WORTECS

H2020-ICT-2016-2
RIA

Project-ID: 761329
WORTECS
Networking research beyond 5G

Deliverable 4.4

Users' test acceptance

Contractual Date of Delivery:	**2019, Novembre 30th**
Actual Date of Delivery:	**2019, December 10th**
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Work package:	**WP4**
Security:	**PU**
Nature:	**Deliverable**
Version:	**version 0.3**
Total number of pages:	43

Abstract

This deliverable studies the impact of the technological choices made on the first demonstrator on the user experiment. It present the results of tens of users that experiment the system in various conditions, in order to "quantify" the degradation this demo setup introduces compared to the reference VR setup.

Keyword list

Virtual Reality, High Quality / Low Latency, Multi-gigabit, Terahertz, Baseband processor, Wireless, OWC, FWF, radio transmission, MAC Layer, HW implementation

Executive Summary

This task focuses on the user experiments degradation when using the wireless transmission system defined for the demonstrator v1. As a reminder, the overall latency introduced by the video conversion on both server and user side, plus the latency of the wireless transmitter and the heterogeneous switch must be smaller than 3ms.

In this document, tens of user performed some tests with different set up configurations and theirs feedback allow to "quantify" the impact of this demonstrator on the user experiments.

Some conclusion gives the impact of the technological choices that have to be done, and plan the futures test that should be realised on the next demonstration.

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Document History

First name	Last name	Version	Comments
Nico	Pallamin	2019 - Nov 29th	First draft
Guillaume	Vercasson	2019 - Dec 05th	Prototype description

List of Acronyms

Acronym	Meaning
Eth	Ethernet Protocol
FWF	Fibre Without Fibre
HDMI	High-Definition Multimedia Interface
HMD	Head Mounted Displays
IP	Internet Protocol
IPQ	Igroup Presence Questionnaire
ITU	International Telecommunication Union
JQVIM	Joint Qualinet and VQEG team on Immersive Media
Mbps	Megabits per second
OWC	Optical Wireless Communications
RF	Radio Frequency
SSQ	Simulation Sickness Questionnaire
SUS questionnaire	Slater-Usoh-Steed questionnaire
UQO	Université du Québec en Outaouais
VAE	Virtual Arctic Expedition
VQEG	Video Quality Experts Group
VR	Virtual Reality
WORTECS	Wireless Optical/Radio TErabit CommunicationS

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1. Introduction

The WORTECS project aims to deliver ultra-high data rate wireless combining high frequency (above 90GHz) radio communication with optical wireless communications using novel heterogeneous networking concepts. A typical virtual reality setup is used to demonstrate such a high throughput and low latency transmission system. The high definition of the next generation head mounted display drives a huge amount of data that should be transferred from the computer to the head set. Usually, such a video data throughput is reduced with very efficiency video encoder but in the special case of VR set up, the latency introduced by this compression algorithm is not allowed. By the way, only low latency compression could be used, resulting in a small compression rate.

The first WORTECS prototype is composed of a video converter (to adapt video signal from HDMI standard to IP one), a compression algorithm to adapt the video throughput to the wireless link capability, three wireless transmission link and a heterogeneous network that selects the best link at a time.

On this first user evaluation of the WORTECS technologies, we will focus on the impact of the integration of two elements; the latency and the video quality. The latency will be introduced by both the video compression/un-compression phases and the wireless transmission. The quality will be mainly impacted by the compression/un-compression phase.

Considering that wireless transmission links have small latency (almost zero for the FWF), and that some connection loss could append if the user is sometimes not in good transmission condition, it appears that it would be difficult to extract from the user' test acceptance results the part of troubles due to the connection loss from the part due to the latency or event to the quality degradation.

Consequently, for the first user 'test acceptance, the wireless transmission will not be integrated in the test set up, only video conversion and compression will be considered, and an optical fibre link would replace the wireless link. By the way, it could be easier to quantify how the quality or the latency (only of the video converter) would impact the user experience in virtual reality.

The video converter and the compression algorithm are two core elements of the WORTECS wireless set-up and will be present in the system regardless to the wireless technology that will be used.

