine and water. The head is a tight cover and offers the possibility of filling the tanks. The air enters the tank through the two pipes, replaces the vacuum and drives out the liquid (wine and water) that flows to the ewer by two pipes hidden in the forearm of the servant. The two slots are of unequal dimensions so as to respect the ratio of two thirds of wine and one third of water. When the flow of liquids is finished, the guest can take his or her cupback his or her cup. The counterweight present in the curvature of the butt allows the arm to return to its initial position.

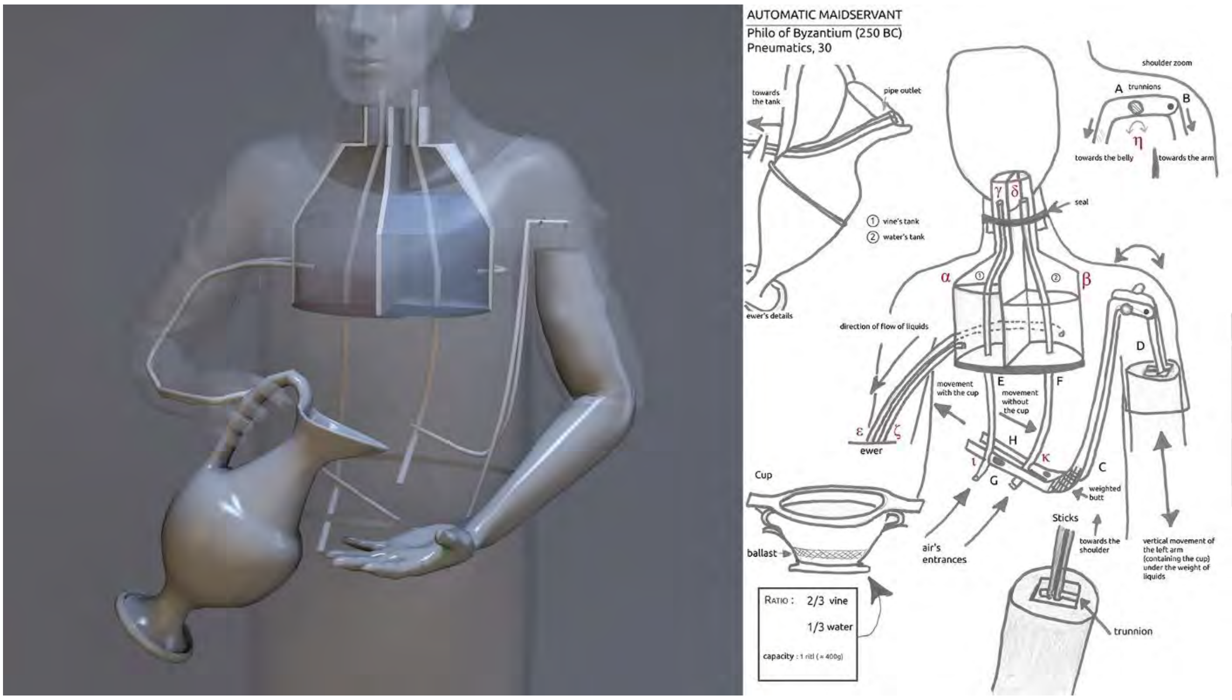


Figure 1. Internal mechanism (right) and virtual reconstruction (left) of the automatic maidservant.

3.2. The miniature game of Heracles and Ladon by Hero of Alexandria

This automaton is described in paragraph 41 of book #1 of the *Pneumatics* by Hero of Alexandria. This is a miniature game, where the controller is represented by an apple placed on a base that triggers a hidden mechanism. The automaton illustrates the mythological conflict between the demigod Heracles and the dragon Ladon. This myth is part of the eleventh of the twelve works of Heracles consisting in bringing back the golden apples from the garden of the Hesperides (see Figure 2). The entire mechanical system of the automaton is constructed on a waterproof base. This base is separated in the middle by a diaphragm. It is a watertight wall that allows the structure to be divided into two identical tanks. The top of the base has a filler cap, while the bottom of the bottom tank has a drain valve. An opening is made in the center of the diaphragm and a "hollow truncated cone" is attached to it. The small opening of the cone is oriented towards the bottom of the tank. There is just enough room to let the water run out. In this cone is inserted another cone, that is full. This second cone closes the first tank to allow the water to remain there. This cone nesting system is similar to that of our current sinks, where the cap allows us to keep the water in place. In the alignment of the cones, a golden apple is placed on the base of the automaton outside. It is necessary to drill a small hole below to be able to connect the apple to the cones. The apple will act as a trigger. A small copper chain connects the apple to the upper end of the cone. When the apple is lifted, the cone moves, and it allows water to flow into the second tank. Under the representation of Heracles, and on the diaphragm, a small pulley is installed which allows to adjust a rope. This rope connects the trigger of the hero's bow to the cone. The rope tightens when it is tied to the trigger on the bow. This rope, which is hidden inside the sculpture, comes out of the hand of Heracles. To prevent it from escaping inside, a loop is formed. It is this loop that allows the user to tense the bow and the rope. Now when one lifts the apple, the plug formed by the upper cone rises and pulls the cord. This action releases the trigger from the bow that launches its arrow. An additional dimension is added with the presence of sound in the automaton. A hollow pipe is installed; it is hidden inside the tree and goes down to the second tank. During the movement of water, it allows the air contained in the tank to escape. A small whistle is placed at the top of this pipe. The air flowing through helps to imitate the dragon's hiss of pain.

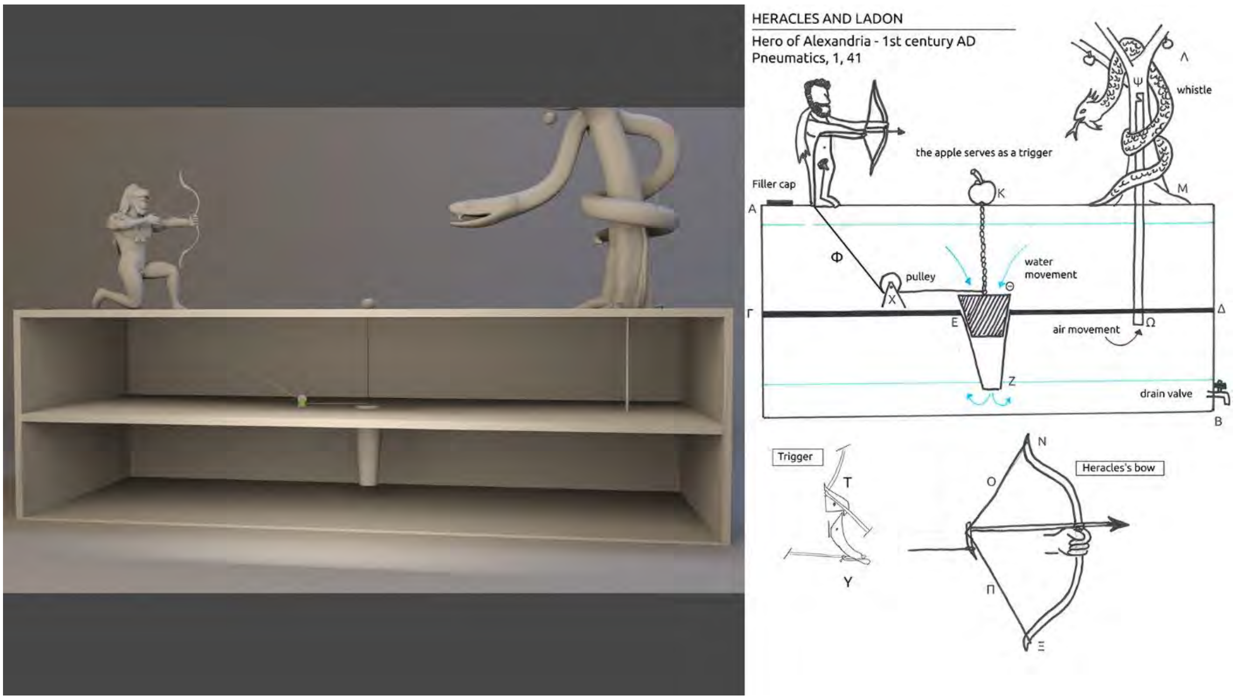


Figure 2 : Internal mechanism (right) and virtual reconstruction (left) of the miniature game of Heracles and Ladon.

4. Interaction by gesture recognition

After modeling the virtual reconstruction of the two automata, we will now focus on how to interact with them. We consider an interaction where the user performs actions with his hands. This therefore requires the ability to recognize hand gestures in real time in order to trigger an item of the mechanism.

4.1. Development of a new method

Recent approaches for gesture recognition are based on machine learning techniques, and in particular on deep learning techniques. We have considered the state-of-the-art approach of Devineau (Devineau, 2018). This method is today one of the most effective in the classification of gestures on the DHG 14/28 Gesture Dataset database (Smedt, 2017). We describe this method in the sequel. The hand is represented by a set of 22 hand joints, each represented by its 3D coordinates within a time period that captures the gesture to be recognized. The approach of Devineau considers the 66 coordinates (X, Y, Z for the 22 hand joints) separately within a time period of 100 frames. Each coordinate (denoted as Ci) is processed using three different branches that have the structure of a convolutional neural network (CNN), made of a cascade of three 1D convolutions and pooling layers. This enables to extract three sets of features for each coordinate, that are concatenated to represent each joint independently. Then, all the features of the 66 joints are concatenated into a single vector that represents the gesture to be recognized. It is the input of a fully connected layer that performs the gesture recognition into 14 or 28 gestures. Figure 3 presents an overview of this architecture (when one considers only the Ci coordinates). Devineau's method does not take into account the physical relationships that exists between the hand's joints (the fingers) at all and that play an important role in the description of a gesture. Our improvement over Devineau's approach will consist in taking into account the movements of the fingers. Indeed, during the performance of a gesture, each finger has a precise position and orientation as well as specific coordination of its joints. To that aim, we add a fourth branch of processing that will compute dedicated features for each finger Di, enabling to capture higher-level cues. Each finger is composed by the following joints, as shown in Figure 3a: finger 1 (inch joints 3-4-5-6), finger 2 (index, joints 7-8-9-10), finger 3 (major, joints 11-12-13-14), finger 4 (ring finger, joints 15-16-17-18), finger 5 (little finger, joints 19-20-21-22). Joints 1 and 2, that represent the wrist and the palm of the hand, are not used to isolate the fingers. In the new branch we have designed, each finger (denoted as Di) is processed by three 2D convolutions and pooling layers. We consider 2D convolution layers since we have 4 joints for each finger on 100 consecutive frames. This is similar to the processing performed by the architecture of Devineau for each 1D temporal coordinate signal.

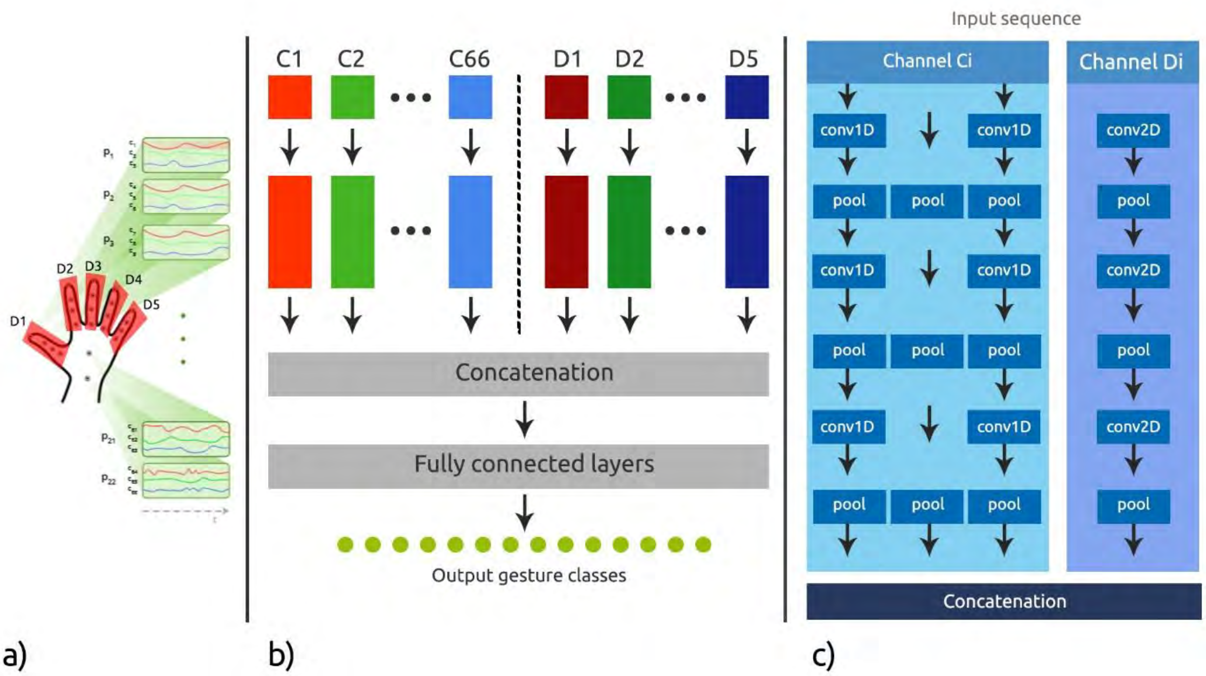


Figure 3: CNN architecture of our gesture recognition method. a) Illustration of the different input parameters of the model: the channels Ci for each joint's coordinates and the channels Di representing the fingers. b) General view of the neural network. c) Illustration of the parallel branches allowing the features to be extracted.

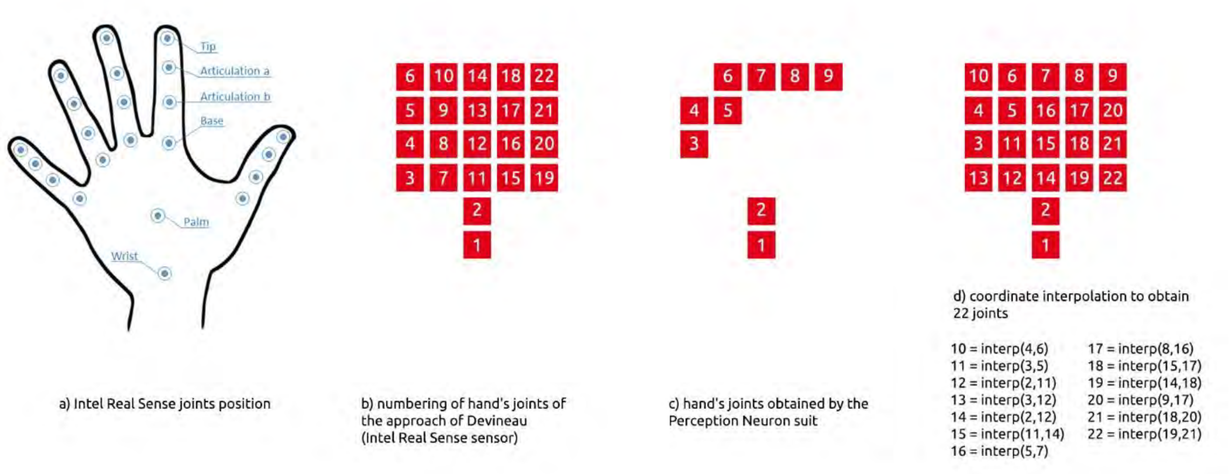
Theoretically the management of each finger should allow a gain of precision in the recognition of gestures. This can indeed capture overall movement features of each finger that represent statistics taken at a higher semantic level. The features extracted for each finger are concatenated together with the output of the Devineau's approach and transmitted to the fully connected layer that performs the classification. This last layer classifies the different gestures into 14 categories when used with the DHG 14/28 Gesture Dataset. This new method that we have developed obtains a classification rate of 89.97% on the DHG 14/28 gestures database. This is slightly behind the approach of Devineau that has a classification rate of 91.28%. The standard non-deep approach of De Smedt obtains a score of 88.24% (De Smedt, 2016). However, in the context of the interactive immersive application, we do not need to recognize all the gestures that are present within this database. In particular, after looking closely at the results, we have noticed that for the "*catch*" gesture, our method is more effective than that of Devineau with a recognition rate of 95.2% versus 94.8%. This gesture being of paramount importance for the virtual interaction with automata, shows the benefit of our approach that captures the higher-level cues of the finger. In addition, this motivates the building of a specific dataset that contains only the gesture we are interested in.

4.2. Interaction Gesture Dataset

For the purpose of our application, a new gesture database was created in February 2019. This database, called *Interaction Gesture Dataset (IGD)*, brings together two useful gestures for interacting with ancient automata. They have been obtained with the “Perception Neuron “ motion capture suit:

1. *Catch*: used to detect when an object has been taken. The combination with the movement of the arm allows to know in which direction the user is carrying the object. The gesture begins with an open hand and ends with a closed hand.
2. *Pour*: is combined with the first gesture. It tells if the user is pouring something, especially when filling a tank. The entire gesture is carried out with a closed hand.

The *Interaction Gesture Dataset* was built by a panel of 4 people (3 are right-handed and 1 is left-handed). Each person performed the gesture 30 times, which gives 4 x 30 = 120 executions per gesture. The dataset provides a total of 240 gestures. We plan to distribute this new database on a dedicated website this year.
However, the Perception Neuron suit used to build this new dataset is different from the Intel Real Sensor. It provides a hand skeleton with only 10 joints unlike the Intel Real Sense sensor that is made of 22 joints (see Figure 4 a and b). The model of Devineau, as well as our new approach presented in the previous section, is designed to take as input a hand skeleton of 22 joints. Therefore, to train these models and further classify them, we have to transform the 10 joint skeletons into 22 joint skeletons. To do this, we use a specific linear interpolation with physical constraints to take into account the shape of the hand and the position of the joints (see Figure 4 c and d). To interpolate the coordinates of a missing joint, we consider its two closest neighbors and compute a weighted average. On this IGD database a classification rate of 84.26% was obtained with our new approach. The state-of-the-art approach of Devineau obtains a lower classification rate of 83,57% on these same data. This shows the advantage of having built this second specific database because it specifically contains the gestures that we need to interact with ancient automata and enables us to obtain better results than the state-of-the-art approach of Devineau.



a) Intel Real Sense joints position

b) numbering of hand's joints of the approach of Devineau (Intel Real Sense sensor)

c) hand's joints obtained by the Perception Neuron suit

d) coordinate interpolation to obtain 22 joints

10 = interp(4,6)
11 = interp(3,5)
12 = interp(2,11)
13 = interp(3,12)
14 = interp(2,12)
15 = interp(11,14)
16 = interp(5,7)
17 = interp(8,16)
18 = interp(15,17)
19 = interp(14,18)
20 = interp(9,17)
21 = interp(18,20)
22 = interp(19,21)

Figure 4: Principle of interpolation of coordinates in order to restore a skeleton of the hand with 22 joints, similar to the Intel Real Sense sensor.

4.3. Integration of the method in an interactive immersive application

The use of the designed interaction method within the interactive immersive application makes it possible to obtain an effective and efficient level of detection of user gestures. When the Trigger is activated by the user's hand, the algorithm performs gesture detection every 20 frames in order to limit the risk of errors, by aggregating successive temporal gesture recognitions. In the worst case (approximately 1 in 12 times), we will have to do the gesture twice so that it is well recognized. A demonstration of the interactive application was led during a public show on April 4, 2018 (see Figure 4), in front of an audience of 264 people of very varied age[2]. Its purpose was to virtually interact with Philo of Byzantium's automatic maidservant to demonstrate it and let the audience understand how its internal mechanism works. This presentation was really well received by the audience. Each automaton is integrated in its context (see Figure 6) and the interaction with the user

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[2] https://www.youtube.com/watch?v=bkrmy6Nlpuc&t=2140s

makes it possible to judge the degree of reliability of its reconstruction. The method has obtained good results in terms of real-time gesture recognition (a classification rate of 90.4% was recorded afterwards on the fifty gestures performed during the demonstration).

Figure 5 : Virtual interaction of the automatic maidservant of Philo of Byzantium.

Figure 6: Contextualization of automata.

5. Conclusion

In this paper, we have considered the virtual reconstruction of ancient automata. The approach has required background knowledge both in studying ancient sources and learning how machines work. The study ancient sources has enabled us to propose a virtual reconstruction of two automata. Machine learning has enabled to provide gesture recognition as a tool for interacting with the designed virtual automata. Linking 3D models of machines with virtual interaction adds an extra dimension to the user's experience and enables to appreciate the effectiveness of virtual restitution. This virtual immersion revives the thaumaturgy effect of using automata on users. The whole immersive application has been realized under Unity 3D, where the user navigates and interacts in a natural way with the ancient automata.

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Using collaborative VR technology for Lean Manufacturing Training: a case study

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Abstract

Research on the application of virtual reality (VR) to training has shown VR environments could contribute to the acquisition of procedures with minimized risks, costs, and timing. In the field of Lean Manufacturing (LM), VR can improve decision making in factory layouts. However, in the field of training, no evidence yet existed that VR immersion could communicate LM concepts as well as physical immersion. This project aimed at comparing both the process of learning a procedure and the transfer of LM concepts, on manual workstations, with the same process in a VR environment.

The results confirm VR is a time gaining, cost reducing, easily accessible tool to train operators on procedures before onsite training. They also show that for an optimal appreciation of assembly procedure issues in the VRLE, increasing interaction fidelity and improving physical simulation would give students a better appreciation of Equipment and Materials issues.

1. Introduction: context and project goals

Higher education and in-company Learning Environments are evolving, to answer recent technological and organisational evolutions, to train students and workers to master the tools of Industry 4.0. CESI is a French multicentre higher education and vocational training institution. It delivers Engineering degrees, as well as vocational qualifications, including in the fields of Industrial Organisation and Performance. Lean Manufacturing is taught in several of CESI's vocational training degrees, in line with industrial companies' wish to reduce production costs, manage delays, and waste (Abidi et al. 2016). CESI's teaching methods are student-centred, situated, active pedagogies and skills-based, learning by doing approaches (Badets, 2016; Ageorges et al. 2014). This led to the implementation, in one of its training centres, of manual workstations, allowing Lean Manufacturing (LM) students to immerse physically in a simulated production line, using a "learning by doing" pedagogical approach where students have to detect LM problems in an assembly line, taking on the role of an operator, or an observer.

The expertise of CESI's research laboratory, LINEACT, is two-fold: it both enquires the future of manufacturing – use of digital twins, Virtual and Augmented Reality technologies (Havard et al. 2019) – and the impacts of digitally enhanced learning environments on learners. With this dual perspective on Digital Innovation both for Companies and for Learning, the benefit of this paper is that it is a cooperation between researchers from both fields. In this context, a collaborative VR environment, based on a specifically designed framework, was developed, to investigate what such immersion could contribute to students' integration of LM concepts and compare how working on manual workstations or on a VR simulation might affect how students grabbed these concepts. The simulated production line aiming at assembling children's bikes, two learning objectives underlay the training sessions concerned: learn the assembly procedure, but also detect problems and suggest improvements on the assembly line, according to LM concepts.

This paper synthesizes the project goals, based on previous related works (part 2), and then unfolds the research protocol carried out (part 3) and its results (part 4).

2. Related works

2.1. VR as an efficient tool for layout design and production simulation in Industry

In the context of the Digital and Virtual Factory (VF) paradigm (Tolio et al, 2013, p26), VR can reduce time and costs related to the development of factories layouts as it is an easily updated and efficient tool for modelling manufacturing systems, in the design phases. Lee et al. (2011) have demonstrated how "*mixed reality-based digital manufacturing environments*" gave promising results for the layout planning of factories. In their case, they combined VF models with real objects like printed 2D images to simulate factory layouts before implementing them. VR has also proven an effective tool for LM processes in companies. Indeed, like Abidi et al al. (2016) explain, VR can simulate production flows in real time, actually visualize them and "*detect stocks and queues from production simulations*" (p182) and thus optimize production times before queues and stocks even become problematic in the real system.

Havard et al. (2019, p473) specified the interest of VR to validate factory designs and simulate production flows, specifically when combined with digital twins that can simulate new configurations and communicate data to the VR environment, as part of a Cyber-Physical Production System (CPPS). Digital twin approaches that combine the real, physical system, with its virtual representation can be used to simulate and monitor all the components of a production system (Uhlemann et al. 2017). However, what Havard et al. (2019) suggest, is that in VR environments, the operators are real persons "*acting and taking risks, as they would do on the real workstation*". This is very interesting in terms of LM concepts and ergonomics if you wish to compare how users behave on manual workstations, and how they respond to the VR simulated workstations.

2.2. VR as a learning tool

2.2.1. Immersion, motivation and the development of reflexive skills

VR has also been widely experimented as an effective tool for education purposes, thanks to its main immersive, experiential features. The visual, situated experience it implies, with its "*sense of scale, depth and spatial awareness*" affects students' learning process and motivation (Sampaio, 2019, p18), in line with constructivist theories on learner-centred, situated learning.

In addition to the development of students' motivation, VR's efficient reflexive potential is also pinpointed. Lourdeaux, as soon as 2001, highlighted how VR permitted to improve students' learning processes with visual or sound aids. Virtual Reality Learning Environments (VRLE) enable the delivery of information in different and adaptable formats, and thus allow users to either come back to parts of the scenario, or benefit from intelligent tutoring systems, that both give users reflexive opportunities. Hanson et al (2008) mention how VR is "*a participatory learning environment in which students are allowed to ground their knowledge via participation by knowing and doing*" (p120).

2.2.2. Safer and cost-effective training: VR as an effective procedure acquisition tool

The costs generated by the development of training equipment in specific fields (biomedical, potentially hazardous environments in industry…) has led to an increase in VRLE use. VRLEs (Le Corre 2012, p2) allow designers to ignore time and space constraints, and users, to easily immerse themselves and manipulate otherwise hardly accessible environments, tools and simulations.

These features offer original, dynamic learning situations (Oubahssi et al. 2017, p212), and safe training environments. We can quote examples such as the training of operators on Hydroelectric Power Units (Sousa et al. 2010), on wind turbines (Saunier et al. 2016), where learners discover safety procedures without having to go on-site. Lourdeaux (2001) also mentions this feature: users can safely train, make mistakes and learn from these; designers can re-create specific, extreme environments and situations to test learners' behaviour under duress. Ganier et al. (2014) have demonstrated that VR training on maintenance procedures allowed learners to transfer skills as well as onsite training, but with reduced training costs. VRLEs are also deemed to affect the relations between learners and their actions (see Barot, 2014, on learners' freedom of choice), learners and instructors, and in learning groups.

2.3. Authoring virtual environment and scenarios

The previous section has mentioned that VR is a multi-purposes and domains learning tool. However, there is still an open issue about authoring VR environments and scenarios. As Lee et al. (2011) explain: "*the greater the level of precision, the higher the cost of virtual environments. Yet the level of improvement in the sense of reality and immersion is unsatisfactory compared with the time and cost overheads*". In other words, as for now, high computer science skills are still necessary to create VR applications and even if VR is useful, it is not yet cost-effective.

In order to alleviate this content authoring issue, the models in literature allow defining a language that will specify entity features in the VR scenes, as well as possible interactions users can carry out. Several approaches exist: either UML-based (Querrec et al., 2013; Martínez, et al., 2014; Bouville et al., 2015 ; Richard et al., 2018) or ontology-based (Barot, 2014; Hervás et al., 2010; Havard et al., 2017). UML-based approaches are powerful since they use a standardized formalism used by many tools. However, content authoring is performed with UML editors that do not permit 3D representations of the system the VR scenario is about. Moreover, the expert editing the content must be trained to formalism before authoring it.

Ontology based approaches allow adapting the VR environment to the company vocabulary. Therefore, it is possible to align ontologies to develop a VRLE that will train people, generated from real-world internal procedures. However, ontologies prevent from formalising complex scenarios.

3. Research methodology

3.1. Research protocol design

Research in Sociology, Education, IT, has profusely enquired, with mostly quantitative approaches, how such VRLEs could affect students' motivation, or learning processes. Few research protocols have undertaken, as we have in this project, to analyse a cohort of students' performance and experience during a learning situation where:

1) Half of the cohort is working in a physical learning environment – manual workstations in a simulated children's bikes assembly process, in our project –

2) The other half works in the VR simulation of the same environment

3) All carry out a series of tasks, with the same learning objectives.

The aim of such a research protocol was to:

- Check how the different learning environments affected the learning process of assembling the bike;
- Test VRLE as a tool to develop professional skills, and specifically, Lean Manufacturing skills.

The design of the research protocol was divided into four main stages, and was put together as a cooperation between IT and Education researchers together with LM department heads:

- Definition of assessment criteria to compare students' understanding and use of LM concepts in both environments. Experts created a performance-based assessment rubric that would be used as a standardized tool to evaluate students' identification of problems encountered on the workstations, and solutions they suggested;
- Assess that a generation of the virtual environment and scenario based on the framework proposed hereafter is usable;
- Joint creation of the research questionnaires and qualitative data collection protocol;
- Outline and planning of the experimental training session.

3.2. A framework to create collaborative scenarios in a Virtual Reality Learning Environment (VRLE)

As explained previously, the virtual environment scene and scenario must be configurable. In this section, we will first describe the overall learning scenario, and then explain the model used to create this scenario. We will then explain the collaboration features implemented.