The integration of these two elements in a conventional virtual reality set-up will add processing steps to the normal video flow. Such extra processing will obviously imply an increase (even if minimal) of the video transmission time and potentially some modifications in the video signal delivered to the virtual reality headset.

The aim of our study is to assess if these modifications (in time and nature of the video signal) are relevant enough to affect the user experience in the virtual environment. In particular we will focus our assessment of the user experience on the following three aspects: the innocuity of the system assessed via a virtual reality sickness questionnaire, the global quality of the experience assessed via a presence questionnaire and the visual quality of the experience assessed via a perceived quality questionnaire.

2. The WORTECS prototype of demo #1

In the demo #1, an end to end proof of concept has been proposed. All elements from the VR server to the HMD has been presented and linked together. Nevertheless, in order to clearly explain user' test results, the wireless link has not be included in the user 'test setup.

2.1 The user 'test set up

The setup is mainly composed of a VR server, a head mounted display, two video converters and a direct optical fibre between them. Here after, the presentation of the elements used in this set up is illustrated in Figure 1.

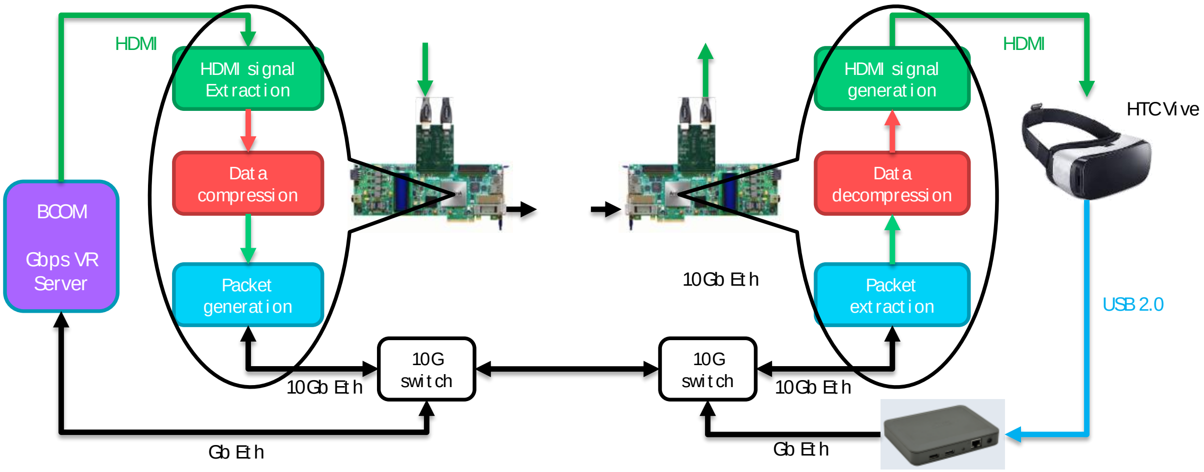


Figure 1: Demo #1 set up

On the VR side, the video converter deals with both uplink and downlink. The downlink is composed of the video format conversion from HDMI to 10G Eth, and the data throughput reduction. The uplink is composed of forwarding location information from the 10G Eth link to the VR server.

On the user side, the video converter also deals with both uplink and downlink. The downlink is composed of the video format conversion from 10G Eth to HDMI, and the data throughput expansion. The uplink is composed of forwarding location information from the HMD to the 10G Eth link.

2.1 Degradation contributor

Regarding the reaction time degradation (latency growth), the main contributor is the video throughput adaptation. The module used is a very low latency IP from a third party provider IntoPix. Their IP allow a compression factor that can vary from 1 (no compression) to 1/6.8 (maximum compression ratio), and the latency introduced by both compression and un-compression modules are approximatively the same whatever the compression ratio used. Other elements (signal extraction, 10G switch …) generate a deeply smaller latency.

Regarding the quality degradation, the only contributor is once more the video throughput adaptation. Effectively, all the other modules only modify the way the data are transferred, and never modify the data themselves.

2.1.1 Latency degradation

On Figure 2, the latency (in µs) introduced by the different functions of the video converter (up and down link) are presented.

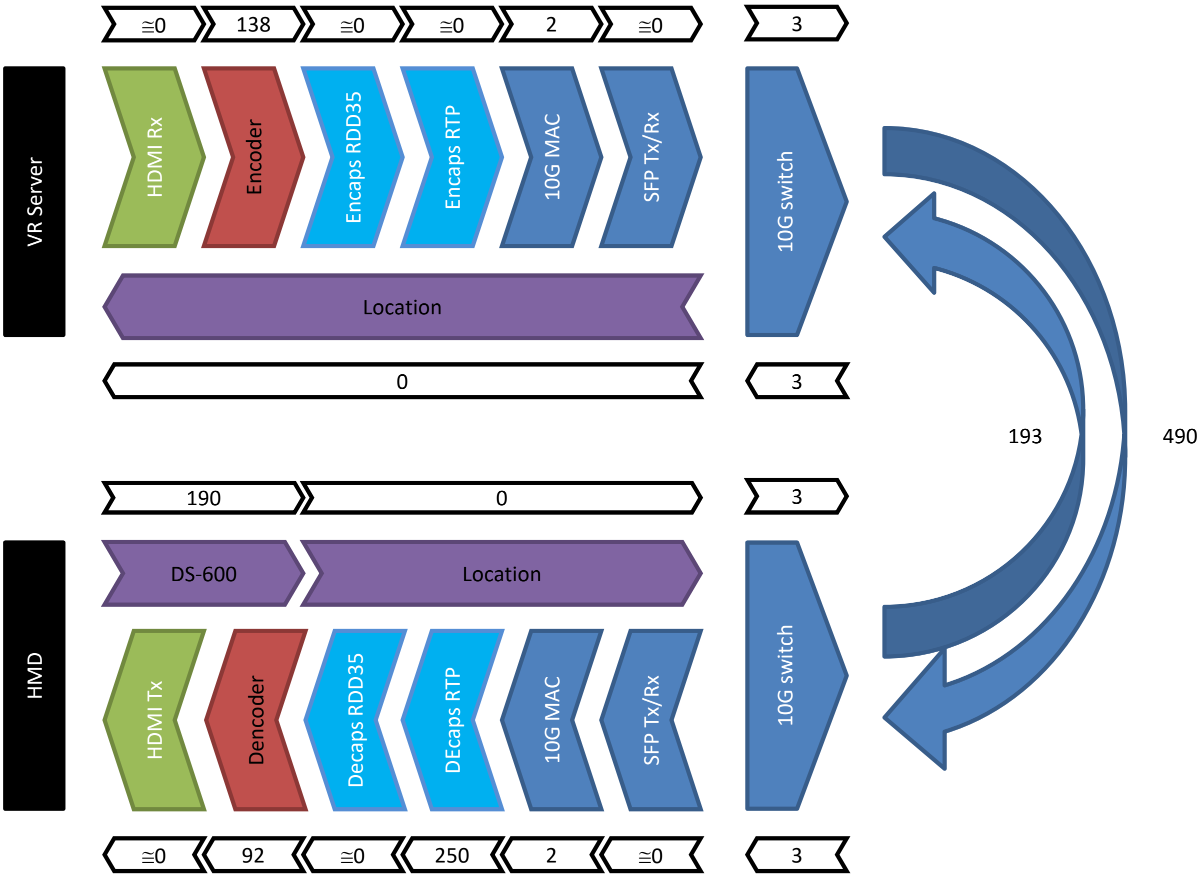


Figure 2: Demo #1 set up latency (in µs)

The overall latency added by the set up compared to a direct standard VR set up is **683µs**.

2.1.2 Quality degradation

On the demo #1 set up, the smallest wireless link throughput is about 1 Gbps. In order to fit in this data rate, and considering that the input video throughput is 5.57 Gbps, a compression rate of 1/6.8 has been used. It is the highest the IP can provide, and probably introduce some quality degradation as it removes some high frequency information on the incoming signal. The resulting data throughput becomes approximatively 860 Mbps (5.57 Gbps/6.8 + RDD/RTP header)

Additionally, to be able to isolate the degradation due to this high compression ratio, the smallest compression ratio is also available. By the way, using one or the other alternatively, keeping all the other elements of the design as it is, should provide a fair bench for quality degradation.