3.2.1. Study of the training process

As shown in Figure 1, the training scenario is made of four steps authored inside the VR application. First, the trainees must carry out the assembly process. Thanks to that first experimentation, they must make improvements on the process: first, rearrange the tasks assigned to each manual station, then design each workstation according to the tasks assigned, and finally improve the workshop layout by organising the distribution of the stations.

In the use case presented, the lecturer carried out the yellow part of the process; learners the purple part in order to get them to discover what improvements needed to be done, through experiencing the VR simulation.

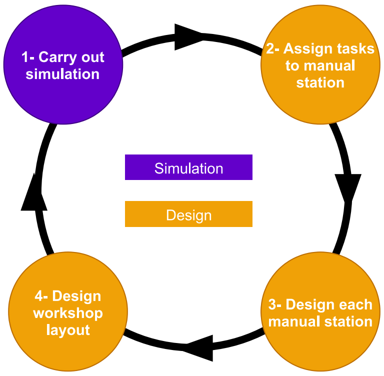


Figure 1: training scenario

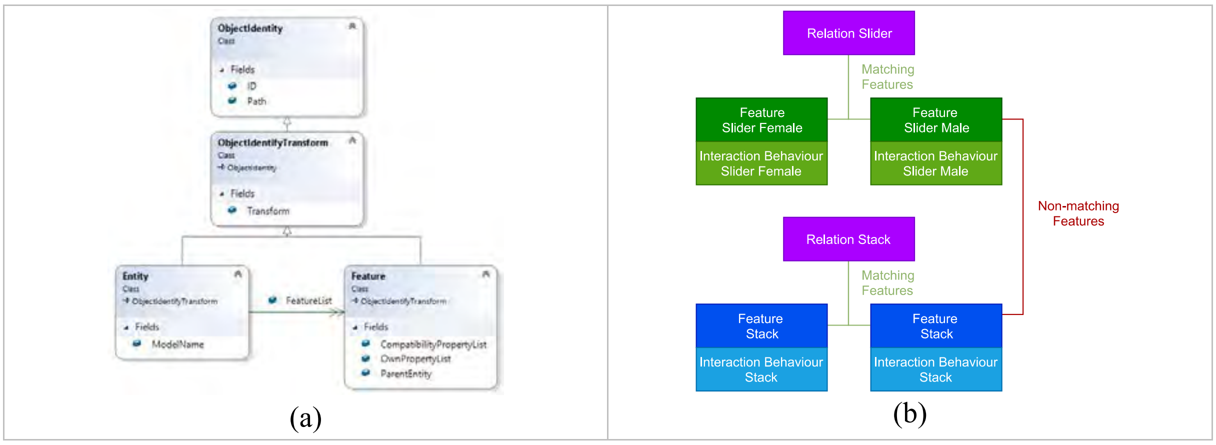
It is worth noting that this process can be used both to train people and inside an industrial process, as an iterative tool for redesigning workshop layouts (Havard et al, 2019). It involves several types of jobs into the process (operator, process & method, ergonomist…). Once the workshop is designed, it can be used as a training tool for new operators. To create the VRLE, it is mandatory to model the possible interactions of each entity inside the scene. Therefore, the interactions and scenario can be updated according to learning needs. The model used will be explained in the next section.

3.2.2. Model based on Feature Interaction and Relation on Entity

This section describes the model used for managing interactions and creating a virtual environment as an open world, i.e. that enables users to act like in real life and make mistakes during the VR session. To allow for a massive adoption of the VRLE tool, our objective was to come up with a framework that simplified authoring VR scenarios by simplifying the possible interactions. The model is thus based on four main concepts called, Entity, Feature, Relation and Interaction, as shown in Figure 2 - (a).

Entity is a virtual representation of a physical object, such as a screw, a metallic bar. It is identified thanks to a unique ID and Path in the scene and it has a 3D pose (position and orientation) in the scene (see Figure 2 - (a) ObjectIdentity and ObjectIdentityTransform).

In order to make it interactive, we defined how each Entity could be associated with another thanks to several **Features** (see Figure 2 - (b)). Each Feature gives information about where it is located on the Entity and defines what other Features it can match, thanks to PropertyList. Specifically, OwnPropertyList specifies the Feature



(a) (b)

Figure 2: (a) Entity described with list of Features in a VR scene. (b) Relation based on Feature matching in a VR scene.

and CompatibilityPropertyList specifies the property the other Feature must have to be associated with this one. For example, if a feature f1 has an *OwnPropertyList = ["Size8_Male"]* and a *CompatibilityPropertyList = ["Size8_Female"]*, therefore, f1 can only be associated with a Feature f2 which have *OwnPropertyList = ["Size8_Female"]* and *CompatibilityPropertyList = ["Size8_Male"]*.

3.2.3. Collaboration inside the VR environment

The model proposed allows collaboration inside the VR environment. Therefore, the scenario on the industrial process can involve several users in the VR simulation in real time. Figure 3 presents the architecture based on the model proposed. The scene state can be synchronized between several Lean Manufacturing applications. First, each user interacts with one of the Entity. Entity pose is synchronized between all applications inside the same room.

Then, when an interaction involves creating a Relation between two Features, an event about this new Relation is raised by the application from which this Relation originates; the event is then dispatched to every application. Finally, the scene state manager of each application creates the relation inside it; finally, all the applications have the same status. Technically, the framework proposed relies on a SDK called Photon[1] for managing the synchronisation events, but could be used with other SDKs.

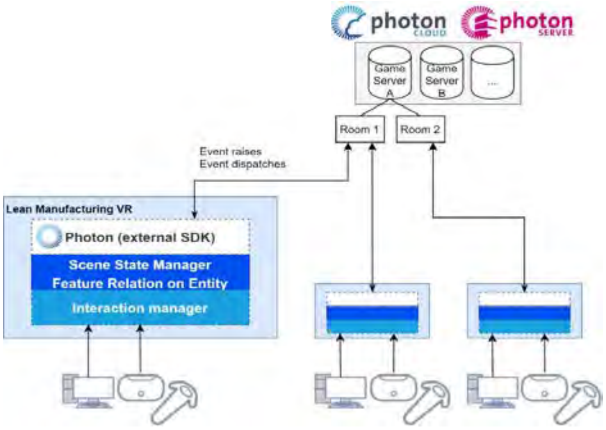


Figure 3: The proposed model allows collaboration inside the VR environment.

3.2.4. Lean Manufacturing VR application

As a result, we have produced the Lean Manufacturing VR (LMVR) application that allows simulating, in a collaborative VRLE, an industrial assembly process composed of 43 assembly steps and 150 parts to assemble spread on up to 6 manual workstations. The application is developed with Unity and SteamVR. Users wear HTC Vive associated with the Vive controllers to interact into the VR world. Moreover, LMVR can be used with a PC with mouse and keyboard in order to observe users inside the VR scene.

We have chosen to simplify VR scene status management thanks to Interaction and Relation Features on Entity. This allowed us to bring collaboration features inside the VRLE, and led us to produce the Lean Manufacturing VR assembly scenario, as illustrated in Figure 4 below. This architecture and application allow several operators to act simultaneously on different workstations, while observers are able to watch what is occurring in the VR scene from a PC. As it is a collaborative application, errors made by an operator are transmitted to the others.

To prepare the session, tutors have set the different real workstations (see Figure 4 – a); then in VR, they have designed each workstation (see Figure 4 – b), then they have set the layout of the VR shop floor (see Figure 4 – b). Afterwards, both groups are doing the activities, as we will explain later on.

The next section will describe the research protocol and discuss the learning outputs of this VR scenario.

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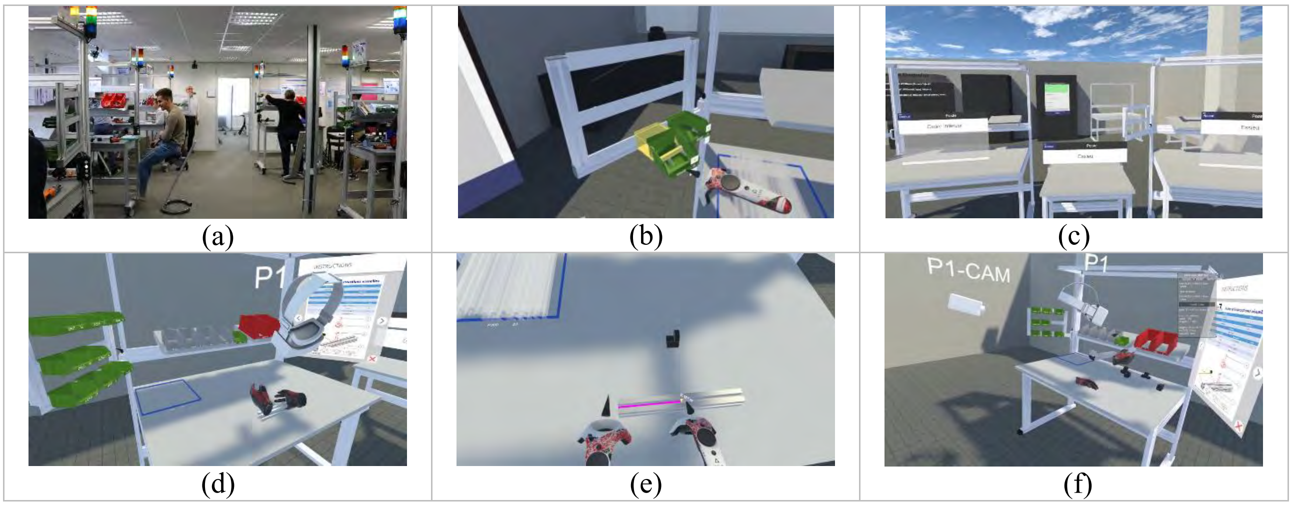
[1] Photon Unity Network https://www.photonengine.com/en/PUN



(a) (b) (c)
(d) (e) (f)

Figure 4: (a) Physical workstation. (b) VR workstation design. (c) VR workstation layout. (d) VR simulation: workstation instructor interface. (e) VR simulation: Operator 1 doing a Relation Slider during the assembly process. (f) VR simulation: Operator 2 looking at operator 1

3.3. Data collection and analysis

3.3.1. Hypotheses

1. The use of VR immersion should allow for a good understanding of workstation layout acuity without the necessity of having the physical environment at hand;
2. Students will develop conceptual understanding of LM principals (in terms of: Materials, Equipment, Methods, Workforce, Environment, Management) through the Virtual immersion as well as with the physical workstations;
3. Students may experience difficulty handling the VR tool, which might bias the experimentation.

3.3.2. Experimental Session of the case study

Twelve students, as part of their training as future Organisation and Industrial Performance managers, took part to the experimentation. It occurred at the beginning of the weeklong project, during which the trainees had to work on the improvement of the children's bike assembly line. Their final evaluation was an oral presentation of their LM methodology and the improvements they implemented on the line.

During this session, they were randomly divided into two groups of six students. One of the groups, the control group, worked on the physical, manual workstations; the other group on the VRLE. The experiment was conducted on the first two workstations only: the collaborative preparation work with department heads determined focusing on these two workstations would be enough to compare the environments' effect on students' LM concepts comprehension.

Two volunteer trainees were assigned workstations 1 and 2 in the physical environment, and two others were assigned workstations 1 and 2 in the VR simulation. Four students in each environment were "observers" during the sessions but could interact with the other students performing the assembly tasks, and were asked to take an active part to the sessions, as they would also be requested to fill in the questionnaires. Although the trainees' age range is wide (20 to over 35), as the results showed no correlation between participants' age and the effects of the environment, we will not elaborate on age issues in this article.

This first experiment is meant mostly to assess the generic response to VRLE for LM training purposes. However, this experimentation is only the first in a series that will add layers of deeper understanding into the more specific question of how a VRLE can be adapted and individualized to answer each trainee's needs, which will imply looking into trainees' individual dispositions to analyse interactions between these dispositions and their response to the environment.

3.3.3. Data collection

In order to answer this dual objective, we designed a mixed research protocol, with a collection of data through questionnaires, meant for a quantitative treatment, and data collection through filmed sequences and interviews, to gather more qualitative information and a deeper understanding.

Pre and post-session questionnaires, based on a constructivist theoretical approach of learning, aimed at understanding the interactions between learners and their environment, (Badets, 2018). The pre-session questionnaire was designed to enquire about learner profiles (previous work/training experience, experience with VR, with LM etc.), and the post session one, to gather their feedback on the experience. We included Martin Schrepp‘s (2015) *User Experience Questionnaire* as a section of this data collection, and had students analyse assembly line problems and solutions. To get them to do so, LM experts that co-designed the questionnaires with us suggested using a variation of the Ishikawa diagram, so that trainee could express the problems (waste sources) they encountered on the assembly line, as well as the solutions they wished to implement, in terms of: Materials, Equipment, Methods, Workforce, Environment, and Management.

The four analysed workstations (physical or VR simulation) were equipped with two cameras and microphones, and the trainees agreed to be filmed and to carry out post-session debriefings, to discuss their experience, and have an in-depth analysis, with an Education researcher, of several filmed sequences.

3.3.4. Data analysis

For the qualitative data analysis, Clot’s self-confrontation methodology was used (Clot et al. 2000). It proceeded as follows: after the sessions were completed and the post-session questionnaires sent by all trainees, an Education researcher watched all the filmed sequences (about four hours of recorded videos) and selected sections to discuss with the trainees. The selection was made according to three criteria that would allow to discuss the resources students used to perform the tasks and the specific ways in which they carried out each task. The sections selected appeared to either 1) show the trainee performing a task with difficulty; 2) show the trainee performing a task with ease; 3) show an interaction between the trainee and a third party. The four filmed students were shown the selected sequences, with the researcher by their side. They could react to what they saw and were invited to analyse their choices and reactions, and comment on their actions.

For the quantitative data analysis part, factor analyses were used, mainly to compare data from VR environment users and physical workstation users. The triangulation with the experts’ evaluation of the learning objectives with the standardized rubric system permitted to get a more objective insight into the experiment.

4. Results

4.1. UEQ and correlation tests

The quantitative treatment of the data collected cannot be considered statistically valid as only twelve students took part to the experiment. It gives us interesting generic information on these twelve users’ experience.

The twelve students expressed how the session was original and interesting for them, regardless of the environment in which they immersed. VR is confirmed as a motivational learning environment. The *UEQ* data shows that hedonic qualities take precedence over pragmatic ones, which means the trainees found the session more interesting and innovative than easy to understand and use.

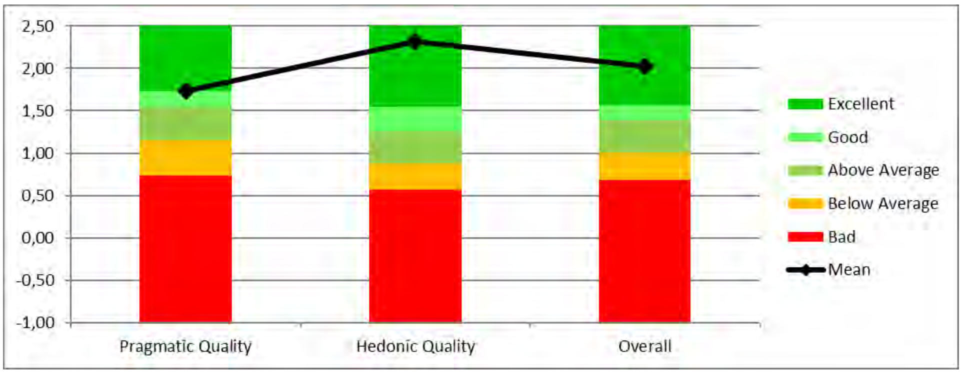


Figure 5: UEQ benchmark results

What is worth noting, and came quite as a surprise (and a contradiction to our third hypothesis), was that the physical workstations were deemed more difficult to use than their VR simulation. Indeed, with a 0.063 p-value (Wilks’ G-test) that is very close to significance level, it appears that students in the real-world environment more often judged it difficult to use than students did in the VRLE. This set of data will be confirmed and will find explanation through the interviews with trainees as exposed in the next section.

4.2. Procedure and Lean Manufacturing concepts comprehension

As the rubric-based evaluation showed, trainees from both environments identified assembly line problems related to Methods and Environment, such as unclear operating procedures or problematic stations layout. However, only the students working in the physical environment identified problems related to Equipment and Materials, such as screws and fitting dimensions, absence of jigs, absence of mounting brackets… The trainees in the physical world identified 15 different problems in the two workstations, with a rubrics score of 41 and the trainees in the VR world identified 9 different problems in the workstations, with a rubrics score of 20. To illustrate this, the handling of bike pieces and assembly tools appeared to be problematic only in the physical environment and, consequently, trainees in the physical environment were able to suggest more improvements for each workstation related to handling simplicity. The filmed sequences revealed that the overall time of the assembly process was longer in the real environment (70 minutes versus 55 in the VRLE). In the real environment, handling pieces and tools appeared longer than in the VRLE, where pieces could float mid-air as there is no gravity constraints in this VRLE version, which seemed to make the assembly a bit easier.

During the post sessions self-confrontation with the four trainees, the ones in the physical environment indeed came back to the difficulty of handling pieces or even the partially assembled bikes, and expressed the frustration, doubts and discomfort they experienced, and spent twice as much time as the VRLE trainees discussing such issues. Another specificity of the experience in the physical environment is that both workstations 1 and 2 trainees expressed how verbal interaction with one another had helped them understand the assembly process and assembly line issues. Such interaction was not mentioned by either of the VRLE trainees, nor by the observers of the VRLE session.

In the VRLE trainees' self-confrontations, however, students expressed how the absence of physical constraints, and how allowing bike parts to hover above their workstation allowed them to focus on the assembly procedure, rather than be impended by handling difficulties. They expressed this was a comfort in the process, and allowed them to understand how the different tasks followed one another, without wasting time on the actual assembly details. This was confirmed by post-session questionnaires. What is more, both VRLE trainees insisted that the VR session allowed them to be more efficient when they carried out the assembly process on the physical workstations in a next session, than they would have been without this VR session. Another important element to mention is that the experts that assessed the trainees' achievement of learning objectives did not observe a difference in the mere procedure application part of the experiment, between both environments.

These elements seem to indicate that:

1) The VRLE developed did allow a comprehension of the global assembly process and of the operation phasing. Learning indeed took place (how to assemble the bikes, and how to detect problems with workstation layouts and ergonomics; Methods issues, for example related to the written protocol)

We can here quote a trainee's comment that clearly synthetizes his view of how VR contributed to his understanding (translated from French): «*To carry out the assembly process in VR is a way to get familiar with the process, with the parts and tools, and then, you can add part and tool weight and handling issues, in the real world*". He clearly envisions VR as a first step in his learning process.

2) The voluntary limitations in the VRLE's realistic rendering of how trainees could interact with bike parts and assembly tools did not allow them to grasp fully the real physical difficulties operators in the real workstations would encounter, especially in terms of tools manipulation. Therefore, for the VRLE to allow a more accurate appreciation of handling issues that might affect LM decisions, the next step shall lead us to look into increased interaction fidelity and improved physical simulation and haptic feedbacks. .

3) Students did not seem to experience major difficulty in handling the VR tool, and reported VRLE to be a motivational learning environment that helped them ease into new concepts, such as LM.

5. Further research questions and discussion

As we have mentioned earlier, this experimentation is the first in a series. We understand that VR alone, and the choice to simplify VR scene status management, gives a mixed response to the issue of VRLE for LM training purposes, in terms of Materials and Equipment appreciation. Since the experimentation confirms the interest of VRLE as a motivating procedure-training tool, and our aim is ultimately to look into VRLE individualization, this first set of data allows us to plan the second stage of our experimentation. In the next experimental stage, the VRLE will be enhanced with:

- Increased interaction fidelity and improved physical simulation and haptic feedbacks.
- Personalized trainee support systems such as a learning assistance tool able to identify learning profiles, to monitor learners' skills development, and thus adapt the flow of resources and tutoring style according to these profiles. Learning analytics data, as well as physiological data (heart rate, skin conductance response, self-assessed stress levels) associated to deep learning algorithms will allow us to improve adaptation to individual profiles;
- The VRLE could also benefit from the adjunction of digital twin (DT) simulation data, which would reinforce the VRLE's efficiency as a procedure-training tool. Indeed, digital twin can simulate the real behaviour of a system. Therefore, with co-simulation, DT and VR gather their advantages, respectively realistic simulation and intuitive interaction, in order to make people learn on system with a realistic behaviour. Just like Le Corre (2013, p 2) mentions, such enhanced environments shall be designed as a tutoring and reflexive tool that would help trainees gain time and a deeper understanding of their actions and choices once they perform their tasks on a real physical system.

6. Conclusion

To conclude, this study is further evidence that VR can be an efficient tool to train operators on procedures before onsite training, thanks to a VR application created from a framework and model that structure features and interactions on scene entities. Trainees gather knowledge of the overall situation, of task phasing, and in the case of an assembly line, of the different workstations, pieces and tools they can use.

This study allowed us to understand, that in terms of skills development, and specifically Lean Manufacturing concepts transfer, the VRLE allowed a good understanding of problems related to Methods (written procedure issues, procedure phasing issues) and Environment (ergonomic issues). This study also helped us pinpoint the improvements needed on the VRLE to give students a better appreciation of other LM important issues such as Equipment and Materials problems: improving interactions, such as how to associate the parts together, or physical simulation and haptic feedbacks. To address the lack of interaction between operators and observers in the VRLE, as this appeared to help trainees understand the assembly process and issues in the real world, developing observers' avatars in the VRLE might be a solution in the next experimentation.

VRLEs' potential for individual tutoring and feedback, as well as a will to be as realistic as possible, should also be exploited. VRLE can indeed be designed as an additional tutoring and self-reflexive tool that allows both trainees, tutors and researchers to gather data and deepen their understanding of the learning process.

Further work should allow us to investigate both aspects, first by improving the realistic rendering of parts handling, as well as using intelligent tutoring systems (ITS) in VRLE, as a tool to monitor learning and adapt resources to the learner during training sessions.

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AR & VR CONCEPTS

Session Chairs: Vincent MEYRUEIS, Arts et Métiers, LCPI
Laure LEROY, Université Paris 8

CAstelet in Virtual reality for shadOw AVatars (CAVOAV)

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Abstract

After an overview of the use of digital shadows in computing science research projects with cultural and social impacts and a focus on recent researches and insights on virtual theaters, this paper introduces a research mixing the manipulation of shadow avatars and the building of a virtual theater setup inspired by traditional shadow theater (or "castelet" in french) in a mixed reality environment. It describes the virtual 3D setup, the nature of the shadow avatars and the issues of directing believable interactions between virtual avatars and physical performers on stage. Two modalities of shadow avatars direction are exposed. Some results of the research are illustrated in two use cases: the development of theatrical creativity in mixed reality through pedagogical workshops; and an artistic achievement in *The Shadow* performance, after H. C. Andersen.

1. Introduction

The essence of performing art is an stimulating issue when exploring the potentialities of virtual reality on a theatrical stage : virtual actors compete with living performers. Working with shadows is very helpful because they payed an outstanding tribute to digital art and they used to guide humans in supernatural worlds.

This paper details an applied variation of AvatarStaging theatrical framework (Gagneré & Plessiet, 2018) in the wake of traditional shadow theater and dreams on virtual theater. Bringing together the immemorial shadow power to make us live incredible stories and the emergent fascinating expressive potentialities of virtual reality, we propose a mixed reality theatrical setup aimed at fostering the dialog between physical and digital entities. We call it CAstelet in Virtual reality for shadOw AVatar (CAVOAV) as an English translation for the French acronym "CAstelet Virtuel d'Ombre AVatar".

Section 2 is a short survey on digital shadows in computing science research projects with cultural and social impacts and gives examples of virtual theater research projects. Section 3 describes the specificities of CAVOAV derived from the AvatarStaging framework concerning the set design and the nature of the shadOw AVatars ("Ombre AVatar" in French, OAV) populating it. It explains how the virtual OAVs are lively animated. Section 4 offers an illustration with two applied use cases: the first is realized in a pedagogical context, and the second is a professional performance that toured in France and abroad. Section 5 concludes and gives some perspectives.

2. Related works

Shadows, that materialize the presence of an object or a body in a stream of light by the absence of light impact on the surrounding space, have always fascinated human beings. In the Allegory of the Cave, in his work *Republic*, Plato used them to illustrate how imperfect is our perception of the real world. In his *Natural History*, Pliny explained how the clay modeler Butades discovered the art of painting by seeing his daughter drawing the outlines of her lover's head shadow cast by a lantern. More widely, shadows inspired a great variety of myths and tales amid all the peoples and gave birth to numerous pieces of art and literature.

In the child cognitive development, understanding shadows marks from 5-6 years old the appropriation of distant action concept. In the history of sciences itself, shadows have played a key role in many discoveries, including that of the peripheral place of the Earth in the solar system, which overturned worldviews in the Renaissance (Casati & Cavanagh, 2019).

It is therefore not surprising that shadows are to be found at the core of the first interactive art experiences in a mixed environment linking a physical participant and a computer generated virtual reality, which were led by (Krueger & al., 1985) within the VIDEOPLACE system in the mid 1970's. With this artistic installation, Krueger built the first virtual theater with digital silhouette shadows allowing the onlooker to interact with an intelligent artificial environment. After these first experiences, capturing the silhouette shadow with video cameras in visible or infrared light remained a widespread way of integrating a participant in an interactive digital installation (Jacquemin, Gagneré & Lahoz, 2011) (Obushi & Koshino, 2018).

(Pasquier, Han, Kim, & Jung, 2008) proposed the concept of Shadow Agent to make human-machine interactions more natural, especially in a dialogue with artificial agents. (Jacquemin, Ajaj & Planes, 2011) listed the various instantiations of digital shadows for a virtual dancer circulating between real and virtual spaces. (Batras, Jégo, Guez & Tramus, 2016) also used shadows to let a participant play with a virtual actor capable of improvising. Thus, using shadows seems to be a promising way for allowing a physical performer to act in a virtual environment.

Besides, the progress of low-cost motion capture devices from the 2010s, such as the Microsoft Kinect camera or inertial motion capture suits (for example Noitom's Perception Neuron since 2015), have fostered the exploration of virtual reality as a possible space for a virtual theater. (Wu, Boulanger, Kazakevich & Taylor, 2010) introduced a real-time performance system for virtual theater. (Jdid, Richir & Lioret, 2013) detailed the characteristics of virtual reality which would offer the spectator a renewed immersive experience. (Pietroszek, Eckhardt & Tahai, 2018) demonstrated an actor management tool in a computational live theater. CAVOAV system aims to bring together these two tracks of research by proposing a new instantiation of digital shadows within a virtual theater in a mixed reality theatrical environment.

3. CAVOAV Setup Architecture

The setup is derived from the AvatarStaging mixed reality framework (Gagneré & Plessiet, 2018).

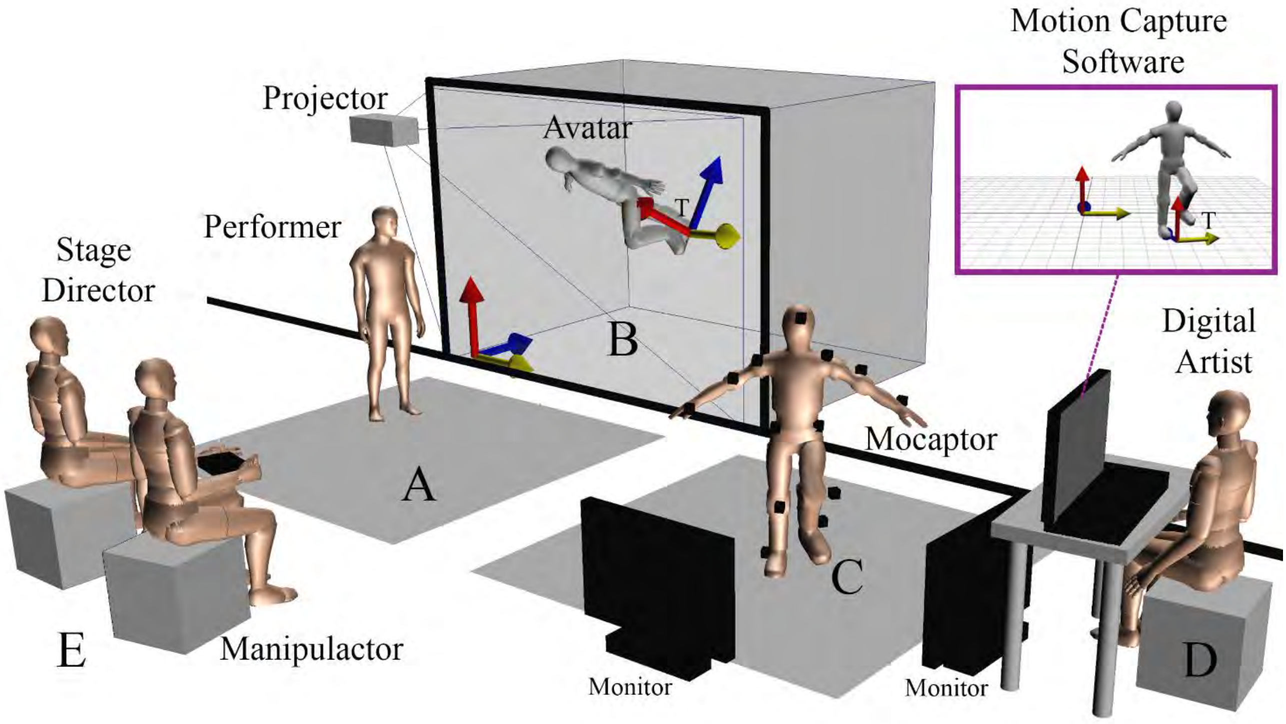

Figure 1: AvatarStaging mixed reality framework.

To control the avatar, the mocaptor wears a motion capture suit and the manipulactor uses a gamepad.

In AvatarStaging global framework, a performer wearing a motion capture suit (that we called mocaptor) acts in space C and controls an avatar in virtual space B interacting with a physical performer in space A, in front of B. A and B form the mixed reality stage in front of the audience E. His partner using hand devices as gamepad or midi controller (that we called manipulactor) helps the mocaptor control his avatar in the mixed reality stage.

CAVOAV setup specifies the nature of both the set design and the avatars in this way:

1) Virtual space B represents a traditional theatrical stage behind a frame,

2) Avatars are flat human silhouette shadows with 2 types of behavior.

It uses two different approaches for directing the avatars in the virtual set.

3.1. Set Design Specificity

In the expressions “shadow theater” or “puppet theater”, the word theater has two meanings. The first is the style of living art using shadow or puppet which is different in nature from the performing art with physical actors. It requires either immaterial silhouettes or manipulated objects. The second meaning is the specific architecture necessary to present shadows or puppets to the audience. The traditional structure is often small and raised, that allows puppeteers to easily move behind the frame and manipulate several puppets. Moreover, the structure is equipped with light and set design to produce shadow effects or set changes. In French, this small theatrical structure, that could remind of a large model, is named “castelet”.

The idea of the virtual “castelet” is to simulate both the living art style of playing with shadows and puppets, and the physical structure with its light and set requirements. CAVOAV is the French acronym for the “CAstelet Virtuel d’OmbrAVatar” concept, that we adapt in English as CAstelet in Virtual reality for shadOw AVatar.

Figure 2 : Shadow Theater and Shadow Avatars

Left: the video projected virtual space, with the size of a traditional puppet theater, is beside the performer; right: the virtual space is slightly bigger that human size and in continuity with the physical stage.

Fig. 2 shows two versions of the setup. Left image shows the performer sit left side behind a small table with a desk lamp on. The virtual stage is projected on a kind of elevated slide screen, approximatively the same size as a traditional shadow theater. The performer reads a text to the audience and interacts with a shadow avatar looking at him from the screen. Right image shows the same situation differently arranged: the screen is much bigger and seems to give access to a real stage with strange actors. The set inside the virtual stage is composed of a backstage translucent screen letting appear “traditional” shadows that seem to come from characters on the other side and lit from behind. It exemplifies one of the numerous combinations allowed by the setup virtual nature to play both with shadows and/or puppets characters.

3.2. Nature and shadowing behavior of the shadOw AVatar (OAV)

In fig.2 right, an OAV stands front stage looking back at the translucent screen. It is a flat human silhouette moving in 3D, inspired from the *Peter Schlemihl's Miraculous Story* by Chamisso (1814) in which the Devil peels from the floor Peter Schelmihl's shadow cast by the sunlight, and keeps it in exchange of a magic bottomless gold sack that makes fortune to his owner. An OAV is therefore a sort of flat shadow able to move in 3D. In the physical world, it could be figured out by a piece of paper cut with a human shape, but it surely won't be easily manipulated. In a video game engine, it is easily built by rigging any human flat shape and controlling it through a motion capture device.

Of course, an OAV projects its own shadow (see fig. 4). However, this « natural » shadow of the frontstage OAV is invisible because its light rendering feature is set to "non casting shadow", which is a common property in 3D software. Anyway, an example of this shadow is visible on the backstage translucent screen. It seems that OAVs move backstage behind the translucent screen and are lit with a rear projector, that produces the traditional result that one sees in shadow theater. For rendering reasons, instead of being produced by a rear light, the shadows are made up with an "invisible" OAV in front of it, using the 3D graphic object feature not to be rendered, but keeping on its feature "casting a shadow". They are therefore invisible but cast a shadow.

Numerous other graphic combinations can be explored in the setup with this OAV avatar. One of the main motivations for CAVOAV is to play with the idea of circulation between different states of "reality". From the state of a shadow on the wall, the OAV accesses a 3D existence as if one peels its shadow. This transformation is visible on the two OAVs at each extremity of the translucent screen in fig. 2b. By giving the possibility to precisely simulate a realistic shadow effect meanwhile developing it in a magical direction by common 3D visual effects, the virtual theater offers a powerful tool to foster the suspension of disbelief necessary to bring out dramatic situations.

3.3. OAV direction

For building a virtual theater, after the set and the characters, the stage direction is one of the key issues. Following Plessiet classification (Plessiet, Gagneré & Sohier, 2019), it would be great to cast virtual actors that can play autonomously on stage, or at least virtual golems that could follow by themselves the director instructions. These actors are however out of our scope for the moment, and we propose to direct OAVs in the 3D space as virtual puppets according to two approaches.

3.3.1. Living and animated virtual puppets

Figure 3. Unreal Engine 4 animation Finite State Machine of a specific type of OAV

Firstly, OAV can be controlled in real time by a mocaptor, acting in front of the screen, or aside the stage, hidden or not. The OAV figures out a living shadow that acts on the 3D stage in respect of a scenario in relationships with the actions of its partner on the physical stage. The setup is currently using Noitom's Neuron Motion Capture suit and Axis Neuron software to process the data. The motion retargeting from the Axis Neuron data to the OAV virtual character is done with Autodesk Motion Builder and the Noitom's MotionRobot plugin. The retargeted data are sent to Unreal Engine 4 video game engine (UE4) through the LiveLink plugin, released in 2018 by Epic Game to facilitate on-set previsualization with third-party softwares. Secondly, OAV actions are recorded and combined to block a scenario. However, theater imposes to respect a "real time acting process" condition to keep its essential nature of living performing art. Looking at performers constrained by the imposed rhythm of a time fixed movie is unacceptable for the audience. A solution has been found by programming a specific virtual puppet based on a finite state machine (FSM) mixing two buses, each one combining the same mix of two animation channels (fig. 3). Action channel uses any action starting from one idle pose to another one. Idle channel uses non looping idle animation.

3.3.2. Idle animation built on the shelf

Considering that CAVOAV setup is dedicated to theatrical performances, projects involve often a lot of characters acting during a long time according to animation standards, closer to an hour than few minutes. UE4 offers a tool, called Sequence Recorder, that allows to record animation track of any object during a motion capture session. This tool allowed Epic Game to win the *Real-Time Live!* contest in Siggraph 2016 conference with a demonstration showing a director shooting a short movie featuring two characters, with the same performer, in real time (Antoniades, 2016).

The UE4 Sequence Recorder is used to record "step by step" actions with their starting and final idle poses. The motion capture sessions are done with a mocaptor controlling the OAV living puppet (see 3.1.1.) in the virtual set and following instructions of the stage director, as in traditional theater rehearsals. In a post-production phase, each animation is cut in three parts directly inside UE4: starting idle, action, ending idle (than is also the starting idle of the next action) poses. The starting and ending parts feed the idle channel of the animation FSM.

The idle channel is composed of a sub-system that mixes the animation with itself in a reverse mode in order to avoid the looping jump effect, given that an idle animation never ends with the same pose as it starts. This sub-system allows to quickly blend any animation to an idle one in order to suspend the OAV action, without having to build a proper animation with a third-party software as Motion Builder. It considerably shortens the time to build a complex scenario with numerous OAVs on stage.

Finally, the OAV actions are triggered step by step by an operator following living actions done by the performers on the physical stage. Therefore, the CAVOAV setup offers the minimal conditions to have physical actors and digital characters acting together in a mixed reality environment.

4. Two use cases

CAVOAV has been used in two different contexts in 2019. The first one involves pedagogical masterclasses and workshops intended to introduce theater students to act and improvise with avatars on a mixed reality stage. The second one results in the production of a performance, *The Shadow*, that toured in Ukraine and France in fall 2019 (Gagneré, 2019).

4.1. Pedagogical use

For example, fig. 4 left image shows a student-mocaptor who controls the OAV in the center of a virtual set representing a room with libraries and fireplace. The shadow of the living OAV is very visible and the student-mocaptor is asked to take it into account in the expressivity of the virtual OAV movements. Another animated OAV is present backstage and will act specific actions with which the living OAV will have to interact.

They are two acting challenges for the mocaptor in this kind of pedagogical situation: inhabiting the virtual body of the OAV and moving properly in the virtual set, making the movement esthetically interesting according to the reinforced quality of presence given by the status of the virtual body shadow. Moreover, students are invited to play in their improvisation with all the 3D visual effects on hand (see 3.2).

Figure 4. Masterclasses (left) and *The Shadow* performance (right) use cases.

Even if an immersive use of CAVOAV has not yet been practiced, the combination of avatar embodiment and play with the avatar own shadow results in an acting constraint that elicits the students to a better understanding of the expressive possibilities of the mixed reality stage virtual part. That deepens the interaction qualities between physical and digital partners. Virtual reality brings a new and unique possibility of making alive 2D shadows and enlarges the range of theatrical situations.

4.2. *The Shadow* performance

The shadow is a performance after the homonymous Andersen's tale (1847). It tells the story of a Scientist who lost its shadow during a journey abroad and met it again many years later. The Shadow became a sort of human, but unfortunately deprived of its own shadow. He came back to make a deal with the Scientist in order to get married to a Princess.

Fig. 2 and fig. 4 right images show two different moments of a public performance. Fig. 2 is an excerpt of the beginning with the transformation of five "traditional" shadows in five OAV characters. Fig. 4 happens later and shows a theatrical situation involving the Princess, frontstage in white with shadow, and near the cylinder backstage the Shadow in black without shadow and the Scientist in grey with shadow. The performer is sitting left aside at a small table. He tells the story and triggers cues with a midi controller, step by step, according to the text and his way of acting. All the OAV actions have been recorded previously by the director with a mocaptor controlling an OAV living puppet in the different sets. Fig. 4 right image shows a moment of interaction between the performer and the OAV white Princess.

Performances have been given to young children from 8 to 12 years old and some impressions have been informally collected. Globally, audiences were immersed in the story. Some children weren't even conscious of the real time process and perceived the animation as a feature film. Others believed that hidden actors were playing offstage, directly reacting to the actor's words. The majority were very intrigued by the OAV shape and believed it was of paper or aluminum, not aware of motion capture possibilities. CAVOAV gave promising results as an artistic tool to captivate audiences.

5. Conclusion and perspectives

In this paper, we introduced a research mixing the theatrical direction of shadow avatars and the building of a virtual theater setup inspired by traditional shadow theater in a mixed reality environment. We described the virtual 3D setup, the nature of the shadow avatars (OAVs) and the issues of directing believable interactions between virtual avatars and physical performers on stage. Two modalities of OAV direction have been exposed. The shadow avatar virtual theater (CAVOAV) has been used in two contexts: the development of theatrical creativity in mixed reality through pedagogical workshops; and an artistic achievement in *The Shadow* performance, after H. C. Andersen.

We intend to develop the research in mixed reality environment by rehearsing more complex interactions between physical performers and OAVs, notably by exploring OAVs virtual golem behavior. We would like also to test CAVOAV setup in an immersive virtual reality context, both for performers and audience.

6. Acknowledgments

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Mona VR - recreating an experience

An artistic and expressive queueing simulator

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Keywords: Virtual reality – digital art – cultural heritage – authenticity – virtual museum

Abstract

Since October 2019, the extraordinary fame of *Mona Lisa* has pushed the Musée du Louvre to try and implement additional safety measures. Now, visitors have to queue through barriers to see the painting. The museum also presents an official virtual reality experience which allows the visitor to meet face to face with Lisa Gherardini herself, thus removing the crowd and the difficulty of access to the painting. Although the initiative is laudable and the experience remarkable, we can wonder: what if the current conditions of visit of *Mona Lisa*, however unpleasant they are, were actually part of the authentic *Mona Lisa* experience in the 21th century? In this article, we present a virtual reality experience which deliberately chooses to replicate the exact conditions of visiting *Mona Lisa* today, as a humourous, playful and imaginative way of reflecting about core concepts of cultural heritage : originality and authenticity.

1. Introduction

Visiting Leonardo da Vinci's most famous painting today is a peculiar experience. Since October 2019, visitors are asked to queue through barriers of the same kind we find in most popular attraction parks, such as Disneyland. The idea of using the power of virtual reality to be alone with the painting, to meet its character face to face, has already been explored, notably by the Musée du Louvre itself, as we will see further in this article.

Yet we can wonder : by removing the crowd, don't these experiences remove what could be considered part of the authentic *Mona Lisa* experience in the 21th century? In this article, we will start by describing our virtual reality experience and queueing simulator *Mona VR*, before presenting how we tried to provide an answer to that question.

It is very important to specify, though, that this experience and article are *not* a criticism of the Musée du Louvre, whose *Mona Lisa* situation is as complicated for professionals as it is for the visitors, and who does try to provide solutions, most notably through virtual reality. Our work merely aims at being a playful, humorous and imaginative way of reflecting upon the notion of authenticity and originality, which, as Bruno Latour and Adam Lowe write [3], are a true obsession of the 21th century.

2. *Mona Lisa* : digital experiences and authenticity

2.1. Mona Lisa and VR

Da Vinci's most famous painting has already been the subject of VR experiences. In 2015, Luis Tejeda recreated the entire *Salle des Etats* under Unreal Engine. The goal was to "get [the user] a private access to view the most famous painting in history."[6] In 2019, Emissive studio created a VR experience entitled *Mona Lisa: Beyond the Glass* for the Musée du Louvre. Officially presented by the museum from October 24, 2019 to February 24,2020 in the Napoléon Hall, "this experience is an integral component of the museum's landmark Leonardo da Vinci exhibition, which commemorates the 500th anniversary of da Vinci's death in France."[5] The experience is also available on Viveport and other VR platforms. In *Mona Lisa : Beyond the Glass*, the visitor is invited inside the painting, where they can meet Lisa Gherardini in person, best known under the name of "Gioconda". It is a beautiful and poetic experience, which creates a remarkable balance between artistic reinterpretation and scientific information about the painting.

Both these experiences have the same goal, to enable a direct encounter with *Mona Lisa*, without what is today considered as a major problem: a massive crowd in a ill-adapted space. Jason Farago, in the New York Times, writes that "30 000 people pass through the gallery where Leonardo's painting hangs, each day, according to the director of the museum [1]. As the popularity of the painting never ceases to grow, the situation becomes logistically very difficult to handle, for the visitors themselves as well as the museum's staff. Since October 2019, when the *Salle des Etats* was reopened after renovation, visitors must line up in a "snake of retractable barriers that ends about 12 feet from [the painting]."[1] From there, you have less than a minute to try and get a proper look at the painting, and take a selfie, before being ushered out by museum staff. As Jason Farago says, the situation becomes dangerous, and very disappointing for the visitors themselves, which are in for a very unpleasant moment, as well as the museum staff. That is why the journalist pleads for a specific, massive building to be built especially for her, a building that would be well adapted to handle such crowds. Indeed, according to Jason Farago, "the Louvre does not have an overcrowding problem per se. It has a *Mona Lisa* problem"[1].

2.2. The question of authenticity of an experience

We can, however, muse over one question: why couldn't we consider the current experience of visiting *Mona Lisa* an actual, authentic experience? What guarantees the authenticity of the experience of seeing *Mona Lisa*? Is it to watch it alone in intimacy, or to be surrounded by a crowd of people attracted by its celebrity? We can refer here to Bruno Latour and Adam Lowe's notion of "trajectory" of a work of art, or its "career" [3]. Indeed, the two authors write that what characterizes a work of art is its history of reception. That reception is permanently renewed along the centuries and people who "receive" the work of art. We can find the same idea in Yves Jeanneret's work, when he writes that cultural heritage is a "cultural being". According to him, "objects and representations do not remain shut upon themselves, they circulate and pass through the hands and minds of people" [4]. In this regard, "nothing is transmitted from a man to the other, from a group to the other, without being elaborated, without being transfigured and without giving birth to something new."[4] As a result, we can say that the way *Mona Lisa* is "experienced" in 2020 is as authentic as the way it was experienced in the 16th century, when it was hung in François 1er's bathroom. Indeed, it says something of the painting, of the role it has in the eyes and minds of millions of people throughout the world, and ultimately of 21th century society.

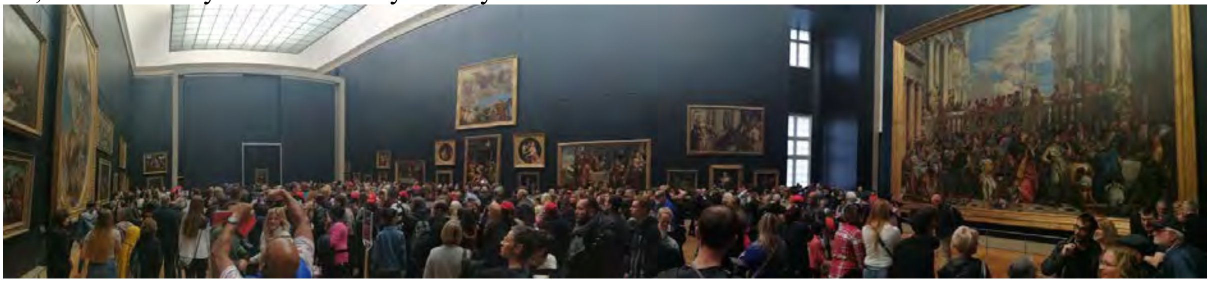


Fig. 1 – *Salle des Etats*

Picture taken in the perspective of creating the experience. *Salle des Etats*, Musée du Louvre, October 30th 2019, in the morning. This panoramic view clearly shows the dynamic of the visitors in the room, massing towards *Mona Lisa*, whereas Veronese's painting attracts only a few of them.

That is why, unlike the previous VR experiences that were created around *Mona Lisa*, we chose to play around and embrace this particular configuration in the painting's career. To do so, we went to the museum to see it, and to grasp all the elements that we thought were crucial to restore the true atmosphere and experience of "living" *Mona Lisa* today. The permanent noise and massive crowd through which we are invited to queue, of course, but also the fact that nobody looks at the other paintings. We chose to stress this particular fact by the blurring of the paintings, and replacing them by images that had nothing to do with the original artworks. In doing so, we wanted to convey the idea that these paintings are not seen or noticed at all, whatever they might be representing. Their identity is crushed by *Mona Lisa*'s presence. We made an exception exception for the *Nozze di Cana*. Because it is massive, it is almost impossible to miss, and yet we can distinctly see that it only retains the attention of very few people (figure 1). In this regard, we designed a specific visual effect that unveils only whatever part of the painting the user is consciously looking at. Another crucial aspect we wanted to capture was, of course, the practice of making photographs and selfies, which is considered by some researchers as the "photographic practice most representative of contemporary visual expression" [2]. In the selfie feature, we replaced the user's head and hand by emojis to remind of the ubiquity of social media in the 21th century, and the essential practice of sharing one's experience with a larger community. We also added camera sounds throughout the room in order to encourage the user to take pictures of their own, but also to convey that feeling of a collective experience. Which is absolutely what visiting *Mona Lisa* means today: being immersed in a collectivity of people receiving the painting at the same time as we do.

3. Recreating an experience digitally

3.1. Recreating the setting

Before adding any interactivity to the simulator, it was important to make sure the setting itself was properly recreated. The *Salle des Etats*, the room where the *Mona Lisa*, or *Gioconda*, is exhibited, was recreated to a 1:1 scale, including its October 2019 Prussian blue coat of paint. As such, it is currently one of the only VR experiences representing the *Salle des Etats* in its present state (figure 2). The *Grande Galerie* and the *Salle Denon*, visible from the room, have also been included (figure3).

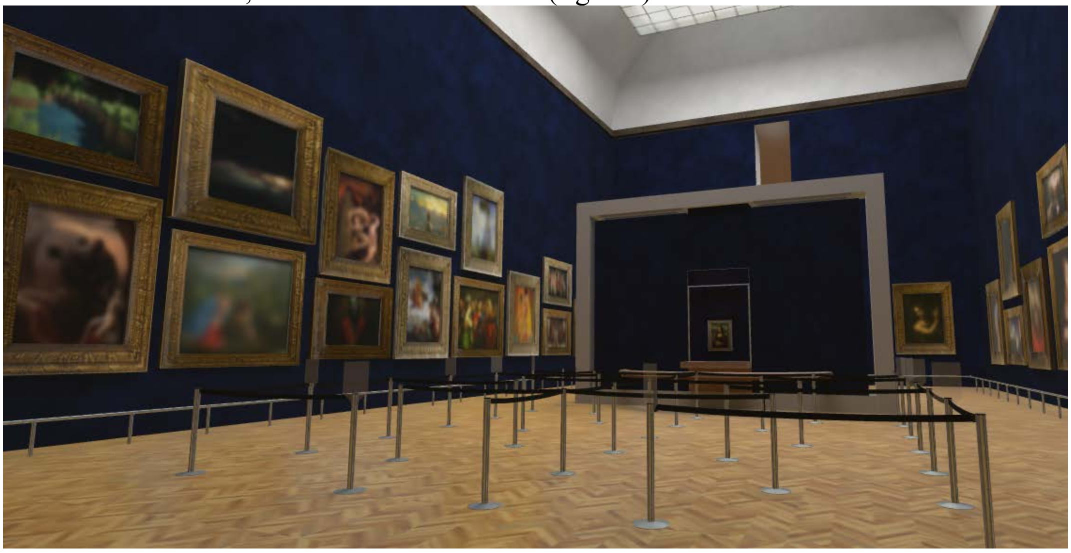


Fig. 2 - Virtual recreation of the *Salle des Etats*.

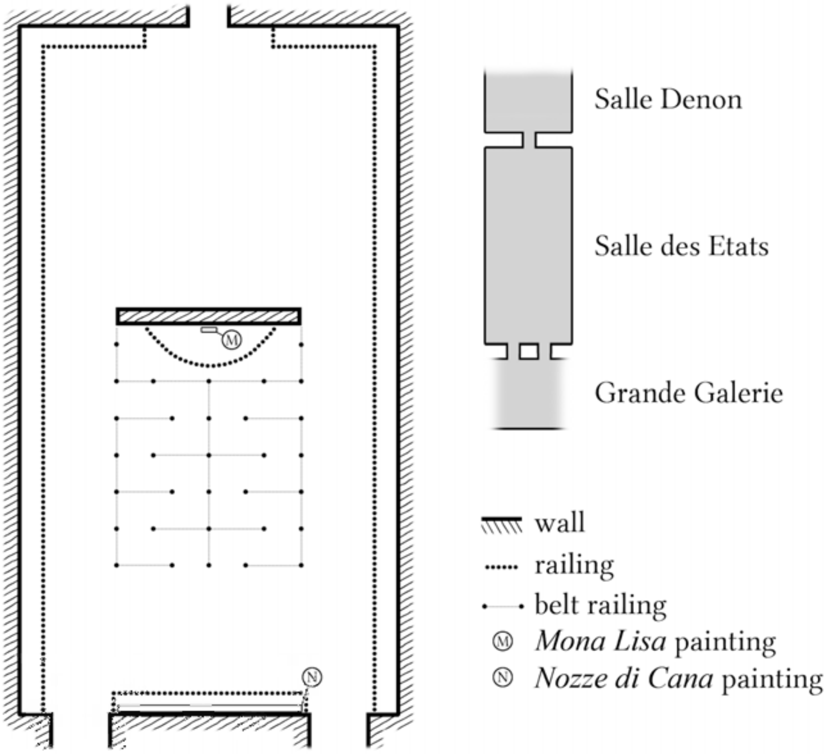
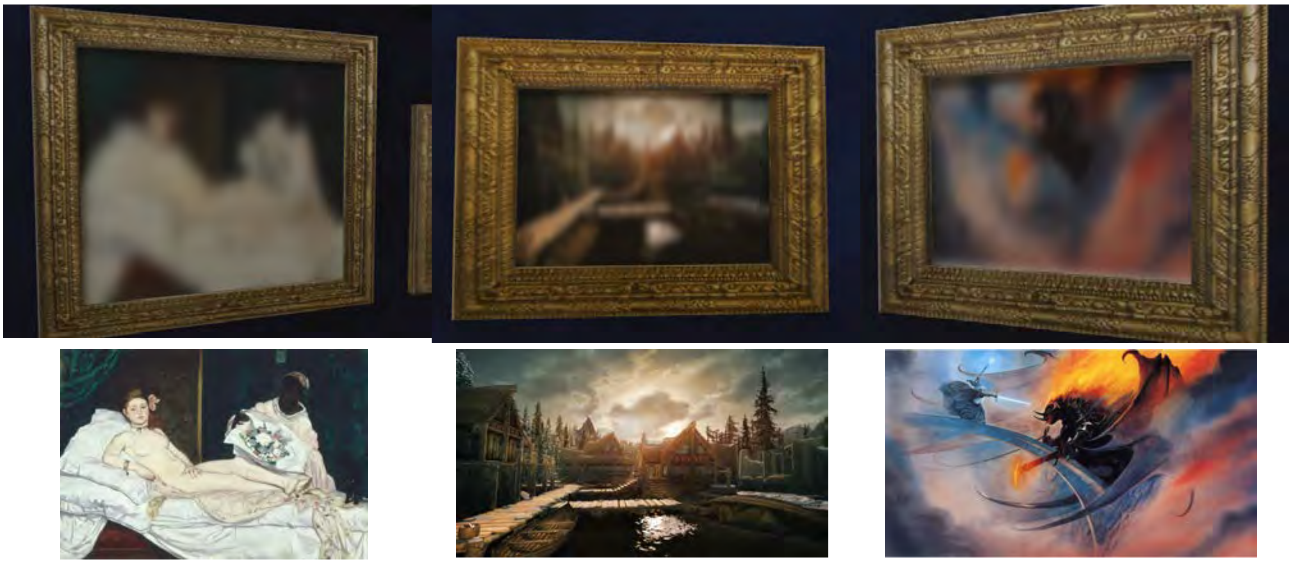


Fig. 3 – Floor plan of the *Salle des Etats*.

As we have explained earlier, all of the other paintings have been blurred. This allowed us to take liberties with the represented paintings, as some are historical, while others are taken from various sources : namely movie stills, video game screenshots, or contemporary artworks (figure 4).



Painting based on
Olympia
by Edouard Manet (1863)

Painting based on a view in
The Elder Scrolls V : Skyrim
by Bethesda (2011)

Painting based on a
Lord of the Rings
illustration by John Howe (2000)

Fig. 4 - Selection of blurred paintings in the virtual recreation of the *Salle des Etats*, along with the original image for each of them.

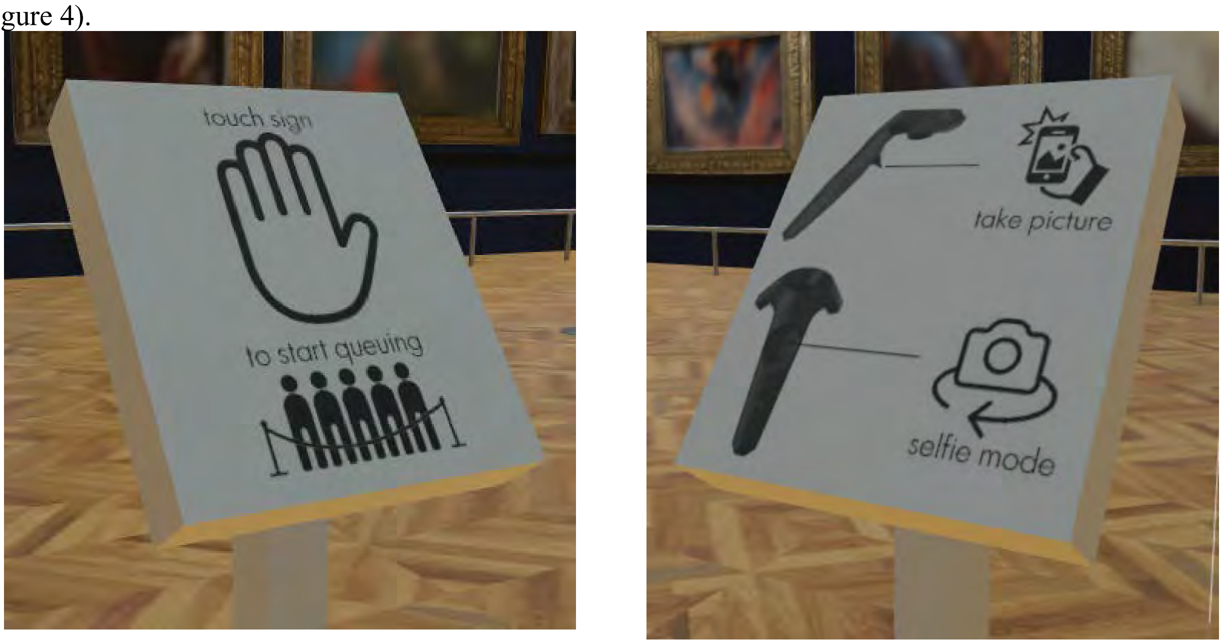
Besides the *Mona Lisa*, one other painting in the room is authentic, though : the *Nozze di Cana*, by Veronese. It was our decision that the painting be blurred too, but appear normally in an area around the user's gaze (figure 5). A specific shader was developed to achieve this effect, and a simple physics raycast was used in order to establish the central point of the headset's view.