3. The quality of experience in Virtual Reality

The evaluation of a virtual environment could focus on different aspects of the user experience like the visual quality of the environment, the efficiency and reactivity of the chosen interfaces, the perceived realism of the scenes, the level of entertainment or the level of involvement of the user.
In the frame of the WORTECS project we focus our evaluation on the three following elements:

1. The innocuity of the system, assessed via a virtual reality sickness questionnaire.
2. The global quality of the experience, assessed via a presence questionnaire.
3. The visual quality assessed via a video quality and artefacts questionnaire.

The first aspect we decide to evaluate is the harmless of the WORTECS technology that we are developing. For this reason we decide to include in our experimental protocol a questionnaire to assess the virtual reality sickness.
The virtual reality sickness (VR sickness) is the feeling of discomfort that user can feel while experiencing virtual reality content. Such discomfort is often so intense to force the user to quit the virtual experience. Virtual reality sickness is recognized as one of the limiting factors to the massive diffusion of consumer grade VR devices.
According to some studies [1] virtual reality sickness could be induced by the lack of efficiency of the VR system (high-latency and low frame rates). Some authors [2] consider that the critical end-to-end (motion to photon) latency to reduce the insurgence of virtual reality sickness is 17 ms, but other authors [3] found this threshold to be even lower. In the frame of the WORTECS project is then important to assess that the adoption of the developed technologies do not increase in a significant way the latency of the VR system inducing a higher level of sickness in the participants.
The virtual reality sickness and the way to assess it will be presented more in detail in the section 3.1.

The second aspect we decide to evaluate is the fact that the introduction of the WORTECS technologies did not have a negative impact on the global user experience. For this reason we decide to include in our experimental protocol a questionnaire able to assess the user feeling of presence. Presence is the subjective feeling of the participant to be “really” inside the virtual environment and is often used as an indicator of the global quality of the user experience. The feeling of presence is multidimensional and could be negatively affected by the presence of visual artefacts or lack of reactivity in the system. Including the assessment of the feeling of presence in our protocol allow us to verify that the technologies developed in the WORTECS project do not impact negatively in the user experience.
The feeling of presence and its assessment methods will be presented in the section 3.2.

The third and last aspect of the user experience that we decide to assess is the perceived video quality. These last assessment focuses on the impacts of the two tested technologies (the video converter and the compression algorithm) have on the user visual perception. While the first two assessments concerned general aspects of the user experience, this last evaluation focus specifically on those aspects that are more probably affected by the tested technologies. The video converter and the compression algorithms in fact could degrade the quality and introduce processing artefacts in the video signal. The aim of this last evaluation is to assess if the inclusion of the WORTECS bricks induce any degradation of the visual quality of the virtual experience detectable by the participants.
The perceived visual quality and the related assessment method are presented in the section 3.3.

3.1 The virtual reality sickness (VR sickness)

Virtual Reality (VR) sickness (also known as simulation sickness or cybersickness), like sea-sickness or car-sickness, is a sub-category of that generic discomfort known as motion sickness. VR sickness can be simply defined as the feeling of discomfort (similar to motion sickness) that could occur while experiencing virtual reality contents [4]. VR sickness can affect between 50 and 80 % of the population depending on virtual content and it’s presentation [5].
Several theories have been proposed to explain the causes of motion sickness (and VR sickness). Some of these theories are: the poison theory [6], the postural instability theory [7], the rest frame theory [8] [9] and the sensory conflict theory [10].
The most widely accepted of these theories is the sensory conflict theory. According to this theory, VR sickness is the result of conflicts and inconsistency between the different sensorial information sent to the brain when the user explores the virtual world. Usually this conflict is a discrepancy between the motion information coming from two separate sensorial systems: the vestibular system (located in the inner ear) and visual system [11].