Fig. 5 - *Nozze di Cana*, with its specific not-quite-blurred effect.

As one would most likely enter the *Salle des Etats* from the *Grande Galerie*, we chose to set the starting point of the experience at the back of the room, next to the *Nozze di Cana*, so that the main body of the crowd was between the user and the *Mona Lisa*.

3.2. Recreating the experience

As it has been stated, it was crucial to us that the experience including a crowd, queueing, and taking pictures and selfies with a smartphone. There are two signs in the starting area that indicate these functions to the user (figure 4).



Queueing function sign

Smartphone functions sign

Fig. 6 - Application's features explained as signs.

The VR controllers are used for this. In their right hand, the user is holding a virtual smartphone, with the camera activated. The left hand is displayed as a regular hand. The camera can be used to take pictures, but can also be flipped into selfie mode. When taking selfies, the user's head is displayed as a "Joy" emoji, and left hand as a "victory hand" emoji (figure 7). The pictures are then saved onto the hard drive, next to the application's files, for potential future uses.

Virtual Smartphone in use

Virtual picture

Virtual selfie

Fig. 7 - Virtual smartphone and pictures.

The crowd itself is generated on-the-go each time the application is launched. Random characters are selected and scattered around the room, with a predetermined density per area. Audio recordings of the actual *Salle des Etats* are played at several locations in the virtual room, for an accurate recreation of the auditory atmosphere. In addition, camera sounds are played at random intervals throughout the room, adding to the general feel of the room, but also enticing the user to use his or her own camera.

The final addition to this project was the queue. In the real *Salle des Etats*, there is a queueing system that allows people to get up close to the *Mona Lisa* in order to take a few pictures. Because this VR experience wasn't set in a physical room with a size comparable to the *Salle des Etats* (and likely never will), we had to figure out an alternative to walking around in order to emulate the queuing experience.

We chose to opt for an automatic-queueing teleporting system. It can be activated by hovering the user's left hand above the appropriate sign. So as not to start queueing by accident, a loading wheel has to be maintained when doing so. It launches the user in a series of teleportations (each with a fade to black and audio fading) that moves them progressively through the queue. With the user having nothing to do, not even move around, the time spent queueing feels longer than it really is (figure 8). The user is then teleported back to the starting area, where he or she can choose to start queueing again.

Starting up the queueing system

Queueing experience

Fig. 8 - Using the queueing system in *Mona VR*.

While the real queueing experience lasts about 10 to 15 minutes, and leaves the audience about 40 seconds of "picture-time", our version of the experience reduces both of these times to about 2 minutes of waiting, and 10 seconds of picture-taking. With the user having nothing to do, not even move around, the time spent queuing feels longer than it really is.

4. Conclusion

As said in the introduction of this article, we wanted to make *Mona VR* a humorous way of musing over the question of authenticity and originality of a work of art and its reception through time. In the light of concepts provided by researchers such as Bruno Latour, Adam Lowe or Yves Jeanneret, we proposed a reflection upon what makes authentic the experience of visiting *Mona Lisa* today. In this regard, we can consider *Mona VR* as a testimony of a specific situation in the history of the painting. It could also provide a solution for people who cannot have access to the Musée du Louvre, or maybe even people who just don't want to have to deal with a real crowd. In a way, *Mona VR* is also representative of the power of virtual reality to provide access to cultural heritage when the latter is not easily, or no longer, accessible.

The idea of reproducing a specific moment of the painting's history also creates an interesting situation in regard to time, between past and present. Indeed, we can say that Luis Tejeda's capture of the former state of the *Salle des Etats* in 2015 is now a patrimonial experience, in that sense that it is a restitution of a past moment in *Mona Lisa*'s career. In the same idea, we can think that someday, if *Mona Lisa* comes to be moved to another building as Jason Farago hopes, our experience will, too, be a restitution of a past moment in the painting's career, when it was set in a Prussian blue setting, and when people needed to queue through barriers to see it.

Furthermore, in regard to what has already been achieved technically, there is always room for improvement. The crowd was generated using easily accessible free assets, and therefore lacks in variety. In addition to using more character models, *Mona VR* would also benefit from having more variety of animations, and even simple crowd behaviours. It would also be interesting to use the pictures that are taken with the virtual smartphone for something. Creating a twitter bot, designed to automatically share the pictures taken within the experience (along with various predetermined hashtags and a generated message), would be a relevant improvement. It would allow a complete *mise en abyme* of the real experience, joining the real process and the virtual one in this common final representation of both experiences : a twitter post.

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Real Body and Virtual Body Hybridations

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Keywords: Real Body – Virtual Body – Embodiment – Virtual Reality – Vicariance – Virtuality – Reality.

Abstract

In this paper, we analyse VR basic dual entities, real body/ virtual body to understand how a duality can transform into a fusion. We study VR theory of immersion/ feeling of presence, vicariance theory of embodiment. Finally, we build a conception of a hybrid virtual embodiment, crossing Merleau-Ponty's approach of virtual bodies and Lacan psychoanalytical conception of specular image.

1. Introduction

In computer graphics and VR sciences, a virtual body is a syntagma referring to a computer-generated three-dimensional appearance of a human body. Opposite is the "real body", the body belonging to a living person. We want to argue that this dualistic approach opposing computer beings and physical beings hinder a hybrid reality. A personal virtual body is interacting with the interactive virtual body. A virtual body can really exist as such only when it is inhabited by a projection of a real body. However, what is a real body? Persons have self-bodies, inheriting the distinction between being an organism obeying biological, physiological laws as well as sociological, cultural, psychological ones and embodying their individual more or less conscious states of being and acting. A real body is not just a thing in the world but lies in an intentional world, is itself a manifestation of a subjectivity. Therefore, a real body is a connector of subjectivity inside the physical world which interiorizes virtual bodies as a parts or prolongations of their being. Thus, an opposition of virtual and real bodies does not allow to understand their interaction on another plane than a mechanical one. This is a limit to the importance of a psychological understanding of VR in a non-objective, first-person point of view. Reality and virtuality will thereafter be interwoven to appreciate what happens in the subjectivity of the person living herself in an avatar or subjective camera movements. We want to develop a first-person point of view, opening a non-objective psychological approach to VR beings, as virtual reality can only be a reality if it is a representation shared by a perceiving individual inside of a social group.

2. A Real body is like a thing in the world.

2.1. VR understanding of what is reality in virtual reality

A body is said "real" in opposition to a "virtual" body in virtual reality terminology. This duality is understood from the point of view of a VR conceiver for which the "real body" corresponds to a real person interacting with a virtual body, an avatar inside a digital world or a subjective camera reacting to the real body inputs according to the virtual world laws. Therefore, the reality of the body is an approach of reality taken from a point of view outside the virtual world user.

Reality is itself a central point in VR, AR or MR. The will to transform reality appearances by virtual projections, make illusions by intertwining virtual and physical objects, make a completely synthetic reality, shows that a kind of reality is taken as a primal reality and a second reality, a synthetic one, is added, included or excluded in order to bring forth another kind of reality.

As shown by Nannipieri, the first kind of reality is the inclusive perspective of VR, in which VR, as an artificial reality [1] is hierarchically depending of natural reality. In this sense, VR brings a poorer reality, eventually a false one. This is shown by next possibility, in which VR can produce an exclusive kind of reality, standing outside any relation to the real world, as a simulacre. It really has no reality outside of its world. From a natural reality point of view, it is a manipulative pseudo-reality. A last kind of understanding of reality is that VR is a compossible reality. Nannipieri observes: *«virtual reality, as natural reality, are two types of possible environments which have been actualized. »* [2] VR is made just like natural reality thanks to technological progress. It is produced and constitutes other possible environments, alternatives to physical ones, as real as them.

The latter sense is chosen as the proper one for VR. VR reality enters inside humans' sensory-motor cognitive procedures. *"The purpose of virtual reality is to make possible a sensorimotor and cognitive activity for a person (or persons) in a digitally created artificial world.*" [3] Reality of VR is taken in a non-epistemic sense. Reality does not stand as an invariant world outside humans' reach, against which knowledge is evaluated. Reality of VR means having a sense, a feeling of reality which is characterized by a sense of presence.

2.2. Real body and subjective presence/ A real body is a cognitive sensori-motor thing

Reality meaning of virtual reality is related to sense of presence, and presence is intrinsically correlated to body perceptions in VR conception. VR needs to make a person enter in a symbiotic relation with the machine through their physiological, sensori-motor and behavioral mechanisms. Understanding how real bodies interact with virtual bodies is part of VR central aim. As Steuer has stated in an independent of technologies definition, "*a virtual reality is defined as a real or simulated environment in which a perceiver experiences telepresence*"4. The experience of presence is more like a sensation related to a state of body and mind, the sense of "being there", despite the means used for achieving it. Hence, Slater precises that sense of presence in VR happens when "*the self has a (suspension of dis-) belief that he or she is in an environment other than that which his/her real body is located"*[5]. It is when the self agrees on not taking into account the difference between one's body environment and a mediated environment, that sense of presence is achieved in an artificial world.

A real body is a position of one's self, located outside virtual reality, which has to be put inside of it. In other words, a real body needs to be virtualized to interact with a virtual body. Amato analyses this virtualizing process as constructing corporality, *"thanks to a phenomenon of neuro-physiological instantiation that actualizes the potential of certain pre-established or* ad hoc *built perceptual and agent-based models, which couple respectively to the perceiving instance and the active instance.*"[6] Real bodies enter virtual worlds through embodiments of machine controls and instantiations in perceptual and active senses. Conversely, the machine instantiates what is necessary for this embodiment. Along Kilteni/Groten/Slater characterization[7], it provides means of embodiment like sense of location through visuospatial perspectives as well as other sensori inputs, sense of agency with extra-diegetic controls and proper processing of interactions effects, sense of body ownership through coherent bottom-up and up-bottom influences.

In this analytical conception, real bodies are embodied intentional subjects. They are able of agency in virtual worlds using virtual bodies, possibly identifying with it. In this sense, A real body is the outer point of a subjectivity and a shell that VR encounters to make changes in this subjectivity by interacting with its inner schemas and images. However, we do not understand, yet, what happens in this intentionality, how it can accept a suspension of disbelief. We would like to speculate what happens in the body/self-relation on an exclusive subjective side when a real body is immersed in a virtual body, and see why virtual bodies can be embodied in a mental way.

3. Virtual body embodiment

A first step into understanding how a virtual body can be embodied stands with a theory of a mirror of the body inside neurological activity as a body-double, a vicarious body.

3.1.Real body, embodiment and vicarious body

Berthoz has understood body/mind relation as a representation in a vicarious brain of a vicarious body. A doublegänger exists inside humans' brains which is a body-double, synthesizing represented body spaces in an inner schema of one's own body. The "vicarious body" is able of vicarious, alternative representations which can invent new ways of realizing actions. Vicariance is virtuality property of substitution, as being the "vicar" of the priest. It narrows the ambiguity of the concept of virtual to a specific kind of ambiguity, the substitute one. Along Berthoz's definition of vicariance applied to neurological structures, *"vicariance provides new solutions by substituting one solution for another to solve a given problem, or by using the solution to one problem to solve another problem*"[8]. In other words, vicariance is being able to be ambiguous in the etymological sense of "what pushes to two sides" [9]. It is a projection of a linguistic denomination into the world of action which necessitates having several identities, functions, in order to keep an identical goal in a changing reality.

Therefore, a vicarious body is an adaptable model of a body which anticipates and generates creative responses to ever-changing situations demands. This double of a body is like a virtual body inside the brain. It processes data coming from diverse sensori-motor, environmental, social sources, and joins them to instantiate an action. This happens in an unmediated world, but in fact the absence of mediation is a lure. Everyone has had to learn the different controls giving them power to act in the "real world". One can therefore identify a natural world with a virtual one and make analogies between the models inside of a brain and the ones in a computer.

3.2. Vicarious embodiment of virtual bodies

This analogy is used by Berthoz, who explicits VR simulations as mainly being a simulation of human ways of acting/ feeling. This is why, for him, VR present a mediated world with much more power of feeling presence than other media. *"The capacity of the human brain to imagine itself, together with its feeling body, in a virtual world, is a major discovery that goes far beyond the well-known feeling of entering a fictional world when reading a novel."* [10]. He explains this difference as lying in the mixture of reality and virtuality in some digital worlds. RV brings physical inputs with cognitive ones which build such a realistic perception that it is difficult for the player to avoid symbiosis with the instantiation of the game avatar or subjective camera and the virtual environment. The mind of the user is inside of VR world in a mental and embodied way.

In doing so, the body schema and image in the brain represent an extension of the real body inside the virtual world. Body-double has been introjected by a virtual world as if it were a real augmentation of its being. This fact is shown by famous experiences like the one of the rubber hand illusion (RHI) [11]. A part of one's body or another body takes its place in a VR simulation with concordant sensori-motor inputs, hence a sense of ownership integrates the virtual part in the real body perception.

Vicariant brain and embodiment, studied from a neuropsychological perspective, show connections between behaviors and activated brain areas when in interaction with a virtual body-double. It demonstrates that a real body can embody a virtual body because it already possesses a kind of virtual body inside of it, a vicarious body inside of its vicarious brain.

4. Virtual self-body and interactive virtual body: hybrids

However, we want to continue this deepening of real bodies/virtual bodies relation in another perspective than the idea of vicariance, which belongs more to a medical cognitivist perspective than a phenomenological one. A medical perspective thinks in terms of physiological reactions, even though it inserts symbolic terms. Integrating imaginary realities into real body/virtual embodiment necessitates a more phenomenological point of view.

4.1. Merleau-Ponty's conception of virtual body as imaginary lived self-body

We want to start this study of the embodiment of the real body from the body-self, the living body, or *body-proper* of Merleau-Ponty. His thought is integrated in cognitive sciences but still one has to look through a side which is not an objectifying one. Vicarious body (Berthoz) and virtual body (Merleau-Ponty) meet on the point that they both are what makes a human able to transform in an adapted way in a changing environment. But we want to introduce a lack of rationality, a gap between what is a neural network and what happens in oneself in a non-utilitarian way.

If we understand that a body-double in the brain synthesizes all inputs and integrates a virtual body as an extension or a substitution so as to give it a sense of ownership, one already sees how a real body is far from being real as a thing put in the world. Its sense of reality has a plasticity. It depends of a general orchestration of sensori-motor, cognitive information and vicariance. Reality feeling is processed without making a difference between what originally belongs or not to the self. This process is made by the brain, which stands as a very complex computing system.

However how can this conception understand imagination richness? Why should its indefinite variety be reduced to an adaptative goal? Merleau-Ponty observes what happens during a theatre performance. In *Phenomenology of Perception*, he gives a description of mental movements and body-proper perceptions produced while watching a theatre performance. A spectator projects him/herself in the body of comedians and the fictional environment performed on stage. *"This virtual body moves the real body to the point that the subject no longer feels in the world where he really is, and that instead of his true legs and arms, he feels the legs and arms that one would have for walking and acting in the reflected room, he lives in the performance."* [12]

Merleau-Ponty shows that our body perceptions can include imaginary ones as if they were real. Body-proper will exist as what he calls "virtual body". This sense of virtual body is a part of perception of one's personal body and has nothing to do with VR. The philosopher calls this felt imaginary body a "virtual body" to make a difference with a body having perceptions from the real world. In this case, perceived self-body is augmented by a projection into the theatre world, which is a kind of mixed reality world, half material, half imaginary. An imaginative body is mentally really embodied. Why not call it then imaginative body?

Imagination is understood as opposite to reality. It is a fantasy world. Body-self gets imaginary perceptions which at some stage tend to encompass real ones as in this theatre. The spectator forgets tangible actual reality perceptions and fills his body-proper with fictive elements. This perception is not imaginary even though it comes from an imaginative source. The concept of "virtual" body in Merleau-Ponty's reflection means that the synthesis of self-body is made with a purely mental source, not a mixed one as in perception of sensorial reality. A virtual body is different of a vicarious body, since it defines itself as coming from an imaginative input, not any input, and it has no natural adaptive goal.

4.2. Imagined self and virtual embodiment

Imagination irrationality or "arrationality" is an important stance to understand what happens in the self during an interaction with a virtual body. Having a virtual body as a body-proper, as oneself, is being unrealistically and freely projecting self-body into images and worlds which are unfit. Merleau-Ponty reduces virtual bodies as existing only when a body-self projects itself in a fictional being. However, one can conceive a mental virtual body in every perception, real ones as much as imaginary ones. One way of seeing the importance of a virtual body in humans' mental existence is shown by the importance of imagination in embodiment interactions. Peter Nagy analysed how interactive virtual bodies drive self-body identity in a study in a half imaginary/half realistic persistent world experience made in Second Life. It showed an influence of avatar identity on personal identity. *"[...] The user alters perception of one's own self which may also involve the purchase decision processes"* [13] Its buying actions indicated that avatar virtual body, especially when not realistic, made one live in an imaginary world up to the point that the self would transform one's actions in order to express a new virtual self.

A virtual self opens a body-proper perception towards dreamed and desired images and actions of the self. This happens in MMOLRPGs in which body-proper are fantasized into virtual bodies and imaginary worlds. Distinguishing purely mentalizing media with highly immersive VR because sensori-motor inputs are so powerful does not see the incidence of imagination itself to capture one's full attention to the point that a virtual body comes to existence in one's body-self. In a body-proper virtual being, imagination gives way to ownership of other sensations without restricting it to a specific media. Imagined identities identified by self-customized avatars bring about a clear occurrence of presence of virtual embodiments in one's minds.

The fact that an embodiment does not have to be physical is obvious since multiple ways of existing characterize persons. The law conceives moral as well as physical persons. Politics shape symbolic identities. For example, according to the crown lawyers of Edward VI of England. The person of the King has a double body, a human physical body, the organism of the man who is King and a symbolic body which makes him king: a legal, immaterial body consisting of "Policy and Government"[14].

From the very early age of computer and Internet use, Sherry Turkle has shown how users project a multiple identity on computer entities. In Life on the screen, she concludes: *"what is the self when it divides its labours among its constituent "alters"? Those burdened by post-traumatic dissociative disorders suffer these questions; here I have suggested that inhabitants of virtual communities play with them."*[15]. Imaginary selves produced by users in video games project identity complexity. The self is not basically unitary. It is a complex tinkering of mobile centres of personification. Interactive virtual selves are lived through virtual body incarnations as an image giving a social identity, an environmental one and a personal one. Virtual body-selves are virtual selves' embodiments which combine themselves to constitute an actual body-self.

4.3. Virtual Image, self-body existence and hybrid embodiment

The importance of mental virtual images in identifying one's real body is clear in psychoanalysis. Psychoanalytical theory demonstrates that virtuality is literally a part of self-body construction. Along Freud's famous "mirror stage" conception, Lacan has specifically searched how the body, which is a partly internal, partly external entity, is invested by the self. One's real body only becomes one's self-body through specular image. This image in a mirror is namely a virtual image. It identifies the reflected organic body as being the subject's body, differing from the other people's bodies and from the image that others give of the one's self-body.

Identification of the personal body through the looking glass is the first step of acquisition of an identity, of becoming a subject differentiated from objects and others. Identifying through virtual image is included in building a complex sense of identity process, as it brings a perspective from the object world inside the subject one. Hence, real body refers to a sense which is out of reach, which is hardly embodiable, since the real stands outside self-body/symbolic body duality. *"SR (symbol Reality) [...] is not (as we believe) to adapt to a more or less well-defined, or well-organized reality, but to have one's own reality, in other words, one's own desire, recognized"*. [16]

Between desired-self, which is an imagined and symbolized self-body, and a real body which is an objective outer stand impossible to reach as well as an inner force of the self which is not definable, stand specular images. A specular image is a virtual image coming from inner images made through mirror stage. Specular images are images coming from the gap between different bodies, making possible for imagined and symbolic self-body images to become consciously perceived.

Virtuality is therefore part of self-body productions as an identified embodied virtual self-body. Interactive virtual bodies can be extensions of all personal bodies, projections of a sense of phantasmagoric reality answering virtual self-body identity construction. Looking for the real body, virtual self-bodies project their imagined selves onto virtual beings, whether they be Faust, Madame Bovary, the "Funambule Virtuelle" [17], or a symbiotic customized avatar, an adequate virtual world first-person life. Thus, an interactive virtual body will make specular images and symbolic significations of the self tend towards a phantasmatic embodiment. For Sherry Turkle, including psychoanalysis into an understanding of life in the screens, "our need for a practical philosophy of self. Knowledge has never been greater as we struggle to make meaning from our lives on the screen".[18]

Symbiosis with interactive images permeates subjectivity to a point which makes a hybrid creation of self-body with an interactive virtual body. In other words, what is called self-body which is also a specular image will invest the virtual interactive image in such a way that this image will become a real image of the self, inside virtually-real worlds of action. One's self-virtual-body is a virtual image in the virtual world of the computer as it is in the mirror, augmented by a power to give itself imagined self-bodies, imaginary selves. And, virtual mirrors reflect virtual bodies in a numerically more intersubjective way than a real mirror since it brings into communication a virtual multitude, a potential collective. "Being is being perceived" [19] as Berkeley conceptualized it (*esse es percipii*), hence, being in the mirror of a persistent virtual world gives more reality, since it has more quantifiable credibility than physical mirrors.

5. Conclusion

We have arrived to a conception for which real bodies are not just holders of sensori-motor and cognitive receptors and actors integrated in VR devices artificial simulation. Real bodies have dissolved in multiple processes which include mental virtuality (specularity) besides brain vicarious networks. Consequently, real body reality entering in interaction in a VR world is a very ambiguous one, a hybrid made of virtuality and vicariance, of imagination, symbolism, and search for reality. Virtual bodies in VR are an intersubjective body mixing technological virtuality and specular virtuality.

Duality between real body and virtual body has transformed its polarity. It is not an in/out duality, but an "in/in" one. A real body is a self-body, not a manipulable thing in the world, through coherent stimuli. It has an inner polarity between virtual and actual self. Conversely, an interactive virtual body is real in terms of modelled existence in a computer virtual world, and virtual in the sense that it is made to become part of a mental reality in a psychoanalytical sense. Understanding how one's body becomes one's self-body makes it possible to understand how there can be a symbiotic relation with an outer virtual body. It is because self-body is partly virtual (specular) that it includes interactive virtual bodies in oneself as imaginary expressions and parts of oneself.

As Couchot wrote, *"[...] the virtual is what exists in potency in the computer - a potency capable of actualizing itself in sensitive forms (images, sounds, texts or perceptual stimuli) during the human-machine dialogue* [20]". Virtual images only come to perceivable existence through their actualization by a computer user's request. So are virtual bodies, requirements for a request to actualize into a virtual self, from a subjective perspective as well as a computer one. Engagement of humans into VR machines needs to integrate psychoanalytical understanding to reach a complete model of this particular phenomenon.

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Möbiusschleife: Beyond the Bounds of a VR System

Enhancing the Presence and Interaction of VR Player to the Real World for Collaborative VR

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Keywords: Reality-Virtuality Continuum – Mixed Reality – Bidirectional Interaction

- **Abstract**

Our previous research "Möbiusschleife" focused on mutual interaction between VR and the real [1]. We demonstrated it in VRCAI' 19 and found some problems in our proposing methods, therefore we improve them by the following ways: displaying light field image, synchronizing VR player's posture, controlling physical devices with VR controller, and proposing a new way to use "Virtual Window" method. For expressing our concept, we develop a VR collaborative game. The same goals for a VR player and audiences clearly describe the contents and research concepts. Our new application with our new methods enhances the interaction and the presence of the VR avatar in the real world.

- **1 Introduction**

Virtual reality (VR) has become popular to be utilized in a variety of fields, from games or entertainments to medical care or surgery because of development of VR technology, especially head-mounted display (HMD) like Oculus Rift or HTC Vive. HMDs provide immersive VR experiences by covering the VR player's head and showing another image to alter the scenery.

Nevertheless, audiences cannot experience or share it because they are separated from the VR environment. There are also restrictions such as preparing equipment, minimum age, and difficulty to play with multiple players.

Recently, researches and applications focusing on the interaction between the VR and real have been increasing. Our previous research "Möbiusschleife", one of the above-mentioned researches, tried to provide bidirectional interaction between the VR and the real world [1].

Figure 1: Demonstration in VRCAI'19

We demonstrated our previous research at VRCAI'19 (Figure 1). Though a few interactions such like looking at each other were well-received, some people who experienced it pointed out that research concept was hardly comprehensive because the purposes or tasks were not obvious in our demonstration, and the purpose of the VR player jumping out of the boundary and into reality was not fully realized due to technical limitations.

In this study, according to opinions or suggestions given in the previous study, we improve our methods that allow a VR player to interact directly with the real world. In order to realize the bidirectional interaction between a VR player and audiences, we introduce a light field display for a VR avatar, synchronizing its posture to the VR player's one, and controlling physical devices in the real world. Besides, we also propose a new way to use the existing method "Virtual Window".

After that, we develop a new application of a collaborative VR game which makes a VR player and audiences understood our research purposes and contents clearly because it imposes common goals. Our new application also utilizes our new methods, therefore the interaction for mutual interactions, especially from the VR to the real world, is enhanced and the presence of the VR avatar in the real world becomes much stronger.

2 Related Works

First of all, we explain some researches which literally capture physical objects or surroundings and reproduce them in VR. All proposed methods consisted of complecated systems, which required expensive devices, a large space, and prolonged time to prepare and set up. For example, a research "Catching a real ball in virtual reality" realized a subject in VR could avoid or catch a physical ball in a real space by showing the predicted trajectory of the ball tracked with infrared cameras and markers [2]. "Share VR" achieved a collaborative VR system and contents between a user wearing an HMD (HMD user) and bystanders not wearing it (Non-HMD users) [3]. Non-HMD users could join if they held its VR controller to which a display is attached. Honoka et al. attempted to extend doll play with electronics and programming in their project "Can I GetToyIn?" [4]. Unlike the above 2 researches, they prepared CG models of a physical doll house and dolls, embedded a microcontroller and sensors in the house, and connected the devices to a computer for the purpose of realizing interactive doll play. But this system offered only preserved actions.

Some other projects tried to mix VR and the real world by superimposing CG models on an actual view. A VR application "SIGHT OF THE LIVING DEAD" made us felt as if we were in "zombie movie" [5]. This application displayed a captured video streamed from a stereocam (ZED mini) attached to the center of a HMD, then tracked postures of people who came near to the VR player with a depth camera (Kinect) for overlaying a zombie polygon as its pose synchronizes to that of tracked people. It combined VR and the real into one story by casting the VR player as a treed person and outside audience as zombies. However, the VR player cannot move anywhere because of its situation and system. "Encounters" was an MR media art connecting between the real and a CG world with Microsoft HoloLens [6]. The proposed method in this project differed from ours, because it did not connect the real to a CG world but overlap CG objects and effects on the real world based on the measured geometry.

On the other hand, there are resarch projects extracting the elements of a VR player or experience. "TeleSight" provided a head-model robot, which followed its heading corresponding to the direction of the VR player's head and had sensors to enable audiences to interact with the contents [7]. That head-model robot only brought the sight of the VR player and a few interactions: talk and shading the sight. "Levitar" displayed a stereoscopic image of a VR avatar which moved corresponding to the heading of the HMD wearer [8]. Although its presence in the real world was much better, there was no interaction except just seeing with each other. Apart from the previous 2 researches, Hikaru et al. projected an image of the surroundings where the VR player stood in the real world. Though bystanders could watch what the VR player actually see and do without any external apparatus, the system required a large space, set up and adjust devices. In addition, it was unable audiences to interact to the VR application.

Simpler methods are also proposed in some other researches or applications. Sugiura et al. proposed a collaborative VR system "Dollhouse VR" for interior design [10]. This system provided a first-person view inside the room with an HMD and top-down view of the whole room with a touch display. It had a similar feature to our research that a VR player and audiences can see mutually, but bidirectionality was weak because its interactions designed asymmetric. TAITO corporation announced an arcade game "Tetoteconnect" will debut in 2020, which a player can play the rhythm game with a CG character through a game screen [11]. The concept of this game is similar to our research, but partner of the game is a non-player character (NPC) instead of a VR player, it responds to player's controls with defined actions. Same method is used in a concept cafe Luppet Cafe [12]. It serves talking with a virtual character teleoperated by a VR player staying in a distant place, but we can not experience any interaction except speaking or listen to the character.

• 3 System

In order to incarnate our concept of bidirectional interaction between VR and the real, we propose 2 methods: "Virtual Window" and "Teleport to the Real". Briefly, the former works as a "window" connecting the VR world to the real, and the latter brings a VR player closer to the real. We will explain the description of these methods in the following section 3.1 and 3.2.