This conflict, illustrated in Figure 3, occurs when the motion is perceived by the visual system (i.e., central nervous system related to the process of visual details) without the stimulation of the associated vestibular system (i.e., sensory system related to the sense of balance, self-motion and spatial orientation).
This discrepancy will be detected by the brain and will induce, within sensitive participants, the symptoms of VR sickness [12].

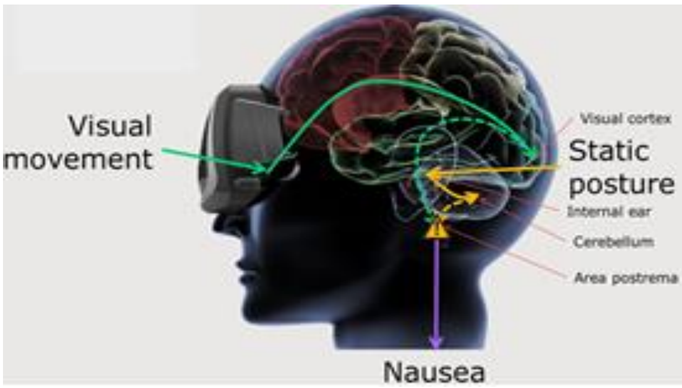


Figure 3: Conflictual motion stimuli during VR session

The most commons and detrimental symptoms of VR sickness are nausea and vomiting. Other symptoms like headache, disorientation and eye strain can occur [13].
The intensity as well as the duration of the symptoms is quite variable but often the discomfort induced by the VR sickness is so intense that the participant decides to interrupt the virtual experience. In the majority of cases, the symptoms disappear some minutes after the end of the stimulation however, some users may experience symptoms several hours after the VR experience [14].

3.1.1 The assessment of the virtual reality sickness

The most common way to assess VR sickness is based on the adoption of questionnaire.
In the case of our evaluation we decided to use the French version of the Simulation Sickness Questionnaire (SSQ) originally developed by Kennedy [15].

The SSQ is the most widely used questionnaire to assess the VR sickness. It is constituted by 16 questions to assess the severity of the symptoms using a 4 steps Likert scale with value ranging from “None” (absence of the symptoms) to “Severe” (highest intensity of the symptoms) as illustrate in Figure 4.

General discomfort	None	Slight	Moderate	Severe
Fatigue	None	Slight	Moderate	Severe
Headache	None	Slight	Moderate	Severe
Eye strain	None	Slight	Moderate	Severe

Figure 4: Sample of the SSQ questions and scale

In the recent version of the questionnaire the 16 questions are congregated in 2 groups corresponding to the two main categories of symptoms (nausea and disorientation/ocular fatigue). As a consequence the analysis of the SSQ questionnaire produce two SSQ partial scores (one for the nausea and one for the disorientation/ocular fatigue) as well as a global score obtained considering all the questions.
The SSQ questionnaire has the goal to assess the impact of the virtual reality experience in the user comfort. As a consequence the questionnaire has to be fulfilled by the participants 2 times: one immediately before and one immediately after the virtual experience. The answers obtained before the experience will serve as baseline to estimate the effect of the virtual reality on the variation of the symptoms. The questionnaire fulfilled before the virtual experience serve for instance to detect if a participant suffers from a headache or a visual fatigue before starting the experience.
For our evaluation we adopted the French version of the SSQ translated and validated by the laboratory of cyber-psychology of the “Université du Québec en Outaouais” (UQO) [16].
A copy of the used questionnaire is present in the Annex A (§7.1).

3.2 The feeling of presence

A concept often encountered in the researches investigating the user experience in virtual reality is the concept of “Presence”. The feeling of presence is defined as “a state of consciousness”, the psychological sense of being in the virtual environment [17], or , using the words of Witmer and Singer “the subjective experience of being in one place or environment, even when one is physically situated in another” [18].

The concept of presence is often used as a generic indicator of the quality of the virtual environment. The feeling of presence is in fact influenced by a multitude of aspects of the virtual experience like for instance:

- The ability of the system to react in realistic ways to the actions performed by the participant
- The coherence and synchronicity of the information presented to the user
- The visual realism of the perceived media
- The general reactivity of the system
- The physical comfort of the device adopted
- The ergonomics of the interfaces
- The naturality of the interactions

In the frame of the evaluation of the WORTECS project, the assessment of the feeling of presence could measure the general impact of the developed technologies on the user experience. In fact, an increase in latency, sensitive variations of the image frame rates or compression artefacts induced by the introduction of the video converter could drastically impact the user experience.

3.2.1 The assessment of the feeling of presence

The most common way to assess the feeling of presence is via questionnaires.
Various questionnaires have been developed to assess the feeling of presence, like for instance the Presence Questionnaire [19] or the Slater-Usoh-Steed (SUS) questionnaire [20].
For our evaluation we decide to adopt the The Igroup Presence Questionnaire (IPQ)[21].
The IPQ is one of the most popular questionnaires to assess the feeling of presence. It includes questions originally introduced in others presence questionnaires and have been translated and standardized in various languages.
The French version of the IPQ questionnaire that we used was downloaded from the Igroup website http://www.igroup.org/pq/ipq/download.php and is present in the Annex B (§7.2).

The IPQ questionnaire is constituted of 14 questions in the form of a 7 items Likert scale. The 14 questions assess the following four dimensions of the feeling of presence:

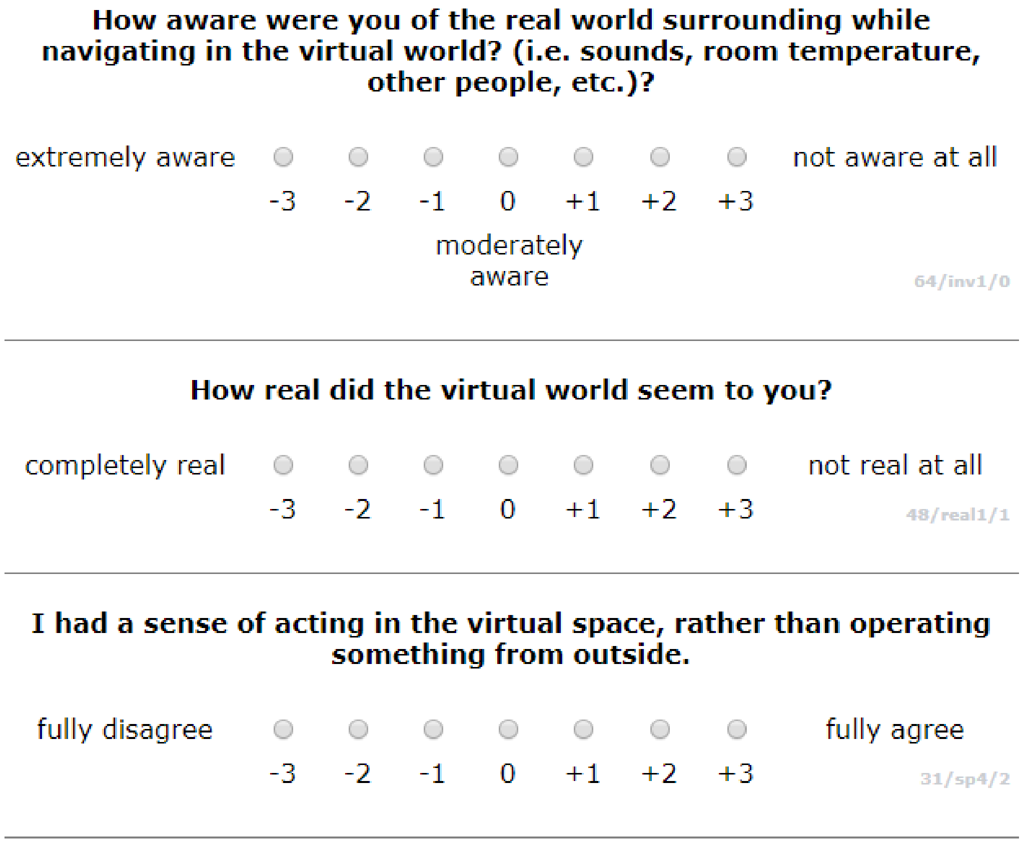
1. **General Presence** that is assessed by the following question:
   In the computer generated world I had a sense of “being there”

2. **Spatial presence** (the sense of being physically present in the environment) that is assessed by 5 questions like:
   I *had a sense of acting in the virtual space, rather than operating something from outside.*

3. **Involvement** (the degree of attention given to the environment and the user involvement in the experience) that is assessed by 4 questions like:
   I was completely captivated by the virtual world.