Figure 2: All devices conposing our VR system

In our VR system, 2 VR-ready computers operate all devices and applications (Figure 2). We choose a light field display for implementing our second method, but running it toghther with VR gadgets in a single computer is quite difficult because using even one of them occupy almost all computer resources, expecially GPU (see 3.2).

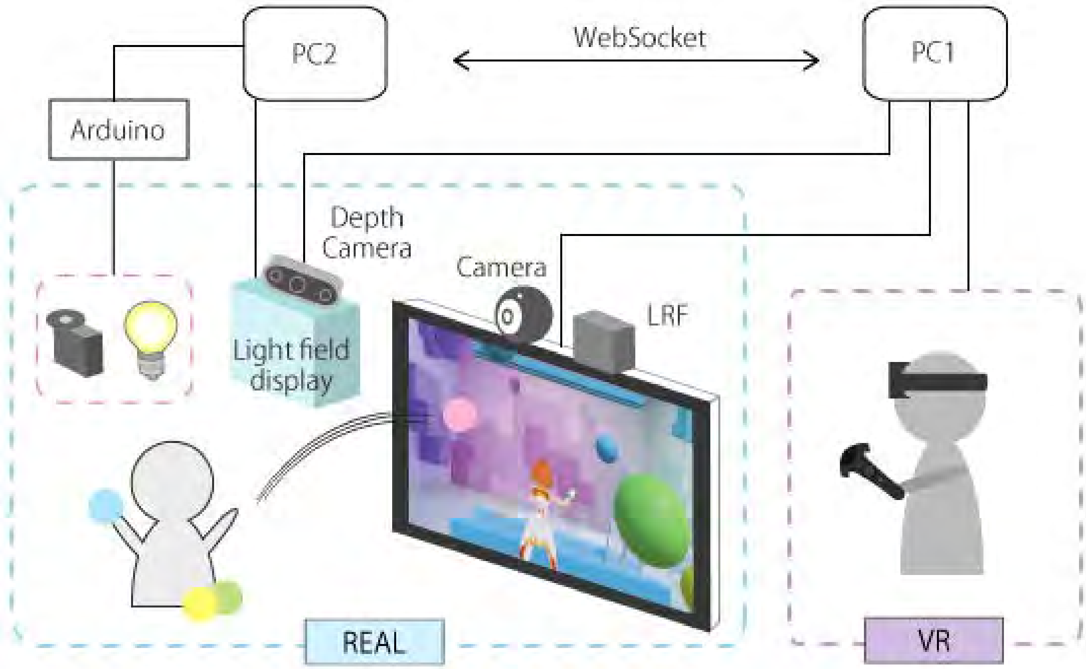

Figure 3: System schematic

Figure 3 describes the schematic of the whole system. Mainly one of our application controlling a standard HDMI display and VR devices utilizes "Virtual Window", on the other hand, the application outputting a light field image does "Teleport to the Real". Although, the application managing VR devices also takes some part of the method "Teleport to the Real", that is, showing a 3D model of the physical world where audiences place instead of a planar image on a screen.

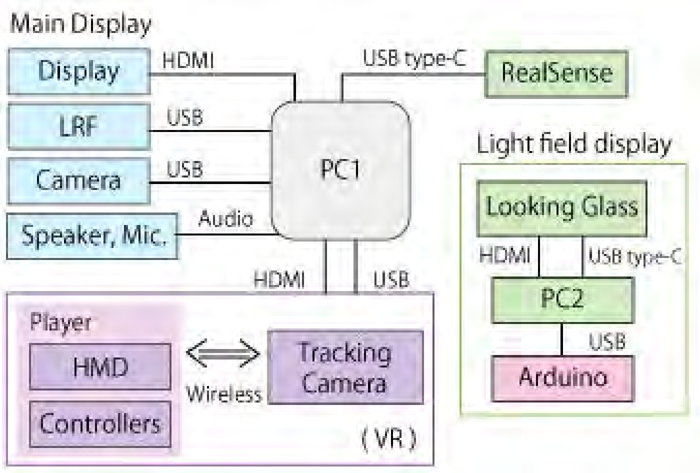

Figure 4: Hardware configuration

Figure 4 represents all hardware components connected to the computers. For developing our VR system, we prepare a VR-ready computer PC1 (embedded with Intel Core i5-8400, Nvidia GTX 1070, and 16GB RAM), VR headset and devices (HTC Vive), a display, a 2D LIDAR "Hokuyo URG-04LX-UG01", a webcam, and an Intel RealSense D435 camera. We also prepare a gaming laptop PC2 (Intel Core i7-8750H, Nvidia GTX 1070 Max-Q design, 16GB RAM), a light field display "Looking Glass", and a microcontroller board "Arduino" for our light field display system.

We use Unity3D and SteamVR for developing all software. To realize synchronization of the VR player's posture and input, we adopted WebSocket as a networking protocol.

- ### 3. 1 Virtual Window

Figure 5: Concept image of our proposal method "Virtual Window"

"Virtual Window" plays the role of "window" between the VR and the real, which enables the VR player and audiences to see and interact with each other (Figure 5). It provides a virtual display in VR and a physical one in the real world for subjects in the both area to see the opposite site each other.

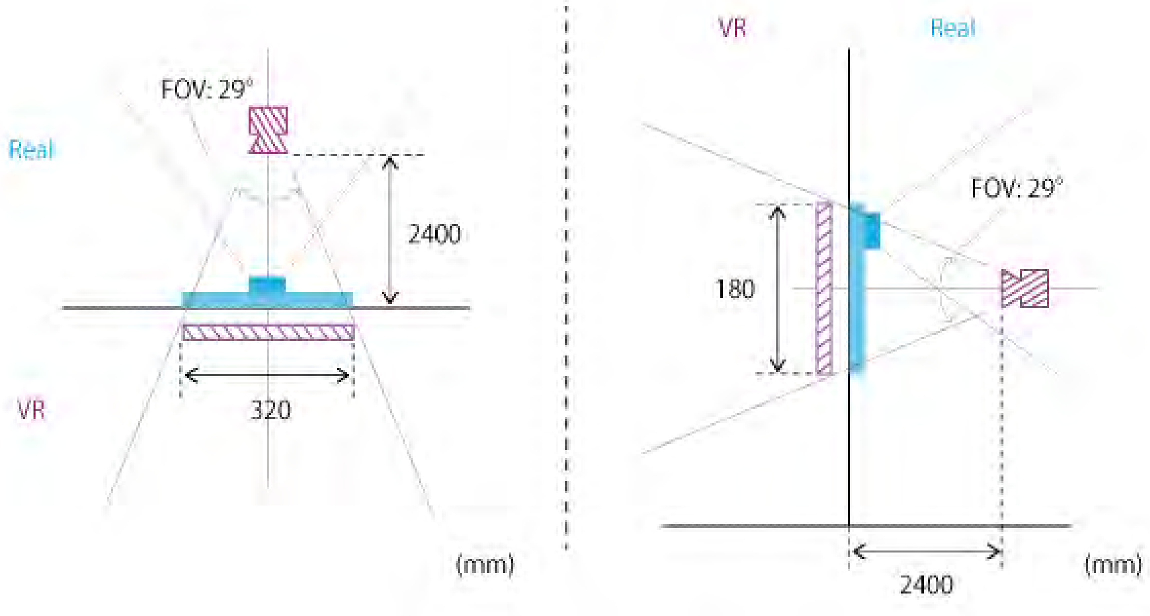

Figure 6: Setting the position of cameras and displays

Our VR system creates a texture image from a stream image from the webcam and pastes it to a plate object. Then our system transmits an image from a virtual camera behind of the plate to the display audiences watch. These processes provide the connection between the VR and the real world through the "window" (Figure 6).

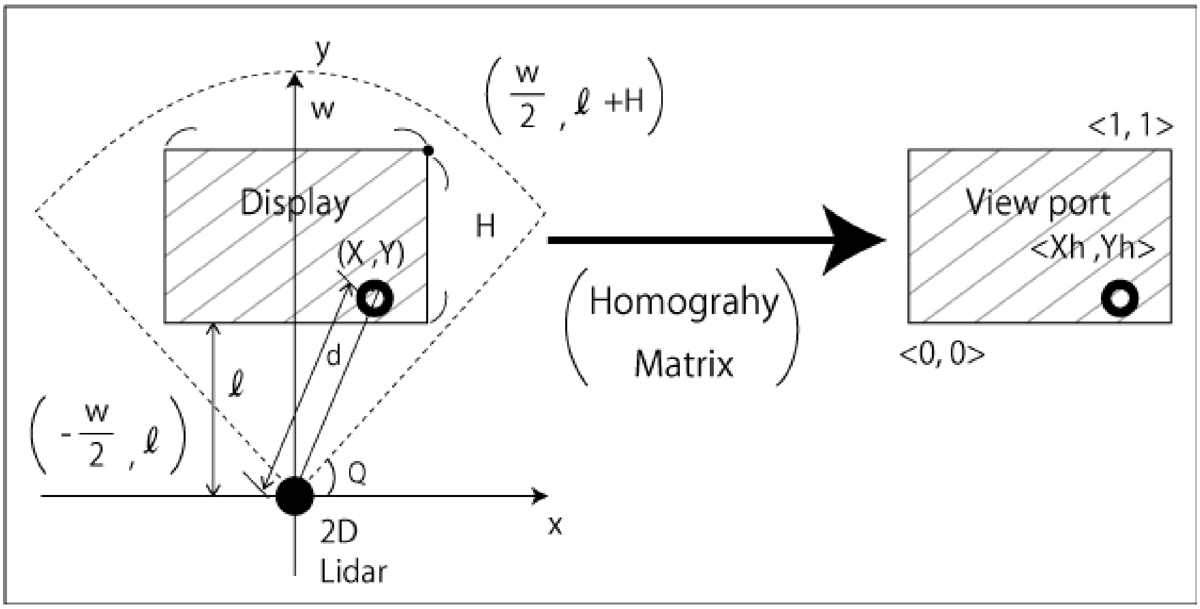

Figure 7: Converting scanned point to screen corrdinates

The display detects where audiences touch with using a 2D LIDAR. Conversion to a Cartesian coordinates system is required because the LIDAR outputs scanned points as a polar coordinates system dealing with the center of the device as its origin. Our conversion method does the following processes; (1) Setting the scanning range in consideration of the size of the display and the relative position of the 2D LIDAR from the display. (2) Calculating a homography matrix transforming the scanning range to the screen rectangle in our Unity3D application [10]. (3) Converting a detected polar coordinates measured by the 2D LIDAR to a Cartesian coordinates. (4) If the converted point is inside the scanned range set in (1), multiply the calculated homography matrix in (2) left to it, so that the system acquires touched points in the display (Figure 7).

Basic installation is the same as the previous research [1]. In this research, we propose the way for a VR player and audiences to touch mutually with each other in addition to throwing an object from the real to the VR. It is impossible to put one's hand into a CG world directly through the screen or vice versa, therefore we implemented an alternative solution that a VR player touches a touchable object with his or her VR controller appeared by an audience's holding his or her hands in front of the display.

- ### 3. 2 Teleport to the Real

Our previous research expressed as if a VR player leaping into the real world by showing a pseudo light field image of a VR avatar with a display and a half mirror [1]. However, due to its technical limitation the VR avatar of a VR player did not have an enough presence in the real world, hence some subjects who experienced our demonstration hardly understood the purposes of this method.

Accordingly, we try to make the presence of the VR player in the real world stronger by implementing light field display and controlling objects in the real world.

First, we adopted Looking Glass for showing light field image [11]. Looking Glass displays a light field image with a 45 degree of viewing angle, and it offers an SDK for Unity3D. Looking Glass occupies resources of a GPU for displaying a light field image, that means utilizing VR HMD and Looking Glass with a single computer is quite difficult. For solving this problem, we prepared another computer and software to connect and use Looking Glass.

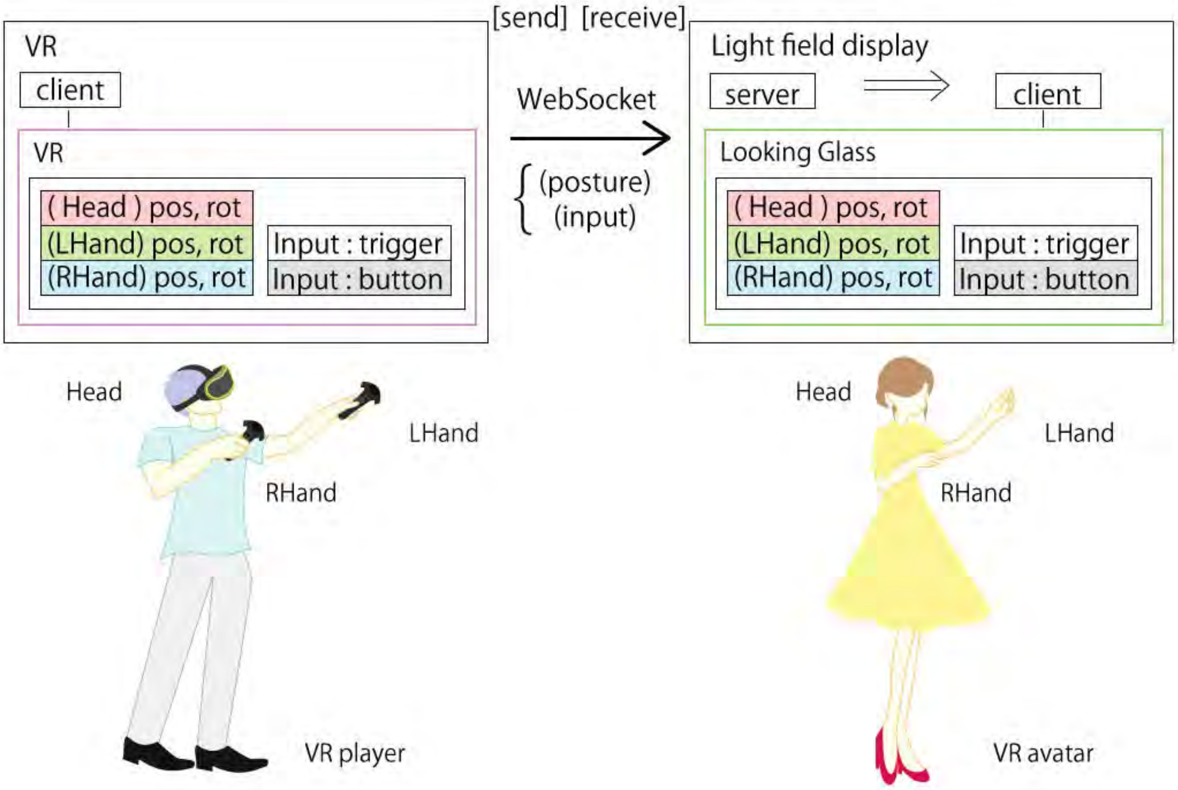

Figure 8: Network structure and processes via WebSocket

Software for displaying a light field image of a VR avatar synchronizes its posture to that of a

VR player. The VR player cannot manipulate his or her avatar shown on the light field display, because the VR system and components are not directly connected to the PC controlling the display. Therefore we realize synchronization between the posture of the VR player and the avatar in the light field display by placing the same CG models to the same place at the beginning and communicating the position and angle of the VR player's head and both hands via WebSocket protocol (Figure 8).

Communication processes via WebSocket are the followings; (1) Starting a WebSocket server which broadcasts and receives packets in the light field display application. (2) Starting a WebSocket client in the VR and light field display application. (3) The VR application contains the information of the position and angle of the player's head and both hands into an array with an identification text tag. (4) Converting the data arrays created in (3) as JSON format and transmit it. (5) When the light field display application received them, it perceives the posture of the VR player based on the identification tags. The posture of the VR avatar is calculated from Inverse Kinematic (IK) with a Unity3D asset "Final IK" [12].

The VR player can also control a few objects in the real world with a VR controller. The VR application can also send an input of a few VR controller buttons as JSON data. The light field display application controls an Arduino board connected to an USB port based on the received data.

Figure 9: VR player can see the 3D image of the real world after teleporting

In addition, the VR application renders a point cloud of the geometry of the audience area captured with Intel RealSense D435 in real-time (Figure 9) with expanding the scale of the point cloud model as the scale ratio calculated by deviding the vertical size of the display by the physical size of it and locating it as matching to the installing position of the device. We use an 8.9" Looking Glass, whose display size is W191 x H119 (mm), and set its application height as 2m, that leads the vertical scale of the VR world is reduced to 0.0595 (= 119 / 2000) from the real world. Similarly, the reduction rate of its horizontal scale is calculated approximately 0.0597 (= 191 / (2000 * 1.6)) according to the width and aspect ratio (16 : 10). Because the attached position of the camera device is the top of the light field display display, we also place the center of the point cloud at 1.91m higher than the ground.

• 4 Application

We developed a demonstration game composed of 3 stages for a VR player and audiences to collaborate and enjoy with each other in our proposing method and system. The purpose of this game is for a virtual character performed by a VR player (VR avatar) to escape from a small room displayed through the "Virtual Window". All participants play the following 3 stages.

1. Wall Break
2. Gate Open
3. Welcome to the Real World

The players play a simple shooting game stage 1 at the same time the game starts, then solve a simple trick in the stage 2, and finally a virtual character can "teleport" to another place where they feel to get closer. We used "Virtual Window" for the first and second stage and "Teleport to the Real" for the last stage.

• 4.1 Wall Break

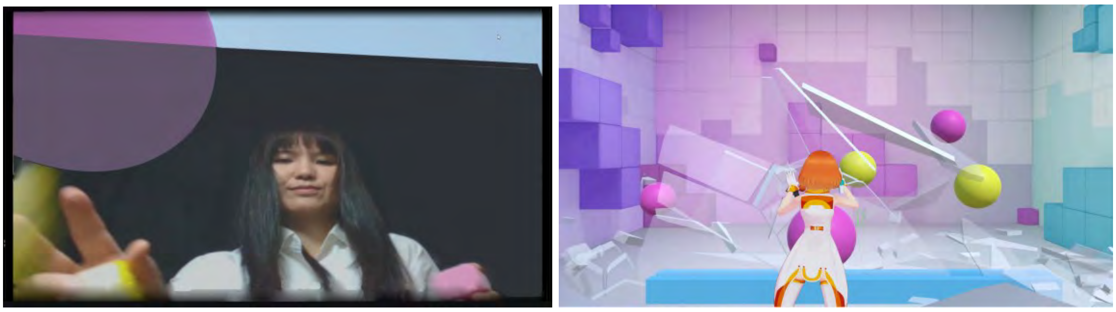

Figure 10: Playing wall break stage (Left: Display on the real side, Right: VR player's view)

We impose the common task "breaking approaching walls to prevent from being squeezed" in the first stage to make the VR player and audiences understood that this application is a kind of collaborative VR game (Figure 10). This stage has the following 3 levels, and the players finis this stage when breaking all targets.

1. Single wall is approaching.
2. Three walls aligned to a single line is approaching.
3. A big and thick wall is approaching.

The VR player can break them by picking up a gun placed near him or her and shooting a bullet, and the audiences can help it by throwing an object to the display and hitting a ball shot from their touching position on the "Virtual Window". For implementing breakable walls, we used an open source Unity3D asset "Voronoi Destuction Effect" [13].

• 4.2 Gate Open

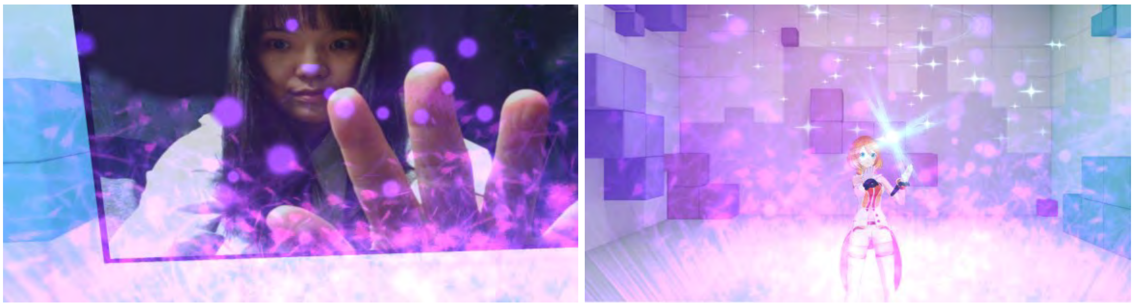

Figure 11: Holding hands to appear gate (Left: Display on the real side, Right: VR player's view)

The next stage orders the VR player and audiences "holding up their hand to the same place" to make them feel as they are a party to solve tasks (Figure 11). First, the audiences need to their hand in front of the display for summoning the warp gate. Next, the VR player touches it and then keeps their actions for 3 seconds to proceed to the next stage.

- ## 4.3 Welcome to the Real World

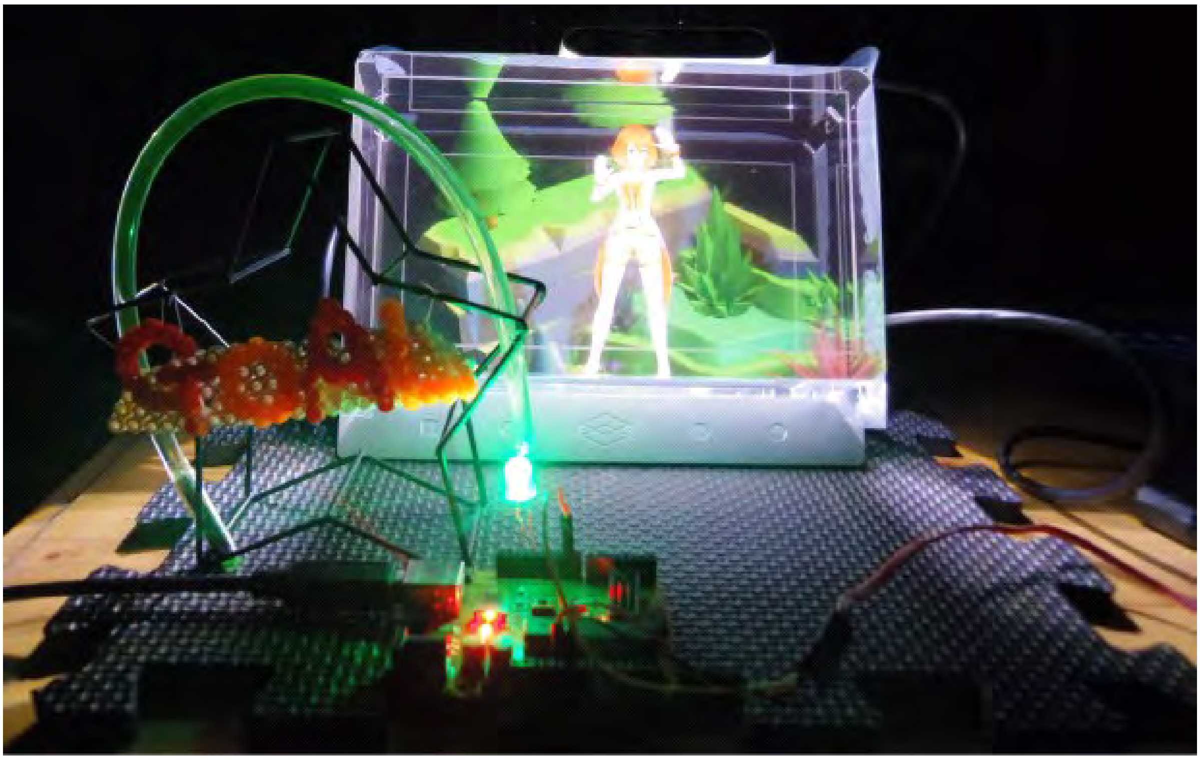

Figure 12: VR avatar appearing on the real world

The last stage is a kind of bonus. We express "teleport" by switching the display to render the VR avatar from the "Virtual Window" to a light field display and rendering the real world as a point cloud 3D model because of emphasis of the presence of the VR avatar in the real world. The VR player can also control a few objects installed in the demo booth, concretely he or she can control a LED and a Servomotor connected to the Arduino with his or her input (Figure 12).

- ## 5 Conclusion

We propose the next version of "Möbiusschleife", a novel mutual interaction system between the VR and the real. Compared to our last research, we ensure bidirectional interactions and VR avatar's presence in the real world by modifying our methods "Virtual Window" and "Teleport to the Real".

For improving mutuality of interactions, we provide another interaction of "Virtual Window" besides the existing one, that is, touching with each other between the VR and the real. Besides, after using "Teleport to the Real", a VR player can control a part of objects (devices) in the real world, which enriches the experience or the interaction for the VR side.

Furthermore, we also attempt to strengthen the presence of a VR avatar in the real world by developing the system to show the light field image of the VR world with Looking Glass and synchronize the VR player's posture via WebSocket. Rendering a point cloud 3D model of the real world where audiences stands fuses the VR and the real world visually.

After that, we develop a demonstration game containing 3 stages. Our previous research did not fully represent our concepts because there is no obvious task or goal. Instead, in this research we clarify our research concept: a VR player and audiences play the same contents together by preparing a collaborative VR game with our new VR methods. They cooperate to break targets (walls) on the first stage, to touch each other with their hands on the second stage, and finally the VR avatar jumps into the real world on the last stage.

Even we have proposed and developed a new VR interaction system and application, in our current system the VR system and light field display are not completely separated because an RGB-D camera to showing a point cloud 3D model of the real world is connected to the PC of the light field display system. We think flexibility of interaction designs in our bidirectional VR methods will increase much more if we can implement a wireless sending system for an RGB-D image with using a real-time communication API like WebRTC. There is also a limitation in our current application that it has no interaction from audiences to the VR world after showing a VR avatar on the light field display. Receiving audience's input with attaching switches to the microcontroller or using buttons embedded in the light field display can solive this problem.

Furthermore, we have not still verified the impact or efficiency of our proposing interactions. We believe the result of experiments to verify our methods in a practical situation would be helpful for developing and selling a VR application being merged and interactive to the real because such kind of applications are already launched and will be increasing [11][12]. Now we are planning to experiment it, and we will challenge to apply collaborative creativity.

• Acknowledgments

This research application uses a 3D model data "Miraikomachi" under the following usage guideline.
(https://www.bandainamcostudios.com/works/miraikomachi/dlcguideline.html#guideline)

We also appreciate offering VR instruments (HTC Vive) from InterRobot Inc. (http://www.i-robot.co.jp/).

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POSTERS

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Into the Womb – Born Again: A VR Experience of Being Warmly Swaddled Using “Otonamaki” from Japanese Method

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Keywords: Virtual Reality– Fetus – Haptics – Relaxation – Emotion

Figure 1: Fetal VR experience with a cloth.

Figure 2: VR video image of a fetus in the womb.

Figure 3: Okurumi, swaddled baby (Halfpoint, Julia Dorofeeva/Shutterstock.com).

Abstract

Some relaxation methods create a sensation of returning to the fetal stage, but often involve large pieces of equipment such as a floating tank. This study develops a portable virtual reality (VR) system that brings users back into the fetal state of relaxation. It explores the effects of being swaddled in a stretchable cloth that simulates the feeling of being in the mother’s womb. The user’s entire body is wrapped in cloth using a Japanese technique called Otonamaki. While being swaddled, participants experience an artistic video and sound representation of the womb. The heart rates and questionnaire answers of swaddled people and those from the control group were compared. Questionnaire results show that being swaddled can reduce subjective tension. Heart rate results show no signs of mental stress caused by swaddling. The future plan is to incorporate this VR setup into medical devices and therapy to relieve tension.

1. Introduction

There are several relaxation systems that provide their users with a feeling of being returned to the fetal stage. This study develops and relaxation a fetal experience virtual reality (VR) system named “Into the Womb.”
The system makes people feel as if they are in the mother’s womb by using a head-mounted display (HMD) and swaddling them, using a cloth to wrap their whole body. Applies the child-rearing method Okurumi to adults (Kimura, Fujii, Hasegawa & Miyata, 2019) (Figure 1,2), that is a method of calming down a baby by wrapping its whole body in cloth (Figure 3).

2. System

This VR experience system makes it possible for users to feel as if they had returned to the fetal stage. After putting on the HMD and holding the controller in both hands, users are wrapped in a cloth. Two camera viewpoints are shown in the 360-degree VR video. Users can view the state of the fetus from one angle and also take the position of the fetal viewpoint at another angle. In the latter case, they can move both hands of the fetus using the controllers. The experience time lasts approximately one minute. Figure 4 shows how to wrap a user in the cloth and shows how to get him/her out of the cloth. The Oculus Quest HMD “Guardian function” is turned off for the HMD to be used inside the cloth.

2.1 360-degree VR video contents

The experience starts after the user select language on the title screen. The user first watches the fetus from a third-person perspective (Figure 2). Subsequently, the fetus comes closer, as if it was linked to the user, and the screen fades out. Afterward, the user assumes the fetal viewpoint and sees the image of the inside of the womb. The images

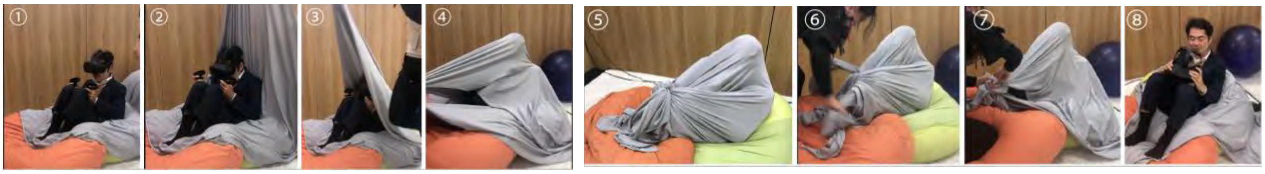

Figure 4: The procedure of wrapping and releasing the participant in cloth before the fetal VR experience.

include legs and hands, which the user can move using the controllers. The background environment shows red water with some bubbles, which resembles conditions in the womb. In the end, the screen fades out again and users look at the fetus objectively. The light pours from above the VR world, the screen fades out to white, and the experience finishes.