4. **Realism** (perceived realism of the environment) that is assessed by 4 questions like:
   H*ow much did your experience in the virtual environment seem consistent with your real world experience?*

An extract of the English version of the IPQ is presented in Figure 3. The whole English version is presented in the §7.3.



How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?

extremely aware -3 -2 -1 0 +1 +2 +3 not aware at all

moderately aware

64/inv1/0

How real did the virtual world seem to you?

completely real -3 -2 -1 0 +1 +2 +3 not real at all

48/real1/1

I had a sense of acting in the virtual space, rather than operating something from outside.

fully disagree -3 -2 -1 0 +1 +2 +3 fully agree

31/sp4/2

Figure 5: Extract of the question of the English version of the IPQ

3.3 Perceived visual quality

The third element we decide to assess in our user evaluation is the perceived visual quality of the virtual experience. The aim of this evaluation is to identify any perceivable change in the video quality induced by the introduction of the WORTECS technologies. The adoption of the video converter and the compression imposed by the limited bandwidth condition could in fact impact the general video quality or introduce compression artefacts.

The video quality assessment is today a well-defined activity. Such assessment plays a main role in all those domains where the quality of a video is a valuable parameter. The range of industrial domains interested in such activities is quite wide going from display producers, broadcasters, network and communication companies as well as video compression developers.

These evaluations could fall in two categories: objective measurements (based on algorithms) and subjective measurements (based on user evaluation). Objective measurements are easy to apply and are particularly valuable for estimating the changes introduced in a video signal by the compression algorithm. The main limit of the use of objective measurements is that they don't give relevant information on how this changes impact the user perception. For this reason subjective evaluation are often unreplaceable.

With the aim to standardize the evaluation procedure and to pursuit replicability and comparability of the results, in the last years various institutions have created guidelines on how to perform subjective video quality assessment. One example of such document is the "Subjective video quality assessment methods for multimedia application" delivered in 2008 by the International Telecommunication Union (ITU) [22].

This standardization effort concerned the assessment of classical 2D non-interactive and non-immersive video content but such standards are not yet available for immersive and interactive content like the virtual environment that will be used to assess the WORTECS technologies.

3.3.1 The assessment of the perceived video quality

While for the assessment of VR sickness and the feeling of presence we could adopt existing standardized and validated questionnaires, for the assessment of the perceived video quality in VR there are no standardized questionnaires.

As a consequence we decide to develop a questionnaires based on the ITU recommendations [22] and on the ongoing effort of the Joint Qualinet and VQEG team on Immersive Media (JQVIM) that are actually working on the identification of a VR video evaluation methodology [23].

The questionnaire is divided in 2 parts. The first part is constituted by 4 questions asking the participant to assess various aspects of the video quality (colour reproduction, contrast, outlines definition and fluidity) on a 7 steps Likert scale. An English example of a perceived quality question is presented in Figure 6.


How would you judge the color reproduction
Very bad ☐ ☐ ☐ ☐ ☐ ☐ ☐ Very good

Figure 6: English translation of a perceived video quality question

The second part of the questionnaire is constituted by 5 questions focusing on the presence (and degree of annoyance) of the following artefacts:

- Flickering
- Ghosting
- Lack of reactivity
- Compression macroblock (blobs of pixels)
- Freezing images or black screens

An English example of an artefact question is presented in Figure 7.


Have you noticed any flickering
Yes ☐ No ☐

Figure 7: English translation of a perceived video artifacts question

The French version of the questionnaire used for the evaluation is presented in the annex D (§0).

4. User experience evaluation

The aim of the evaluation was to assess the possible impact of the introduction of two technological bricks (the video converter and the data compression algorithm) developed in the frame of the WORTECS project on the user experience during a virtual reality session.