3. Experiment

We analyzed participants were 63 healthy people (49 men and 14 women) between 20 and 60 years of age. And whom 31 (21 men and 10 women) experienced the fetal VR with swaddling and 32 (28 men and 4 women) experienced it without swaddling. The experiment involved questionnaires to evaluate their mental states before and after the VR experience.

3.1. Experimental design

Participants responded to a questionnaire as shown in Table 1 before and after the VR experience. They could answer each question using a seven-point Likert scale ranging from "Not at all true" to "Very true." The questions were created referring to a short-form self-report measure to assess relaxation effects (Sakakibara, Teramoto, & Tani, 2014).

Table 1: Questionnaire used before and after the VR experience

(1) I can calm down breathing.	(7) I am relieved.
(2) My heart beats faster than usual.	(8) I am very comfortable.
(3) I feel sleepy.	(9) I feel at ease.
(4) My vitality is full.	(10) I feel nostalgic.
(5) I feel very relaxed.	(11) I am nervous.
(6) I feel very calm.	(12) I am worried about the future.

The experimental procedure was first explained to all participants and it was confirmed that none of them had a heart disease, abnormality in blood pressure, and claustrophobia, they were not pregnant, and they did not feel ill. They were told that they could terminate the experience at any time if they felt ill or if they felt the cloth was too tight. They filled out the informed consent forms and questionnaires.

The participants sat on a large cloth grasping the knees and attached the HMD onto the head. They were asked to hold the controllers in front of the chest. 31 persons of them were wrapped in the cloth using the Otonamaki method. After an instruction by the staff, the VR video and sound started. The participants could move back and forth and sideways freely in a sitting posture. After the experience ended, they took off the cloth and HMD and answer the questionnaire. The average time of the total experiment was approximately 10 min.

3.2. Result

The difference before and after the VR experience with and without swaddling was analyzed by a two-sided Welch's t-test and a significance level of $p<.05$ was determined. The results is shown in Table 2. Items (1) to (12) in Table 2 correspond to those in Table 1.The number is the average change in answers between before and after the experience. Significant differences were observed in "(9) I feel at ease" ($p=0.0131$), "(11) I am nervous" ($p=0.0450$), and "(12) I am worried about the future" ($p=0.0272$). Figure 5 shows the bar graphs of the change of the questionnaire results.

Table 2: Results of questionnaires comparing VR experiences with and without the cloth.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
with cloth	-1.39	1.13	0.323	-0.710	0.548	0.0645	-0.0968	0.581	0.516	1.16	-0.581	-1.16
without cloth	-1.84	1.88	-0.656	0.000	-0.281	-0.281	-1.03	0.0313	-0.719	0.250	0.406	-0.313
p-value	0.381	0.188	0.0937	0.0735	0.0624	0.408	0.0701	0.227	**0.0132**	0.102	**0.045**	**0.0272**

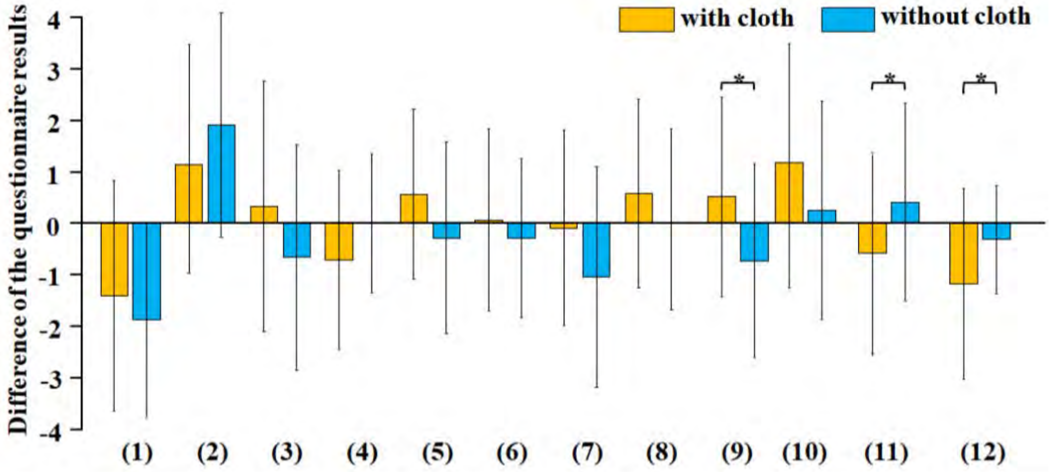

Figure 5: Bar graphs of the change of the questionnaire results between before and after the experiment(*p<.05).

3.3. Discussion: Changes in emotions read from questionnaires

Questionnaire results show that there were significant differences of p <.05 in “(9) I feel at ease,” “(11) I am nervous,” and “(12) I am worried about the future.” Particularly in “(9) I feel at ease” and “(11) I am nervous,” the results showed that the VR experience with the cloth could create relaxing effects, whereas the degree of relaxation became lower after the VR experience without the cloth. These results indicate that being swaddled when experiencing fetal VR can invoke positive emotions and reduce tension.

4. Conclusions

This paper compared the effects of fetal VR experiences with and without the cloth. No negative effects of being swaddled in cloth were found. Using the cloth during fetal VR experiences could reduce anxiety about the future and bring ease. It is suggested that our fetal VR experience has a relaxing effect on people’s emotions. It is believed that this fetal VR experience can contribute not only to the development of relaxation devices and therapy but also to the improvement of the social environment for raising children.

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UMI3D: Extension of Tracking and Embodiment

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Keywords: UMI3D – Collaborative Virtual Environments – Avatars – Asymmetrical Devices

Abstract

The UMI3D protocol is a data exchange model that allows the implementation of virtual reality collaborative applications with the possibility of making full use of heterogeneous devices. However, no visual user representations were established.

Our objective was to set up a protocol for visual communication between the users. Designing embodiments for a UMI3D environment is a challenging issue since the quality of the information about user movements is unknown for the server. That is why we established a data model intended to communicate user's body joints location at runtime. Once this model created, we designed for each UMI3D browser a skeleton representing the device's user tracking potential. Each skeleton is composed of tracked joints and interpolated body parts and is animated in real time.

Finally, it becomes possible to build an appearance by replacing each joint thanks to its given location and displaying them with UMI3D objects in the environment.

1. Introduction

The recent establishment of the UMI3D protocol offers new perspectives on collaboration in Virtual Reality and Augmented Reality. Indeed, this protocol allows different devices to synchronize around the same virtual environment and make the most of each of their specificities.

However, this protocol does not include a verbal or visual communication system yet, and it is not possible to visualize the other users present in the environment. Therefore, we have experimented a generic system of user representation through visible avatars.

In another context, numerous works on avatars have been done, ranging from different methods of creation to the impact that their presence can have on users. Thus, it could be wise to consider adapting these approaches to UMI3D.

We first summarize the UMI3D model concept and behavior and the related works about the avatar creation for virtual environments. Thereafter we explain our approach concerning the creation of user tracking and methods of reconstruction that we have elaborated, and we finally analyze the results within UMI3D.

2. Related Work

2.1. UMI3D

UMI3D is a generic data exchange model that can generically describe a 3D environment. The main advantage of such a model is the total separation between the 3D environment and the devices used [5]. Thus, each device can display and interact with all environments described with UMI3D. The client-server architecture facilitates collaboration between these environments. There is no technical obstacle in connecting several potentially asymmetrical devices to the same environment. The only requirement to achieve this is the need for each device to have a dedicated UMI3D browser developed for them. In addition, UMI3D does not contain any constraint on the tools and technologies used to develop environments and browsers. Thus, a UMI3D browser can be connected to an environment developed with NodeJS (a JavaScript execution used to design Web applications), as well as an environment designed with a game engine [5].

The main concept of the UMI3D model is to describe the interactions between the environment and the device by an abstraction layer composed of a finite set of objects called interaction blocks. These blocks allow the creation of generic manipulations using degrees of freedom to define a movement to be performed by the device. In addition, interaction blocks can be used to define selection and targeting of virtual objects as well as application control [6].

2.2. Avatars

Numerous studies have been conducted on the design and animation of an avatar [1, 2, 3, 4]. It appears that implicit communication could be enhance by the addition of visual elements representing users in the collaborative virtual environment [7, 10]. Also, other studies introduce user representation methods which try to combine fluid visualization and possibilities of virtual interactions [11]. Finally, the appropriation of avatars and the impact of their presence on users are also two areas to consider for the development of collaborative virtual experiences [8, 12].

That is why we managed to adapt these studies in order to create user representation in accordance with the generic specifications of the UMI3D architecture: virtual environments must be able to model the users and to follow their evolutions within them. Moreover, to further enhance the collaboration, we also wanted to take advantage of this representation to ensure non-verbal communication between users and a low latency body tracking.

3. UMI3D Embodiment system

3.1. Data model

In order to support the user tracking, a data model representing each body part had to be designed in the first place. Indeed, since the remote virtual environment is unable to recognize the current devices in use, it is impossible to predict the information quality that could be sent to describe the users. For this reason, we have produced a data model intended to communicate user's body joints location to the server.

Finally, each browser can send in real time the body parts tracked or interpolated by the device in use. The collection of known joints is based on anatomical references to adapt to the tracking capabilities of any device [9].

3.2. User tracking

Once the data model established, we looked for a way to represent a user according to the tracking capabilities of the devices. Each device having its own potential, we have chosen to create for each browser a skeleton representing this potential. A skeleton is composed of tracked joints and possible interpolated body parts and is animated in real time thanks to user's movements in accordance to the physical constraints of the human body. Thus, each joint can be located in relation to a reference and transmitted to the server.

3.3. Mesh reconstruction

The transfer of the body joints data between the browser and the server is guaranteed by the UMI3D routines. The server then receives a set of joints data for each connected user. It becomes possible to build an appearance by replacing each joint thanks to its given location. Next, we added a mechanism to display the replaced elements with 3D objects. Each joint reference can be associated with a 3D model in the server configuration. The assembly of the representations of the joints composes the user avatar. Moreover, these objects possess the UMI3D sharing properties, which finally allows them to be shared between each of the users present on the server.

4. Improvements

This procedure allows users to perceive each other. However, the network latencies existing between the server and the browsers create gaps between the user's body movements and the avatar's reaction to these movements. These gaps mainly cause problems concerning self-representation: they are generally higher than the motion-to-photon latency. We therefore suggest that each browser animates its own avatar. The UMI3D environment transmits to the browser a 3D model for each of its avatar parts. The browser then connects each 3D model with the corresponding joint on its own local skeleton and animates it locally. The user can then view his own avatar without network latencies. The user tracking mechanism previously described as well as the scene synchronization of UMI3D are used to share the avatar to other users.

5. Conclusion

The primary objective of this document was to present an avatar building system usable by the UMI3D exchange model, allowing to reflect the capabilities of a user immersed in a collaborative virtual environment. By combining body mechanics knowledge and user tracking, we managed to create an architecture usable by each of the UMI3D browsers. We then set up a client-server exchange algorithm that transmits users' body posture to the server in order to replicate it in every other connected users' browser.

In addition, we have succeeded in reducing the effects of network latency by locally animating the own avatar of a UMI3D browser. However, further works need to be done to improve the available interaction methods and to support other avatar representation.

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AR/VR for conferencing and remote assistance

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Keywords: Social VR, conferencing, remote assistance, telecommunication, use cases

Abstract

AR and VR headsets can be used for communication purposes. People can be brought together in a virtual environment, either as avatars in a more game-like environment, or photo-realistic using cameras and video streams. The immersion of a shared environment brings people closer together, and life-like and life-size user representations allow for 'normal' group interaction, which resembles more to a face-to-face meeting compared to desktop-based video conferencing due to gaze awareness and full body language. Furthermore, such a system is quite flexible in use. It requires either a PC with VR-HMD (head mounted display) and camera, or soon a standalone VR- HMD and optionally a smartphone as capture device. Compared to high-end video conferencing systems, it does not need a fixed space and can be used anywhere. Given the immersion and naturalness of the communication, AR and VR offer a new opportunity for remote communication.

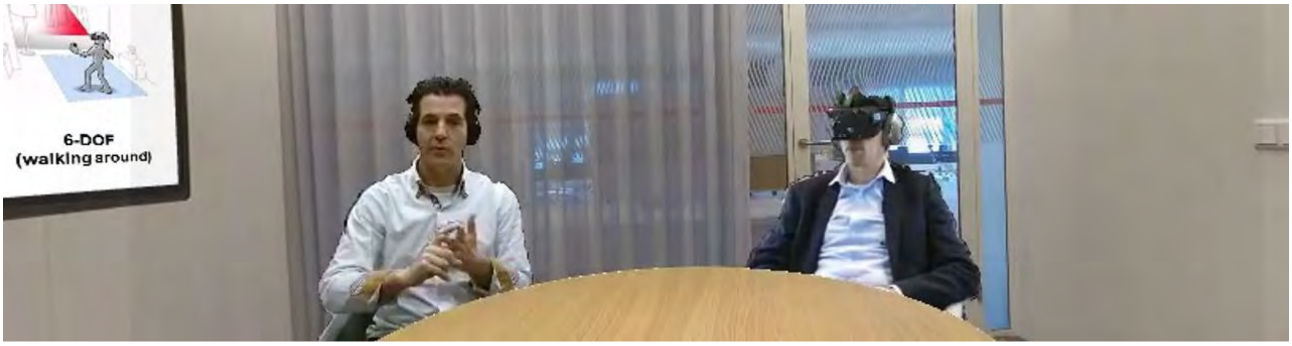

Figure 1: Example of photo-realistic VR conferencing with 3 users, sharing a PowerPoint presentation

1. Introduction: AR/VR has added value for telecommunication services

One of the interesting uses of VR and AR is for social interaction with other people, i.e. it has a big potential for use in telecommunication scenarios. Our focus is on two main telecommunication use cases in the business domain: conferencing and remote assistance.

Video conferencing has for many years the promise of offering more flexibility in working in remote and dynamic teams, reducing travelling costs and thereby also reducing a company's ecological footprint. Even though both high-end video conferencing systems and desktop-based video collaboration tools see a lot of usage, they still do not replace face-to-face meetings. High-end systems offer a good experience but are not widely available. Desktop-based solutions are flexible, but often fail to support good group dynamics.

AR/VR based conferencing systems may fill this gap between high-end and desktop-based systems. They can offer the flexibility of desktop-based systems, requiring only a PC with a VR headset and possibly a camera, while allowing a high degree of immersion and social presence. Multiple participants are arranged in a natural way in a virtual environment. Sharing a single (virtual) environment amongst participants immediately gives a sense of co-presence. Gaze awareness allows for normal turn taking and group dynamics, and the inclusion of a full-body avatar allows for more natural body language. Seeing who is talking to whom and how much people are involved all comes natural to us in a face-to-face meetings. With the help of AR/VR, this is now also available in remote meetings (Oh et al., 2018).

Table 1 Differences between different communication systems

	DESKTOP CONFERENCING	**ROOM-BASED CONFERENCING**	**POINT-CLOUD CONFERENCING**	**AVATAR-BASED SYSTEM**
TECHNICAL REQUIREMENTS	PC Webcam Headset	Room with fixed displays and cameras	VR HMD Camera High-end PC	VR-HMD VR controllers (or hand-tracking)
GAZE AWARENESS	No gaze awareness	Natural gaze awareness	Gaze awareness with 3D avatars	Limited Gaze awareness through HMD tracking
BODY LANGUAGE	Limited body language, only upper torso visible	Full body language and face expressions	Full body language and face expressions	Limited via head and hand movement tracking
SYSTEM COMPLEXITY	Low complexity, quality depends mainly on audio headset	high complexity requiring fixed room calibration	some complexity, e.g. additional functions such as HMD removal	limited complexity, similar to VR games

AR/VR for remote assistance. There are many examples where a specific expertise is needed to accomplish a certain task. Examples range from (industrial) maintenance, medical analysis, consumer support, crisis management (i.e. emergency sector). The ability to remotely consult an expert can enhance performance, in case problems are encountered or specific expertise is needed. Such remote assistance can be enhanced by using AR/VR. First, the physical environment can be shared through VR by setting up and sharing a (360) camera. This allows a remote expert to look around freely to analyze the situation. Secondly, the remote expert can virtually join the environment e.g. by 3D projection in an AR headset. This allows for consultation in the actual environment, including the ability to point at specific things in this environment. By using an AR/VR system for remote assistance, expertise can be instantly available anywhere in an effective manner.

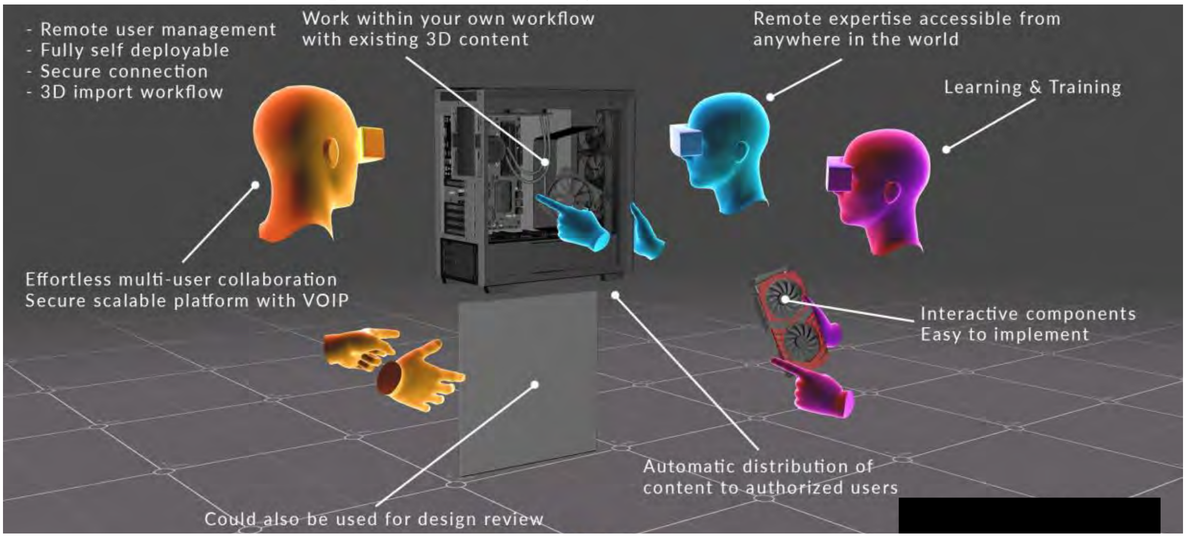

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Figure 2: Example of Social VR for remote assistance

2. Current status: promising Social VR technology becomes mature

In the last few years, many VR conferencing solutions emerged[1]. Most solutions are based on graphical avatars, offering a high ease of use, using a VR HMD's built-in tracking and the VR controllers for controlling the avatar's movement. Other systems, such as one of our systems, include the use of (depth) cameras to create video / point-cloud avatars. This makes meetings more natural, offering a higher social presence, and full body language. Also, VR controllers are no longer needed for body language, which has many advantages.

Our point-cloud based Social VR system was built for research and allows conferencing usage for 8-16 users via a conferencing bridge that is mixing all video streams. The bridge reduces the processing burden on the

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[1] VR communication comparison chart : https://ryanschultz.com/list-of-social-vr-virtual-worlds/

user equipment, as they only upload and receive a single video stream compared to one per remote participant in a peer-to-peer system. Also, we switched from using a 2D video avatar to a 3D point cloud avatar (Dijkstra-Soudarissanane et al, 2019). In initial user experiments (Gunkel et al, 2019), we compared our photo-realistic avatar with graphical avatars, face-to-face and Skype meetings. We were able to show that higher avatar realism increases the quality of remote communication. However, our system was still not able to fully compare with face-to-face meetings. Main drawbacks were a lack in high video quality, occlusion of the face by HMD and lack of interaction capabilities such as note-taking. Feedback we received for the Avatar-based communication system, are that users are completely immersed and totally forget where they are physically. People report they feel that they are together in that same VR space. With the avatar-based system, we want to create a platform where people can easily publish, share and discuss 3D content (i.e. 3d engineering models like Solidworks, 3d architectural models like Revit, but also 'simpler' 3D models created with SketchUp).With this in mind, we are already successfully testing it with several companies for the following purposes:

- Design review (i.e. the design of a complex space such as an operation room of a hospital).
- Training (i.e. the assembly of a complex machine).
- Remote expert (i.e. procedures that are not easy to comprehend).
- Saleskit (i.e. when dealing with products that are large/complex).
- VR meetings (i.e. when working in projects with stakeholders from all over the world/EU).

Currently, the avatar-based system has a lower threshold to use, is more stable and thus has a higher technology readiness level. Operationally, we foresee first market entry for avatar-bases systems, while in the longer term, a switch to photo-realistic avatars is certainly possible.

3. Future outlook: from trials to products and deployment

Given our current progress, we feel confident that our Social VR systems will be fully usable for business meetings. We are looking into lowering the threshold for use, by porting our solution to stand-alone HMDs such as the Oculus Quest (using mobile phones as cameras). The use of our systems should eventually be frictionless; it should become a non-technical solution that everybody is able to use. Challenges we are currently working on, include: photo realistic point-cloud avatars (including HMD removal with eye gaze), Automatically setup safe guardians based on the persons location (for physically moving around), natural hand-tracking and haptic feedback, various forms of interaction for supporting meetings (e.g. including virtual keyboards, VR stylus, etc), improved performance through cloud computing and 5G edge, including AR headsets (for mixing real environments with virtual participants similar to Orts-Escolano et al., 2016).

Given our progress, we are now setting up internal company use, and are talking to various companies for trials. Even though the technology is progressing rapidly, we firmly believe it is now mature enough to start offering real benefits to companies and society, and we are committed to pushing this forward.

4. Acknowledgments

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The Effect of Spatial Qualities, Openness and Complexity, on the Performance of Human Cognitive Task in Immersive Virtual Environments

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Keywords: Spatial Quality, Isovist, Immersive Design, Virtual Reality, Navigation Performance, Memory

Abstract

This paper investigates the effects of two spatial qualities, openness and complexity, on cognitively demanding task within immersive virtual environments. Isovist measure is used to design four rooms with different levels of the two spatial qualities. In an empirical within-subjects study, all the participants had to solve a navigational puzzle game and give a rating of their spatial experience. Findings suggest that these spatial qualities affect some of the measures. This is a first step in the evaluation of the effect of spatial design to enhance participant cognitive performances when training inside immersive virtual environments.

1. Introduction

Architects have developed a series of spatial analysis tools to measure spatial qualities inside buildings (e.g. Hillier and Hanson, 1984). This type of objective evaluations shows how certain spatial qualities are beneficial to specific human activities, which in return help to improve the next spatial design. For example, Peponis et al. (2007) have shown that in an office environment, well-designed corridors can increase employees' productivity. Virtual Reality (VR) technologies have been developed by engineers with the dream of creating a system that immerses users in a new form of spatial experiences. Immersive Virtual Environments (IVE) has already demonstrated a useful range of benefits (cf. Slater et al. 2016). In association with well thought spatial design, IVEs have the potential to become a mainstream spatial cognition training method. Despite the groundbreaking works and progress made in both fields of spatial syntax (e.g. Wiener and Franz 2005, Ostwald 2011} and spatial cognition (cf. Montello 2014}, the effect of architectural design on cognitive performances is still far from being understood.

2. Materials and Method

2.1. Spatial Analysis

The intention of this experiment was to focus specifically on the way added windows and columns affects one's experience navigating a small space. The isovist field was calculated by using a grid of point isovists. The interior visualisations (see Figures 1) shows the isovist field taking into account the permeability of the internal perimeter. It offers clear visualisation of the level of *openness* and *complexity* of the space. Considering the gradient from light to dark, lighter regions of the floor plan are more open while darker regions are more enclosed, as measured by the area of the isovist generated at that location. Also, lighter regions have higher visual complexity while darker regions have lower visual complexity as measured by the length of the isovist's perimeter. This type of visualisations shows clearly the differences in how these spatial qualities come into play in similar spaces.

2.2. Navigational Puzzle Game

The first task is a "Free Exploration" to let the participant familiarise with the new environment. The main event of this experiment is the Navigational Puzzle Game (NPG). Its primary focus is to evaluate participants' spatial abilities. In line with the investigation of the validity of the virtual spatial navigation assessment in comparison with older tasks by Ventura et al. (2013), the NPG consists of a navigational task where users have to collect items, along their paths. The design of the task, and the items specifically, was inspired by the burr puzzle and Tetris (the video game). The time to complete the puzzle was measured in each room. Efficiency was used to evaluate the amount of effort required by each user to complete the task. Efficiency is the ratio of the task success rate to the average time per task.

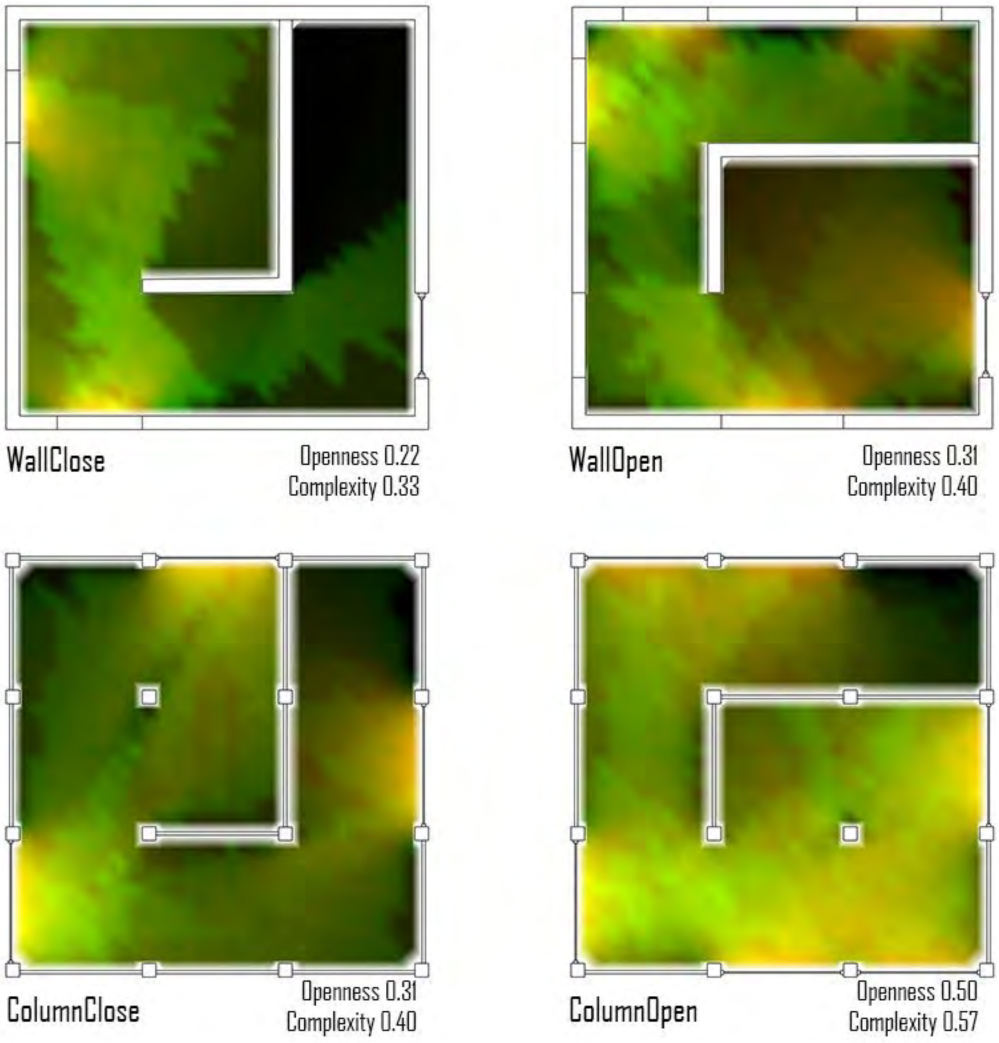

Figure 1: Spatial Analysis using Isovist Field for Openness and Complexity.

2.3. Spatial Quality Rating

The spatial analysis can only be meaningful in regards to an equivalent evaluation from a human experience self-reported measure. Evaluating lived space can be done by asking participants to rate their experience for each spatial characteristic. Inspired by Wiener and Franz (2005), this study brings human subjective experience into the equation. Using a semantic differential scaling technique, subjects were able to differentiate their appraisal using a five-step Likert scale. The rating categories were selected to represent previously mentioned properties: openness and complexity.

2.4. Room-Scale VR system Specifications

The VR system is composed of an HTC Vive HMD and two wireless hand-held controllers; The range of locomotion of the room-scale VR is dictated by the position of the two lighthouses that tracks the HMD and the controllers' movements (2.6m x 2.6m).

3. Results

3.1. Free Exploration

The mean time spent exploring the two rooms ComplexClose (M=28.39s, SD=13.06) and ComplexOpen (M=30.60s, SD=22.18) is higher than for the two other rooms, SimpleClose (M=23.50s, SD=9.89) and SimpleOpen (M=23.86s, 11.30). The standard deviation for the room ComplexOpen is much bigger than for the other rooms. The repeated measures two-way ANOVA shows a statistically significant effect of the mean of complexity (F(1, 34) = 6.96, $p<.05$), but not of the mean of openness ($p=.57$). In the case of the rooms that have only walls, Room SimpleClose (23.5s) and Room SimpleOpen (23.86s), the number of windows does not have an effect on participants' exploration time. However, the mean time spent exploring these two rooms was shorter than the mean time spent in the two more complex rooms with the added columns. That suggests that a higher complexity level slowed down participants' progression; however, the level of openness had little effect on the user's exploration time.

3.2. Navigational Puzzle Game

A repeated measure ANOVA, with the assumption of sphericity not violated, $p=.717$, showed that the mean time completion of the NPG task differed statistically significantly between the four conditions (F(3, 102) = 3.646, $p<0{,}05$). Post hoc tests using the Bonferroni correction revealed a better performance within the room ComplexClose (M=54.48s, SD=25.04) compared to the three others (See plot chart Figure 2). However, from the three other rooms, only room ComplexOpen (M=71.32s, SD=28.28) shows a statistical significance ($p<.05$), the two other rooms showed only a slight improvement with room SimpleClose in 66.60s and room SimpleOpen in 65.50s, which is not statistically significant ($p=.18$ and $p=.22$, respectively). The analysis shows that the room with the most *complexity* and *closeness* (room ComplexClose) elicits a statistically significant improvement in performance, but that it is difficult to understand the difference in the effect between the three other conditions.

3.3. Spatial Quality Rating Task

The Spatial Quality Rating (SQR) task was conducted by asking each participant to rate their perception of openness and complexity for each room, using a five-step Likert scale. The rating options were set as follow; openness: 1-Very Open, 2-Open, 3-Neutral, 4-Close, 5-Very Close; complexity: 1-Very Simple, 2-Simple, 3-Neutral, 4-Complex, 5-Very Complex. The two questions were asked, in random sequence, during the transition period. Participants recognised the more complex conditions with the added columns. The fact that the room had more or fewer windows did not seem to affect the way people perceived the complexity of the room ($p=.917$). Furthermore, it seems that people rate the feeling of *openness* based on the presence of columns or walls more than based on the number of windows. Even though not statistically significant, there is a trend in the data suggesting that the presence of columns drives the feeling of *openness*.

4. Discussion

Compared to previous research, the presented approach is unique in so far that it attempts to address all identified challenges of measuring the effect of spatial qualities on humans cognitive performance within IVEs, rather than singling out one aspect in isolation. In doing so, it also largely overcomes the limitations of previous research, but this is not without any problems that should be acknowledged.

As opposed to the series of studies looking into spatial qualities evaluation that focuses mainly on the spatial analysis (Ostwald 2011), or Wiener and Franz (2005) on the psychophysics, this study proposes not only a more immersive experience but also an advanced methodology to investigate the correlation between spatial analytic and perceived experience. In the study by Wiener and Franz (2005), the setup was a desktop monitor and a joystick. The type of hardware dictates the way one is moving (if moving at all) through the spatial environment. If the feedback appears only on a small flat display, it offers only limited clues on self-motion which in return offers only a reduced ability to perceive the different quality of the space. Considering the number of different spatial qualities, Ostwald (2011) showed a wider range of measurements. Notwithstanding their encouraging conclusions about the reliability of these measures to correlate to human perception of space, people actual feedback was obtained by looking at still images (no motion) viewed on a monitor which was of a low level of immersion.

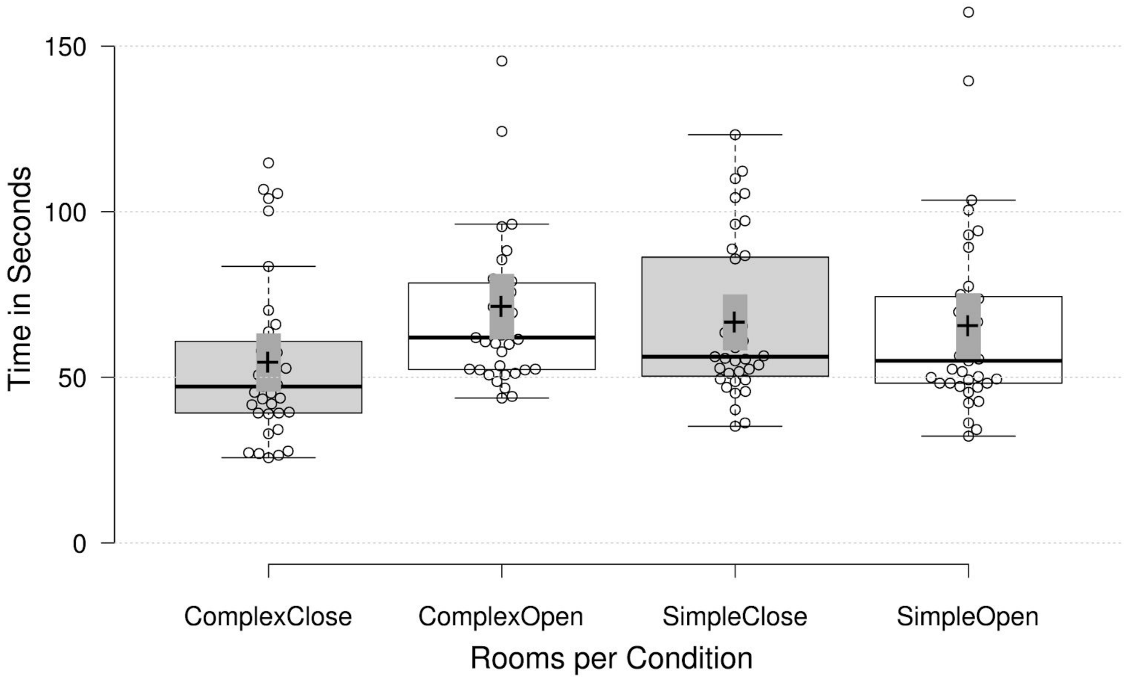

Figure 2: Navigational Puzzle Game, mean time spent in each condition.

5. Conclusions

As the experiment results demonstrated, different levels in spatial qualities such as *openness* and *complexity* can play a decisive role in participants' performance completing the Navigational Puzzle Game. This user-study is a stepping stone to show the potential of using well designed IVEs to enhance learning and training performances.

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Designing identity in VTuber Era.

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Keywords: Virtual identity, VTuber, Virtual humans and avatars, Human factors, Social experience

1. Abstract

Virtual YouTubers (VTuber) are streamers and vloggers who use 2D and 3D computer generated virtual characters and engage in creative activities on platforms such as Twitter, YouTuber, Twitch. VTubers first appeared in 2017 in Japan and adopted anime-like visual characteristics. Currently there're more than 10'000 VTubers and some of them have their own TV shows or work for international companies. Based on identity formation theories, this paper sheds light on VTubers identity construction, reasons for engaging in VTubers activities and gender expression. This research provides evidence that VTubers are not avatars, differences and similarities exist between En, Fr and J-VTubers because they formulate and put into practice different criteria based on individual self-expression and community interactions.

2. Introduction

Virtual characters "provide access points in the creation of identity and social life. It is not simply that users exist as just "mind", but instead construct their identities through avatars" (Taylor, 2002, p. 40). This research proposes a hypothesis to theorizing VTubers as a distinct group of virtual characters (beings) and not as avatars. Avatars found in *Second Life* or *VRChat* are bound to those virtual worlds (Nagy & Koles, 2014), however, VTubers are only bound to the production of crative content and entertainement for viewers on platforms such as YouTube, Twitch or Twitter, making them cross-platform and not linked to a specific virtual world. If a person does not produce creative content such as videos, singing, drawing, games streaming, he or she cannot be considered as a VTuber. Because VTubers cannot be analyzed as avatars since their existence depends on their creative activities, a new research should be conducted in order to understand VTubers and their identities. Individuals who decide to become a VTuber construct their virtual identities based on two choices: individual and communal. Individual implies that identities are built depending on how individuals want to portray themselves (Schegloff, 1992) and communal implies that individuals choose elements of identity that are most relevant in regard to specific social situations and groups of individuals (Van Langenhove, 1999).

3. Results

This survey was conducted between 07.01.2020 – 20.03.2020 with VTubers contacted in Japanese, French and English by e-mail, direct Twitter messenger and Google Form. 95 answers were submitted by majority coming from independent and amateur VTubers and some from small companies. Results that appeared in this research paper were based on spontaneous answers to each survey question and due to this paper's page restriction, only main answers to each question were provided. VTubers' answers were grouped into three categories: En-VTuber (English VTubers) with 44 answers, Fr-VTubers (French VTubers) with 4 answers and J-VTuber (Japanese VTubers) with 47 answers.

Fr, En, and J-VTubers found the appeal of being an animated character, not having to show their physical face for reasons such as privacy due to potential risks of stalking, being anyone and anything, enjoyment, community interactions and content creation. Specific to J-VTubers included performing in an ideal form and being released from the physical body after which virtual freedom could have been acquired, becoming a 美少女(*bishôjo* “beautiful girl”), being likeable for approval needs. The majority of all VTubers groups had a clear idea of what and how they wanted to perform their VTuber identity, some En-VTubers required time before making a decision or their initial idea evolved over time. Some J-VTubers conducted their activity without any specific thought process. Goals and purposes of Fr-VTubers and En-VTubers were to build and help grow a community, to be social and enjoy themselves, to bring positivity by creating a safe space where people could be entertained. While some J-VTubers have also listed the last two goals, other answers included knowledge transmission, business related, spreading awareness of cyberspace as a living environment. En, Fr and J-VTubers characters had specific entertainment abilities, they played games, sang, drew, talked with viewers or told stories. J-VTubers also focused on handcrafts, reading and transmitting knowledge. En and Fr V-Tubers were mostly active on Twitch and Twitter, J-VTubers were mostly active on YouTube and Twitter. Twitch was used for streaming gameplay, majority of En-VTubers who used Twitch preferred to keep their natural voice, gender and phycological identity as they spent long hours talking while streaming. YouTube allows for individuals to curate their virtual content and host live shows. On Twitch and YouTube viewers can engage with VTubers in the comment section. Fans mostly commented J-VTubers lives on YouTube and members of VTubers community or VTubers themselves commented En and Fr-VTuber lives on Twitch.

Regarding choices of psychological virtual identity, 40% En-VTubers and 31% J-VTubers chose an identity for their VTuber close to their generic identity in the physical world: they exaggerated certain aspects of it by being more positive, polite, optimistic, cute or cool, as their goal was to entertain viewers. 22% En-VTubers, 25% Fr-VTubers and 21% J-VTubers chose an identity that was exactly the same as the one in the physical world. 13% En-VTubers, 50% Fr-VTubers and 31% J-VTubers created a fictional persona, En-VTubers often constructed a backstory for their fictional character based on type of content they intended to produce, J-VTubers mentioned creating a personality that fitted character’s visual aesthetics or was decided by employer. Only 11% of J-VTubers have specified choosing an ideal persona as their VTuber identity, for example a *bishôjo*. 22% En-VTubers, 25% Fr-VTubers and 6% J-VTubers have said to possess a fictional persona and a generic identity from the physical world simultaneously, such happened when individuals created content on YouTube with their persona and streamed on Twitch with their physical world identity.

53% En-VTubers, 75% Fr-VTubers, 77% J-VTubers were of male sex and gender, 47% En-VTubers, 25% Fr-VTubers, 23% J-VTubers were of female sex and gender. Regarding choices of VTuber gender, 82% En-VTubers, 100% Fr-VTubers, 48% J-VTubers chose a VTuber character of the same gender and sex as in the physical world. For some male En and Fr-VTubers it would have been uncomfortable pretending to be a girl and it would have demanded great effort; they felt more comfortable playing a character of the same sex and gender as themselves; it was easier for them to identify to a male character. Female En and Fr-VTubers decided to keep their virtual character of the same gender and sex as theirs because female characters were cuter and more popular with viewers; it was easier to portray a female character; they found it off putting to have a female voice come out of a male character; they did not feel comfortable having to portraying a male character. 16% En-VTubers and 50% J-VTubers chose a VTuber of a different gender and sex than themselves in the physical world, all were men using female characters. In Japan, バ美肉 *babiniku* (virtual, *bishôjo*, incarnation) is the act of using a *bishôjo* character and being virtually reborn as a *bishôjo*. The term is not restricted to men, however, in this survey only men engaged in this activity. In the West “crossplay” is used when an individual uses a character of a different gender and sex. J-VTubers chose *babiniku* because they wanted to feel desired; to be released from one’s physical gender identity and social norms, and because *bishôjo* are *kawaii* (cute and loveable). 16% of En-VTubers used female characters because they found them more appealing than male models. 2% of J and En-VTubers' characters had no gender (non-human character). No women using a male character was documented in this survey. 71% En-VTubers, 100% Fr-VTubers and 36% J-VTubers used their own voice for their virtual character, meaning that their voice and their gender matched the voice and the gender of the VTuber character. 9% En-VTubers and 24% of J-VTubers used their natural male voice on a female character. 2% En-VTubers and 2% J-VTubers were male and used a voice changer to get a male voice. 2% of J-VTubers were female and used a voice changer to get a female voice. Voice changer in both scenarios was used to distance oneself from the natural voice and to keep anonymity. 2% En-VTubers and 20% of J-VTubers were male and used a voice changer to get a female-like voice that fitted the female character. 16% En-VTubers and 16% J-VTubers engaged in voice acting — they adjusted their voice to match their VTuber character.

4. Conclusion

This research proves initial hypothesis that VTubers, unlike avatars, are directly linked to their activity as entertainers and creators by engaging in creative activities such as game streaming, singing, dancing, knowledge sharing, video and image creation. Individuals engage in VTuber activities as a way to express themselves (creative expression with content publication), use VTuber as a communication tool (knowledge sharing, business communication or research) or as a way of living (constant engagement in production of creative content and communication). VTubers enable individuals to express themselves and play with anime-like facial expressions; they are not bound by physical laws (for example VTuber can fly, become a melon, or change size and become a *bishôjo*). Current results reflect differences and similarities between En, Fr and J-VTubers identities based on community interactions and individual expression. By being part of a community, En and Fr-VTubers construct their identity accordingly: they create family-like relations between each other (some VTuber are considered to be "mother" figures), they often collaborate together on Twitch and their communal interactions lead them to adopting friendly and not distant personalities. J-VTubers are more interested in "idol" activities of VTubers, the majority interacts with their viewers in the comment sections on YouTube or Twitter. Moreover, the communal interest and adoration of *bishôjo* characters leads to groups of men playing *babiniku*. Majority of J-VTubers are male and 50% choose characters of a different gender with *bishôjo* characteristics, they become *bishôjo* by playing with visual and social codes of a *bishôjo*. These men are "rethinking" the basic issues of life: social interactions, gender codes and body because *babiniku* is an agency and a form of play to express oneself differently from social norms. With VTubers we are possibly witnessing creation of new virtual beings, a revolution in the entertainment industry on individual and professional levels. Future research will focus on adoration of anime-like female characters, prevalence of men in amateur VTuber phenomenon, lack of women using male characters, impact of "idol" culture and *bishôjo* as gender performance.

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Virtual embodiment for training computational thinking

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Keywords: virtual embodiment – cognition – education - immersive technologies – AR - VR coding - 3D prototyping

Abstract

Cognitive abilities required for meaningful processing of digital information are called computational thinking (CT). The study demonstrates that virtual embodiment, via kinesthetic and social channels of eLearning model contribute to teaching such higher-level cognitive processes as computational thinking. Seven CT concepts that transfer to other (programming and non-programming) contexts were learned by the end of the two-week training session of middle school students, using AR immersive technologies, VR coding and 3D prototyping.

1. Introduction. Higher Cognitive Abilities. Computational Thinking.

Growing need in the workforce fluent in digital communication stimulates searching the ways to train a set of skills called computational thinking (CT) (Koh, 2010; Grover, 2011).

In 2012, researchers from Massachusetts Institute of Technology (MIT), Brennan and Resnick, identified seven computational thinking (CT) concepts which transfer to other (programming and non-programming) contexts: 1) sequences, 2) loops, 3) parallelism, 4) events, 5) conditionals, 6) operators, and 7) data (Brennan, 2012).

Together with the SBU Women in Science & Engineering summer camp team, we created a method of computational thinking training based on 3D game coding and 3D prototyping, thus engaging young audience's interest and increasing access to STEM fields.
The training method used in the study was based on eLearning cognitive model taking into account the current state of the art in eContent presentations, that have become interactive, highly personalized, and collaborative (Tchoubar, 2018).

Significant improvement of computational thinking that was demonstrated in the present case study, used virtual embodiment via immersive technologies. (Fig. 2). Virtual embodiment is the physical manipulation of an agent, designed to represent a particular object (Gibbs, 2007). In our study, students physically manipulated (via drag-and-drop) an agent, designed to represent the real 3D objects (3D selfies) and characters (students). Social embodiment builds on the idea that social perception is "influenced by sensory, motor, and perceptual cues in the environment" (Barsalou, 2003; Lakens, 2014). Students participated in 3D scanning and VR coding collaboratively that created conditions for the social virtual embodiment.

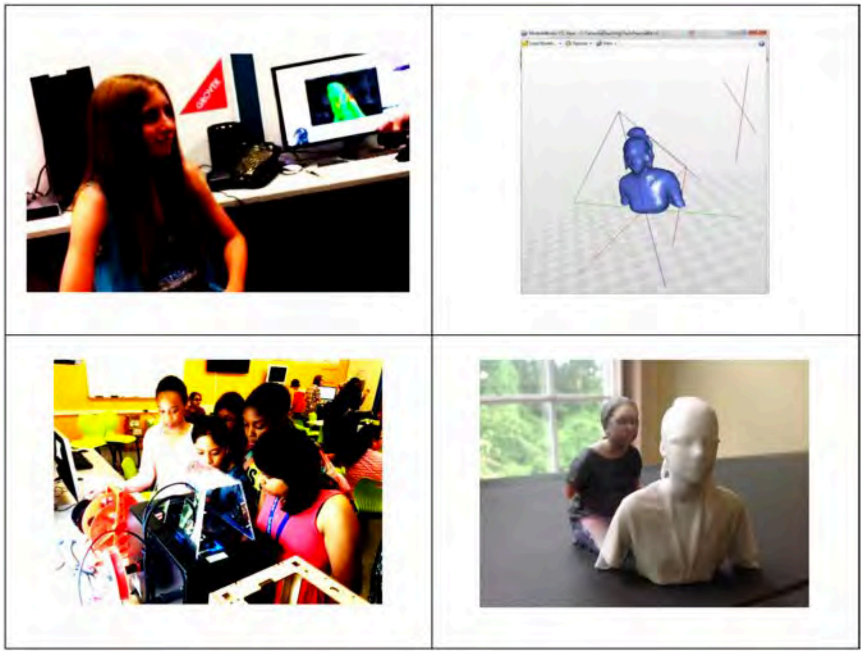

Figure 2. Kinect scanning, modeling, and 3D printing of sculptural selfies by 12-year-old students

We use the concepts, suggested by Brennan and Resnick, completed with the later additions by MIT researchers Grover & Pea (2013), in our case study of a teaching method utilizing immersive technologies and 3D coding to develop computational thinking of the school age students.

```
Scene's Editable Procedures (4)
edit  this performCustomSetup
edit  this initializeEventListeners
edit  this handleActiveChanged isActive: ??? activat
edit  this myFirstMethod
atmosphere
  this setAtmosphereColor color: ???
  this setFromAboveLightColor color: ???
  this setFromBelowLightColor color: ???
  this setFogDensity density: ???
audio
  this playAudio audioSource: ???
```

```
declare procedure myFirstMethod
do in order
  this.camera moveToward this.Tara , 5.0 add detail
  this.Tara think "My adventure is finally over" add detail
  this.Tara turnToFace this.GrannieClaire add detail
  this.Tara think "Madame See! Why is she here?!" , duration 2.0 add detail
  this.Tara think "She's spying on me!" , duration 2.0 add detail
  this.Tara say "Wait..." add detail
  do together
    count up to 9
      this.Tara walk
    loop
    this.GrannieClaire turnToFace this.Tara add detail
    this.camera moveToward this.GrannieClaire , 2.0 add detail
    this.camera turnToFace this.GrannieClaire add detail
  this.Tara straightenOutJoints add detail
  this.Tara say "Grannie Claire! It's really you!" , duration 1.0 add detail
  this.GrannieClaire say "My sweet girl. I knew you would figure it out." , duration 2.0 add detail
  this.Tara say "I thought you were dead" , duration 1.0 add detail
  do together
    this.camera moveAndOrientToAGoodVantagePointOf this.GrannieClaire add detail
```

Figure 2. Alice drag-and-drop object oriented and event triggered coding interface, with the library of procedures and functions (on the left), draggable to the Scene methods code pan.

2 Results

We calculated all the components of Computational Thinking (CT) according to the MIT concepts & Grover, Pea CT elements (2013), for all the Summer 2015 Alice training students' animation coding files, and found a significant improvement of Computational Thinking for the schoolgirls who never coded before. Moreover, CT is well correlated with Digital Fluency (p=.002) (Table 2).

5. Conclusions

The hypothesis that computational thinking can be improved using kinesthetic learning (3D media objects creating and producing) and virtual embodiment (3D coding) has been confirmed. This program is a proof of concept that will allow students to continue working with immersive technologies throughout the years of high school. Therefore, we recommend our training method when introducing students to any program using online or computer-based learning materials.

6. Acknowledgments

We would like to thank Stony Brook University for running the STEM program in this study.

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Virtual reality serving the ergonomics of future Land Systems.

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Keywords: Virtual reality; Human factor; Ergonomics; User experience; 3D Immersive; CAD

ABSTRACT

This article describes how defense ergonomists use virtual reality immersion to improve the ergonomic development processes of future army systems. The method combines skills in ergonomics and user experience, virtual reality immersion technologies as well as the exploitation of CAD[1] provided by defense industries.

INTRODUCTION

Ergonomics in the framework of the defense is:

- Provide users with well-fitted products, according to their needs, to get the greatest operational efficiency for human/system association, when fulfilling the mission
- Ensure maximum safety for both user and equipment
- Balance soldier's mental and physical workload
- Improve liability, availability and maintainability
- Provide life conditions in accordance with sanitary rules and keep the user in good conditions to pursue the mission

To do this, ergonomists work in close collaboration with the army and arms industry in order to develop the systems until they meet operational needs. As described in the IEA[2] (2000), "Ergonomics is the scientific discipline that seeks the fundamental understanding of the interactions between humans and other components of a system, and the application of methods, theories and data to improve the well-being of people and the overall performance of systems ". The importance of human activity being paramount in the ergonomic approach, it is necessary that future users be integrated from the upstream phases of armament programs.

One of the methods used by ergonomists in the framework of armored vehicle programs is virtual reality. VR allows to work with personnel representative of end users through CAD supports provided by defense manufacturers. It gives the possibility of integrating the user experience from the start of architectural choices for the design of Land systems. The exploitation of digital models is a real advance which made possible thanks to the evolution of VR technology.

VIRTUAL REALITY AT DGA LAND SYSTEMS

Immersion tool

The tool used by DGA ergonomists is called IMERSIV: Installation of Experiment Means for Sensory Reality in Virtual Immersion.

This tool is composed by a PC - 200Go of RAM with a P6000 graphics card on which is installed a CAD processing software - CATIA V5 as well as Techviz software allowing to display in virtual reality the 3D CAD

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[1] CAD : Computer aided design

[2] IEA : International Ergonomics Association

models provided by the arms industry. The IMERSIV tool also includes a HTC VIVE PRO kit (VR headset, joysticks and laser stations for motion tracking) as well as HTC VIVE tracker to transpose any object from reality into the virtual universe. IMERSIV is installed in a dedicated room (*figure 1*), designed so that the operator in immersion can move around the virtual model without colliding with real physical elements.

Figure 1: IMERSIV room

IMERSIV allows the ergonomist to be able to integrate the CAD model into the virtual universe projected in the HTC VIVE PRO headset. He can also choose a background allowing the user to project easier elements of his perception of reality in the virtual environment in which he evolves during manipulation (beach; plain ...). As Theureau demonstrates (2004), the user is constantly seeking to translate his intervention in cognition here and now through elements of generality stemming from past cognition. These elements of generality based on experience, it is necessary that the virtual universe is as close as possible to a known real universe.

The immersion tool gives the user the possibility of moving outside or inside the digital model, taking measurements between several elements or even interacting with real objects such as a individual armament or a seat which are referenced in the virtual universe thanks to HTC VIVE tracker. The tool makes the border tenuous between reality and virtual immersion by working on the user's perceptual, proprioceptive and mnemonic judgments which have anchors which can be situated in the situation of the actor or in the activity of the actor.

Figure 2 : HTC VIVE tracker on individual weapon.

Implementation of IMERSIV

Once the CAD has been downloaded, the Techviz software allows an operator representative of future users of the system to be immersed in the digital model proposed by the arms industry. Since the 1990s, the idea of a "user-centered design" has been developed (Norman & Draper, 1986), an approach which recommends taking into account all of the characteristics and needs of users when developing a product, as well as the active participation of the end user in the design process. The ergonomist works jointly with the operator through scenarios that he writes upstream, according to the future use planned by the army. A remote screen allows people present in the room to observe a copy of what the operator sees in real time in his VR headset, this media gives the possibility of better understanding the causes of the operator's verbatim[3]. Thanks to this means, the user can evolve within a virtual universe while undergoing the real constraints with which he will be confronted in the reality of the field: wearing of ballistic vest, ballistic helmet, combat bag, individual armament, etc.

IMERSIV tool has been designed to be able to vary the characteristics:
- Organizational, through the implementation of scenarios dedicated to each system;
- Physical, through, for example, the setting of the brightness or the background of the virtual universe;

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[3] Verbatim: Full reproduction of the words spoken by the interviewee (Larousse)

- Techniques, through, for example, the configuration of versions / sub-versions of the systems or of the different shipments depending on the missions to be represented;
- From the user, depending on the need for each system and the operating modes defined by the army (user representative of a 5th / 50th / 95th percentile female / male; wearing a ballistic vest, etc.)

CONCLUSION

As we have just shown, the possibilities left by the immersion tool increase the realism of virtual reality which is, as Burkhardt (2003) puts it, of paramount importance for the user experience. The users judge positive the IMERSIV experience during CAD evaluation. It is easy to use thanks to HTC VIVE technology already proven in the civil field. In addition, it allows the ergonomist to have sufficient room to manoeuvre, which can then influence the usage environment and the characteristics of the user with regard to the military culture of which he is aware and the needs of each system.

With regard to the purpose of the tool, Burkhardt (2003) also explains the contributions of virtual reality in the field of design. Defense ergonomists use IMERSIV to deal with subjects such as: accessibility to controls, comfort / discomfort zones, dimensions of means of access and evacuation, spaces dedicated to different payloads, the field of vision, etc.

The means is used by ergonomists to assess and refine the solutions proposed by the manufacturer in collaboration with staff representative of end users before working on a scale 1 model which is more time-consuming and therefore less inclined to iteration than the digital model.

IMERSIV allows increased reactivity, a possibility of expertise in the upstream phases of the project and the collection of verbatims from users during the manipulations due to the quality of the immersion.

Although our immersion tool is already satisfactory for all the reasons noted above, it is set to evolve to allow us to further improve the user experience. It is thus planned to implement a bodytracking allowing the representation of the whole body of the user; to acquire new headsets to run scenarios with several operators or to exploit the 3D spatial audio capacity of the headset to perfect the user's perceptual, proprioceptive and mnemonic judgments.

ACKNOWLEDGMENTS

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[4] SCORPION : A program to renew and modernize the army’s combat capabilities.

Testing Kinetosis in XR environments

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Keywords: Virtual Reality – Locomotion – Kinetosis – Motion Sickness – VR Learning – Education – 3D Interaction

Abstract

Virtual 3D worlds are not only used for the visualization of complex learning matter, but get increasing importance in learning environments. Students for example act as avatars in an artificially generated world, in which they learn, develop, and present similarly. However, in our 3D lectures as well in educational computer games some of the learners suffered from motion sickness (kinetosis), an affect that is already known (in conventional 3D applications).

In our project ‘Kinetosis’ (motion sickness) we will examine the causes and the indications of a beginning motion sickness. In order to identify the triggers, we implement appropriate 3D worlds as test settings, for example buildings, computer games, or a virtual rollercoaster.

Our vision is to adapt the virtual environment by detecting kinetosis symptoms of the individuals.

1. Kinetosis: Causes, Symptoms and Counteractions (VR)

1.1. Causes of Kinetosis and Symptoms

The causes for kinetosis are not yet fully understood, but there exist some explanatory approaches.

For example, typical theories to explain motion sickness can be found in the meta-study of Previc [Previc, F.H., 2018], where (among others) the *Sensory conflict theory,* the *Postural instability theory* [Ricco, G, and Stoffregen, Th. 1991], the *Subjective Verticular Mismatch Theory*, and the *Poison Theory*: [Money K.E., and Lackner, Cheung, R.S.K 1996] are depicted. There exist some other theories, for example the *Velocity storage theory*, and the *Otolith asymmetry theory* [Baumgarten, R.J. von, and Thumler, R. 1997].

The symptoms of kinetosis can be dizziness, headache, nausea or general discomfort.

1.2. Counteractions

There exist some approaches to minimize the occurrence of kinetosis. We will present a small selection of these. The limitation of the field of view (*FOV*) is helpful; especially there should be no movement in the periphery area. This is particular effective, if the rim of the surrounding frame is smooth [Evarts, H. (2016)]. One use of the idea using frames is described in section 3.3.

Rotations are often critical. Due to minimize motion sickness, sometimes black pictures are integrated in a rotation animation, similar to teleportation. This effect can be combined with a rotation, where the viewing direction is successively changed in different degree adjustments, for example 0°, 15°, 30°, 45°, etc.

Often, a fix point is useful for a better orientation. For example, this can be a virtual nose [Whittinghall, D, Ziegler B, Case T, and Moore, B. (2015)], a cockpit or the contour of a helmet.

2. Test Environment for Kinetosis in VR

2.1. Overview

We have built VR environments, in which students can test the occurrence of symptoms of kinetosis. We will present some of these projects, each regarding the aims of the specific application and the results of the evaluations: Test environment for motion sickness (section 2.2) and Kinetosis analyzation using eye tracking (rest frame theory; section 2.3).

2.2. Test environment for motion sickness

In order to create a test environment, we mainly focused on two questions: What are the triggers for motion sickness in VR applications? Which methods can reduce motion sickness?

Based on these questions, we have identified a number of measures that we believe may prevent motion sickness: Scale of the virtual world (with big objects, that are far away, even fast velocities are barely noticeable); using fix points (objects, that are always static, for example a virtual nose); distracting (from the movement) for example by doing cognitive tasks like solving math problems); rotations are performed step by step in contrast to a smooth rotation.

Considering this, we have created a test scene with seven parts, in which the movement is gradually increased, simultaneously the users influence to control the environment will be limited. Figure 3 shows the transition from an elevator trip to linear movement.

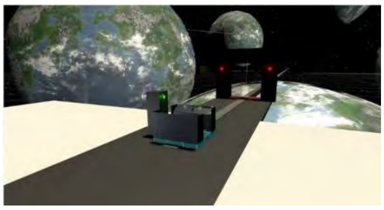

Figure 1: test scene, part 3

Some findings are:

- Fixed points should be provided in order to allow the player to orientate himself.
- Distraction (in our case answering simple questions) of the player could be helpful, but is not suitable for every situation.
- Some persons react very sensitively to rotations that are not self-induced. To prevent them from getting sick, it is useful to make the rotation as fast as possible and, most important, without acceleration. In our case, changing the direction was performed ‘abruptly’ – without ease in/ ease out.
- The virtual world should be very responsive so that every movement the player performs in the real world is represented immediately. Also it is very important that the movement of the player is always possible and is not blocked in any way.

2.3. Kinetosis analyzation with eye tracking

One possibility to recognize kinetosis in VR, is using the so-called rest frame theory [Prothero, J. D. (1998)]. Basically, the theory states that human beings are looking for fixed points in order to maintain their equilibrium. We have used a head mounted display including eye tracking to collect the data of our subjects. The data indicates that it is indeed possible to measure the occurrence of kinetosis in the virtual space with eye tracking data. [Deuser, F, Schieber, H., and Lecon, C. (2019)].

As a test environment, we have performed a ride through a virtual computer – without any fix point.

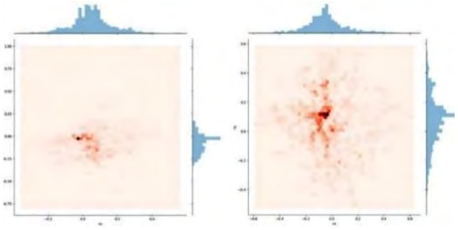

Figure 2: heatmap (rest frame theory)

The heatmap (figure 2) shows the difference eye movements of the subjects: left one can see only little eye movement: the person shows no indication of motion sickness (verified by the questionnaire). Right there is a heavy movement of the eyes: the subject is constantly looking for a fix point, which in our case was unsuccessfully.
In another experiment we could confirm the assumption that symptoms of kinetosis reflect in an increasing heart rate, the oxygen saturation seems not to play a role [Yimer, M., Schlette, V. (2019)].

2.4. General Results

There exist many procedures to minimize the occurrence of kinetosis in VR applications (see for example [Lecon, C. (2018)]). When realizing a VR application, this should be taken into consideration. However, everyone reacts differently on movements of the virtual camera in the 3D world. The findings of the chapter 2 show, that there are some possibilities to get information about a (beginning) kinetosis by using adequate sensors (eye tracking, heart rate, sweating, etc.). In order to refine the sensor´s input and to improve the prediction of the occurrence of kinetosis, we are going to use more sensors. For this, we have implemented a sensor management system. Based on the measured values, an indicator for a probable kinetosis is calculated; if this is the case, a signal is send to the VR application – which in turn can adapt accordingly.

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Touch-Aware Agent: Challenges of Social Touch in Virtual Reality

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Keywords: Virtual Embodied Conversational Agent – Immersive Room – Haptic Interface – Social Touch – Decision Model

Abstract

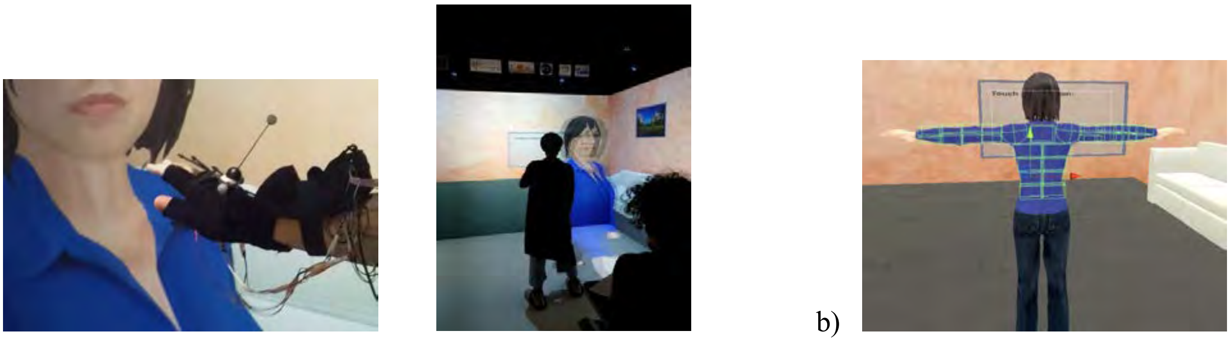
This poster introduces the specific challenges of touch-based interactions with a virtual embodied conversational agent (ECA) in an immersive room environment. When designing a fully functional interactive loop between virtual ECA and human user, three main areas of difficulty can be identified: building a sense of touch for the agent, giving him some kind of decision model and designing suitable social haptic display for the human. Ongoing work aims at exploring some possible solutions, from a virtual sense of touch without tangible interface to a design of haptic patterns suited for social touch.

1. The Specific Challenges of a Social Touch-based Interactive Loop

Embodied conversational agents (ECAs) already have been given the abilities to use verbal and non-verbal behaviors to bond, communicate emotions and build rapport with a human (Gratch, Wang, Gerten, et al., 2007), and social touch has a lot of importance in the process of human bonding (Chatel-Goldman et al., 2014), and is a communication modality able to express emotions, even on its own (Hertenstein et al., 2009; Hauser et al., 2019). Thus, it would seem beneficial to try and build touching ECAs, able to use and take touch into account when interacting with a human. Immersive environments seem like prime candidates for the implementation of such agents, by making their bodies able to come in actual visual contact with the bodies of human, without having to deal with all the other specific challenges of robotics. Such virtual humans taking touch into account are slowly becoming a field of research on their own right (Gijs Huisman, Bruijnes, et al., 2014), and the challenges they have to tackle include not only questions such as: how to make the human aware of the touch of the agent? But also questions as: how is the agent going to be able to perceive the touch performed by the human? What kind of haptic patterns could be considered and understood as actual affective or social touches? How can an agent decide when to touch and which kind of touch to perform at a specific point of the interaction?

2. To Perceive: a Virtual Sense of Touch

The situation of an immersive room seems very appropriate for social touch because it allows the human to interact with a room-scale virtual environment while retaining his ability to see his own body and gestures. However, it makes it difficult to bring tangible equipment inside the room, as it can break the stereoscopic 3D that is being directly projected on the walls, and, with it, the sense of immersion and presence. So is it even possible to build a sense of touch for an agent without having anything to actually touch ? That is the question to which the work on virtual agent Max (Nguyen et al., 2007) tried to bring a first answer by covering the agent's 3D model is covered with flat quadrangle geometries that act as a virtual skin with which collisions with other virtual or tracked objects can be detected. This allows discriminating between touch and no touch, and to determine the place where the body is touched, as well as for how long. However, the immateriality of the agent still makes it impossible to evaluate any measure of pressure on it, and precision of the detection relies on the resolution (number and size) of the geometries. We thus created our own "tactile cells" and changed the way the collision is detected in order to avoid any kind of problem related to the resolution of the grid. Our tactile cells now allow us to determine via local coordinates where the touch is happening on the cell itself. Following the principle of the god-object method, we also introduced to have some kind of measure of the pressure exerted on the agent by the human (Zilles & Salisbury, 1995).



a) b)

Figure 1. a) Human user interacting with a virtual ECA inside an immersive room. b) Grid of the tactile cells

3. Decision Model: When and How to Touch?

For the agent to be able to adapt his behavior based on what he perceives from the touch of the human, he needs some kind of model that can allow him to reason and take decisions on what to do. Since touch and emotion are closely related, and social touch is especially often overlapping with affective touch while mostly happening in intimate or emotional context, we believe that computational models of emotion (Ong et al., 2019) would be the prime candidates for the decision model of a touching agent. Computational models of emotion (CME) allow for the generation of an emotional state for the agent based on the events that it perceives and how those impact the agent's beliefs and goals. CMEs are usually based on the cognitive appraisal theories. In those theories, emotions are generated based on the appraisal (cognitive evaluation) of an event happening to an individual (Scherer, 2009). This individual is going to evaluate how this event might influence his goals (will it help the fulfillment of his goals?) and how this event scores on certain variables (for example, valence, or desirability for others). They have made for very convenient and powerful fundamental basis for CMEs that have since produced very interesting results when it comes to generating believable emotional behaviors (Ong et al., 2019). Such models would be able to take the emotional context into account to refine the interpretation of the touches perceived by the agent. This would in turn allow the agent to choose a context-appropriate touch type to perform back on the human.

4. Haptic Feedback for the Generation of Social Touch

Force-feedback devices allow us to feel the resistance of objects, air blowing gives the sensation of a moving touch, pneumatic devices give us a way to experience pressure, heat and cold can be produced, vibrotactile devices are easy to setup and can have interesting sensations,… (G. Huisman, 2017; Teyssier et al., 2017). Despite all those technologies, there is still no perfect way to reproduce an actual touch sensation. Combining all those technologies is not an easy task and it is often necessary to chose one instead of another. Based on this realization we chose to work on the design of a haptic sleeve using voice coils as vibration motors. Our aim in the design of this device was to achieve a lightweight, easily worn prototype able to produce recognizable social haptic patterns for a human to understand and interpret. We combined a 2x4 grid of actuators with an implementation of the Tactile Brush algorithm (Israr & Poupyrev, 2011) to allow us to produce recognizable and believable apparent continuous motion on the arm and studied the social and affective touch literature to determine which touch types we could try to implement as vibrotactile patterns. Vibrotactile devices however do not enable the rendering of kinesthetic sensations, like the feeling of weight or pressure, nor temperatures, which made some touch types impossible to imitate (grabbing, shaking, pushing for example). In the end, based on their abilities to express multiple types of emotions and their very distinct characteristics in terms of durations, motion and intensity, as evidenced from the literature on social touch between humans (Hertenstein et al., 2009), we selected four types of touch to imitate with our haptic sleeve: hit, pat (or tap), simple contact and stroke (or caress).

5. Conclusion

Through the presentation of our ongoing work on an integrated system for a touching agent, we hope to have shown one possible way of tackling the challenges of designing social touch interactions between a human and a virtual agent. Our system involves a virtual sense of touch without tangible interface (perception) and an easy to wear vibrotactile sleeve (haptic feedback), as well as a decision model based on computational models of emotion (decision). This system has yet to be evaluated, but already gives some pointers on how to design a truly touching agent.

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Enhance VR: an multisensory approach to cognitive assessment and training

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Keywords: Cognitive Training – Cognitive Assessment – Virtual Reality – Enhance VR

1. Abstract

Cognitive training systems aim to improve specific cognitive domains or global cognition, by engaging users in cognitively demanding tasks. While improvement has been shown using screen-based applications, these are often criticized for their poor transferability to daily-life tasks. These systems, however, exclude the user's body and motor skills. In contrast, Virtual Reality (VR) systems present the user with body-related information, such as proprioceptive or visuomotor information, allowing for an immersive and embodied experience of the environment. This feature makes virtual environments a very appealing tool in cognitive training and neurorehabilitation. Enhance (Virtuleap, 2019) is a VR-based cognitive training and assessment application. It offers short daily workouts of immersive games designed to train and assess specific cognitive domains. The aim is to test whether cognitively demanding tasks, presented in a VR scenario, provide a naturalistic system to assess and train cognitive capabilities.

2. Cognitive Training

Cognitive abilities deteriorate across the lifespan of an individual (Anguera et al., 2013, Clapp et al., 2011, Park et al., 2002). Furthermore, this cognitive decline is worsened by the presence of neuropathological conditions, such as dementia, Mild Cognitive Impairment (MCI), Alzheimer 's disease (AD) (Villemagne et al., 2013), among many others. As the senior population continues to grow, cognitive training could become an interesting tool to assess and potentially maintain effective cognitive functioning.

Cognitive training systems aim to improve or maintain specific cognitive processes or global cognitive abilities (Simon et al., 2012). Screen-based cognitive training systems have shown cognitive improvement, however, it is mainly restricted to the specifically trained domains and does not show transferability to real-world tasks (Ball et al., 2002). Additionally, they also seem to be unfruitful when compared to traditional pen-and-paper methods, such as solving crossword puzzles (Owen et al., 2010) or playing active video games (Kable et al., 2017), which have also shown cognitive improvement (Stanmore et al., 2017).

3. Virtual Reality (VR)

Human cognition has been proposed to be related to sensorimotor processing and the interaction with the physical environment (Wilson, 2002). While screen-based systems fail to provide body-related sensory information (e.g. proprioception), VR systems allow for the integration of multiple sources of sensory information (Sanchez-Vivesand Slater, 2005). These sources of sensory information extend, but are not restricted, to proprioception, interoception, vestibular, and visuomotor information (Matamala-Gomez et al., 2019, Perez-Marcos et al., 2018, Kilteni et al., 2015). Thus, enabling a stronger sensory immersion that promotes higher cognitive processing and learning (Bailenson et al., 2008, Gamito et al., 2011, Coughlan et al., 2019, Krokos et al., 2019).

Additionally, the integration of multiple sources of sensory information creates and constantly updates the representation of the body in the brain (Gallagher, 2006), which is crucial for interaction with the environment. Thus, the use of VR systems promotes an embodied experience of the environment. Providing the possibility to present the subjects with ecologically valid environment scenarios that allow precise control over the experimental variables (Bohil et al., 2011, Parsons, 2015).

4. Enhance VR cognitive training app

The Enhance VR (Virtuleap, 2019) app offers daily, short (~10 minutes/session), and cognitively demanding workouts. It takes advantage of the multisensory experience of VR environments to assess and train specific cognitive areas, by engaging not only the visual and auditory systems, but also providing visuomotor and vestibular information.

Each daily session consists of three games, whereby each game is designed to assess performance in a specific cognitive area, such as the ones presented in the following sections. The players progress through the levels as their performance improves, which in turn increases the difficulty of the game. The games showcased in Enhance VR have been designed keeping in mind already existing validated cognitive assessment tests. Furthermore, each player can track their performance by means of their respective user index score, a combined score for all cognitive abilities, and compare their individual user index score to a population-normalized score.

4.1. React, a categorization game for cognitive flexibility

React is a categorization game designed to assess task switching and response inhibition. React is inspired by the Wisconsin Card Sorting Test (Grant and Berg, 1948) and the Stroop task (Stroop, 1935), which are used to assess task switching, the ability to shift between two or more stimuli according to situational demands, and response inhibition, the ability to suppress a predominant response. In React, the player classifies a stream of approaching stimuli into two categories, represented as portals, by swinging the paddles in their hands. As the game progresses, distractor shapes are introduced that the participants need to ignore.

4.2. Memory Wall, a memory game for short-term memory

Memory Wall is a memorization game primarily motivated by the Visual Patterns Test (VPT) (Della Sala et al., 1997). The VPT has been used to assess short-term memory, the temporary storage of a limited number of items. Similarly, Memory Wall requires the subject to reproduce a pattern previously shown on an n-by-n grid of cubes (where n is determined by the level). A number of the cubes light up creating a pattern to be memorized by the player and subsequently reconstructed using the input device. The difficulty of the task increases by increasing the size of the grid and the number of cubes that compose the pattern.

4.3. Hide and Seek, an auditory spatial orientation and selective attention game

Hide and Seek aims to train auditory spatial localization, the ability to localize the origin of a sound, and selective attention, the ability to direct attention to one auditory object sound while ignoring the rest. Auditory selective attention can be assessed by methods that require the discrimination of a target sound (e.g. a list of words) among competing messages, such as the Selective Auditory Attention Test (Chermak and Montgomery, 1992). In Hide and Seek, the user is presented with a binaural environment, whereby a dynamic high-pitched discrete sound is presented in a single location, which the participant has to localise in the immediate environment. The presence of distractor sounds difficults the localization and discrimination of the target sound.

5. Research Motivation

Together with a healthy diet and physical activity, cognitive training has been proposed to help prevent cognitive decline (Klimova et al., 2017). We expect that, after repeated exposure to the Enhance VR games, the participants would increase their performance in the domains that are being specifically targeted by the games. Thus, our aim is to track the performance on different cognitive domains, both in healthy and in the clinical populations.

However, screen-based cognitive training systems have failed to show transfer of benefits to everyday activities (Ball et al., 2002). While these systems lack body-related information, VR systems provide proprioceptive, vestibular and motor information. We aim to test whether, by engaging the sensorimotor system (Sanchez-Vives and Slater, 2005), cognitive training in VR improves transferability into daily-life tasks compared to two-dimensional or paper-based equivalents (Hertzog et al., 2008).

Traditional cognitive assessment tests and specialized videogames have been proven effective to evaluate separate cognitive areas, as well as global cognitive function (Anguera et al., 2013, Coughlan et al., 2019, Strauss et al., 2006) and detect neuropsychological deficits, such as cognitive cognitive impairment (Folstein et al., 1975). We propose that the VR versions of the cognitive assessment tests, such the ones Enhance VR games are inspired on, could provide a more naturalistic approach for the measurement of the cognitive capabilities (Slater and Sanchez-Vives, 2016). We aim to validate the Enhance VR app as a potential cognitive assessment tool, by testing efficacy of the games compared to already existing cognitive assessment tests.

Additionally, cognitive testing has proven to be an effective non-invasive approach to cognitive assessment (Fernandez Montenegro and Argyriou, 2017). Thus, using the collected data, combined with supervised machine learning algorithms, we aim to find non-invasive behavioural markers of neurological disease progression that potentially could support the early diagnosis of cognitive decline.

6. Conclusions

Screen-based cognitive training systems have failed to show improvements beyond the domain specifically targeted by the task. However, these systems do not provide body-related information, such as proprioceptive or visuomotor information. VR systems, on the other hand, present the user with a multisensory environment, resulting in an immersive and embodied experience. By taking advantage of this feature, the Enhance VR app aims to assess and train cognitive functions by means of cognitively demanding immersive games. The presentation of seemingly naturalistic environments could provide an advantage over screen-based systems, whereby VR can become a validated tool for cognitive assessment and training.

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An *in virtuo* system linking data corpus to 3D virtual model for industry 4.0

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Abstract

This poster deals with the possibilities offered by *in virtuo* consultation - during sessions of virtual reality immersion - of information related to the visualized environment contained in a database. First, we show the architecture of the system and how it allows us to develop a three-dimensional model and a knowledge base separately. Our use case explores the industrial possibilities of such a solution in the context of industry 4.0, allowing to contextualize the information resulting from high-speed machining monitoring.

This tool would make the use of virtual reality immersion in design or reverse engineering more effective by making data associated with a 3D model accessible at the appropriate time.

1. Introduction

In the fields of product design, reverse engineering or restitution, digital 3D modeling tools have become in many ways completely unavoidable. In recent years, virtual reality immersion has reinforced the use of 3D by allowing the virtual experimentation of study objects during their design phase [1] or as an end in itself for all types of audiences [2]. In order to democratize the use of immersive 3D in areas where the data related to a three-dimensional model have a decisive influence on the very interest of the model, our main objective was to allow access to these metadata *in virtuo*.

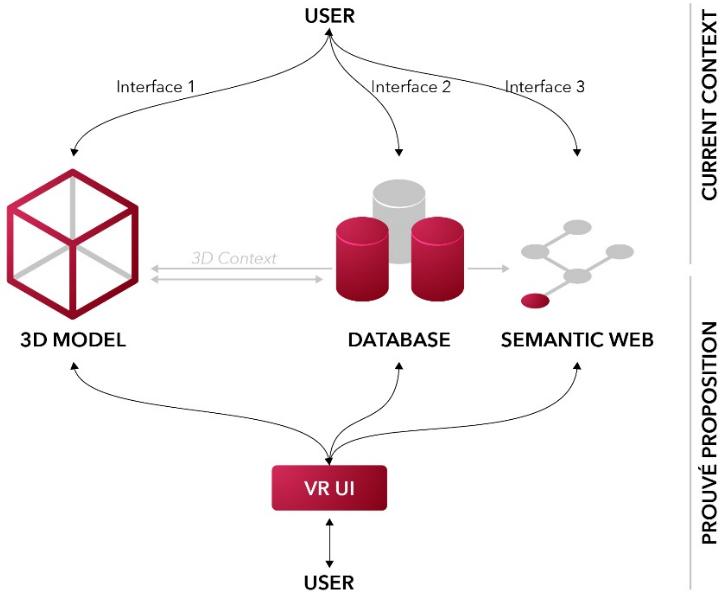

Fig. 1. Current situation regarding the different data and proposal.

Immersive interfaces are used, as previously stated, in many fields where the data processed is highly spatial or geometric. Mechanical design or architecture can therefore easily make use of immersion without having to go through abstract representations of their data. In these fields too, geometric coherence or three-dimensional aspect are the data that take precedence over others: we try to test in virtual reality the coherence of a three-dimensional model in itself. The approach we propose is hybrid since it focuses on the visualization of highly spatial data (a 3D model) - for which the immersion visit is naturally adapted - and data related to this virtual model, which can be of various formats and rather resemble a decision tree [3]. The data manipulated are on the one hand of the text, image, sound, data, graphics, etc. type and are stored in a database with metadata; and on the other hand of the "link" type between several items in a database or between an item and an object in virtual reality.

The main hypothesis we formulate is that the spatial positioning of the information and the link between it and the three-dimensional model makes it possible to judge more effectively the relevance of design choices or hypotheses. In addition, such a visualization would reveal logics related to the spatial distribution of information.

2. Development for industry 4.0

Virtual Reality allow the visualization and modelization of the business processes and products to be manufactured or maintained. Thus, it provides great operational benefits: on the one hand, virtual reality could facilitate and improve learning, and on the other hand, it could facilitate interactions between industrial production chains and their computerized management systems. Thanks to early modelling and immersion tests, all the production space can be optimally used, while the use of these technologies also makes it possible to predict maintenance or after-sales service needs [4]. Two research projects are collaborating to integrate virtual reality technologies into the production industry. The development requires a global knowledge base structured in the form of ontology, gathering all the data and knowledge circulating in the industry [5]. Moreover, through the tools of machining monitoring, we capitalize on all the data necessary to detect the appearance of a malicious phenomenon during machining: chattering, tool breakage, etc.

The aim of the proposal is to provide support for the various actors in the industry in order to better understand the design process and all its potential defects while remaining in a connected, accessible and easy to handle world: the immersion in virtual reality.

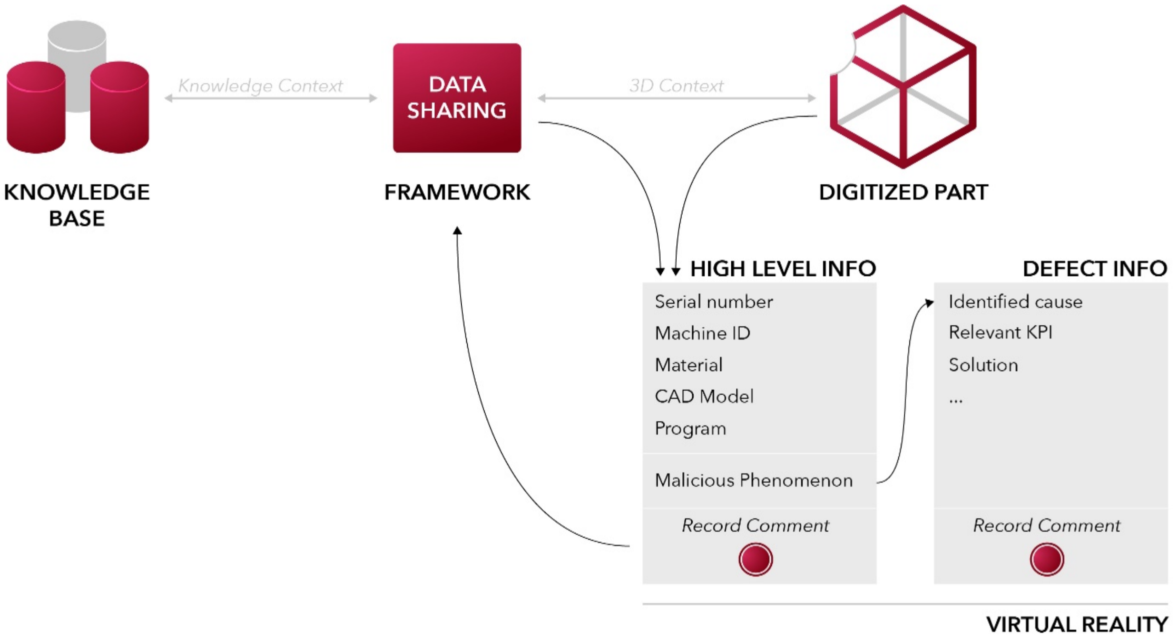

Figure 2: Framework concept to exploit ontologies using virtual reality technologies.

Figure 2 details the principle of our scientific proposal to develop a framework that allows a new way of exploiting ontologies using virtual reality technologies. The challenge is being able to recover all the knowledge concerning a mechanical part in a given three-dimensional context (a part, a portion of a part, a defect) and which can be of a very different nature and type: product data, process, etc. The part in question may be a model or physical object identifiable by its serial number.

By using virtual reality immersion, a 3D digital copy of the part (either from the source CAD file or from a digitization), a digital twin, can be analyzed and put into its manufacturing context at the same time. The user is then able to easily consult all the knowledge and KPIs (Key Performance Indicators) concerning a specific part. In addition, the user can also hierarchically access all the knowledge of the database related to the part (type of machine, details of a machine, etc.). In the example of a defect, it is therefore possible to access the details of the occurrence of a malicious phenomenon during the machining of the part (a chattering, a tool failure, a collision, etc.) and to know its causes and solutions.

Another very important aspect that this system can cover is the possibility of commenting on your immersive experience, and communicating a diagnosis, some remarks or suggestions for improvement or even preventive solutions to deal with the appearance of a given phenomenon. These comments, in audio or text form after automatic transcription, could be reintegrated directly into the ontology and can therefore enrich the overall knowledge base.

This immersion experience and its integration into the industrial environment would thus increase competitiveness and improve productivity from the design phase.

3. Conclusions and perspective

In this paper, we have presented a virtual reality tool allowing the in virtuo consultation of relational and spatialized data. This tool allows users to work more efficiently in virtual reality immersion by adding interactive levels of information to visible and manipulable objects. We have shown the interest of such a tool for two completely different use cases - heritage and industry 4.0 - although the same system must be adapted to meet the specific expectations of these domains and their existing professional tools.

Of course, the question arises of access with this system to non-spatialized data. Indeed, we have insisted in this paper on the need to select a virtual object to display this information, but the design or reflection phase may require access to non-spatializable data (concepts, historical information, etc.). We are therefore convinced of the interest of developing a post-immersion experience in which other interactions would be possible.

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