For this reasons two separate experimental sessions where organized in two different days and with different participants.
The first session tested the impact of the video converter without any compression.
The second session tested the impact of the video converter with a compression to simulate a maximal bandwidth of 860 Mbits (§2.1.2). This bandwidth is equivalent to the one obtained during preliminary test using the Optical Wireless Connection (OWC) that is the less performant (in terms of bandwidth) of the three wireless technologies employed in the WORTECS project.
Assessing the impact of the video converter with and without video compression will allow us to discriminate if a change in the user perception is due to the video conversion process or if the consequence of the compression process imposed by the limited bandwidth is.
Testing the compression at 860 Mbits will also allow us to grant that the user experience will not be affected by the lowest bandwidth today supported by the wireless WORTECS solutions.

4.1 Experimental protocol

The experiment took place at the b<>com headquarters in Rennes (France) the 22 and 23 of November 2019. A total of twenty participants (ten each day) took place to the experience.
Due to the limited number of participants and to optimize the experimental time we decided to perform two separate counterbalanced within-subjects studies. The structure of the Within-subject experimental design is presented in Figure 8.

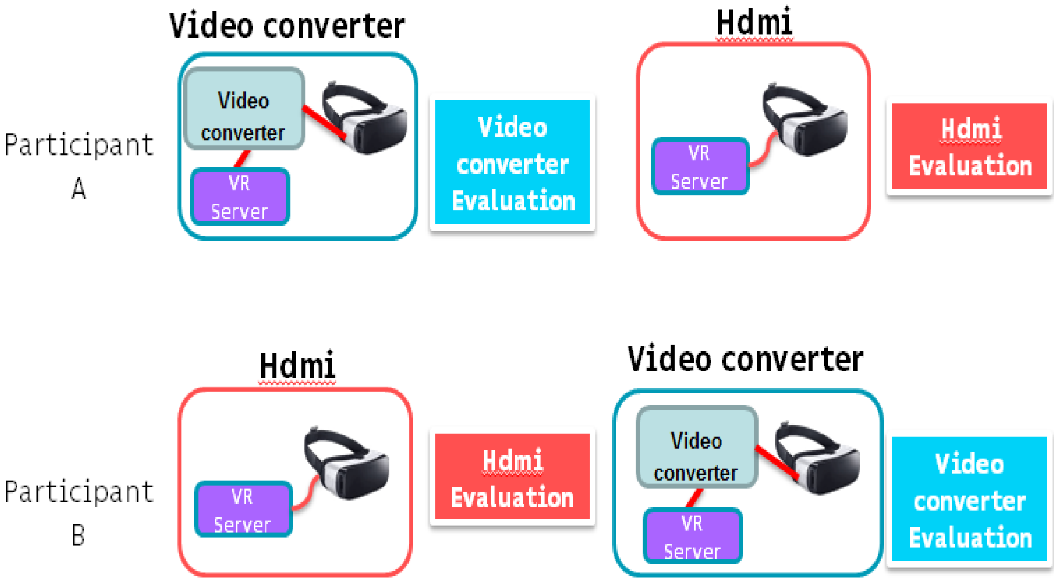


Figure 8 Counterbalanced Within-subject study

During each experimental session two participants will test the same virtual reality experience, one time using a conventional virtual reality set-up and the other time using the set up integrating the video converter. To optimize the experimental time the two participants experience the virtual reality at the same time (one using the conventional configuration, the other using the configuration with the video converter) but in two opposite sides of the experimental space. To avoid any interaction between the participants during the virtual experience each participant wear headphones as illustrate in Figure 9.

Figure 9: Two participants testing the same virtual environment one using a conventional set-up and the other using the set up with the video converter

The virtual reality scene was rendered using two separate but equivalent workstations connected to the HTC vive HMDs. To avoid interferences between the tracking systems of the two set-ups, one of the virtual spaces was delimited by a tubular structure supporting fabric sheets to block the light emission of the HTC Vive Lighthouses. The tubular structure is visible in the back of Figure 10.

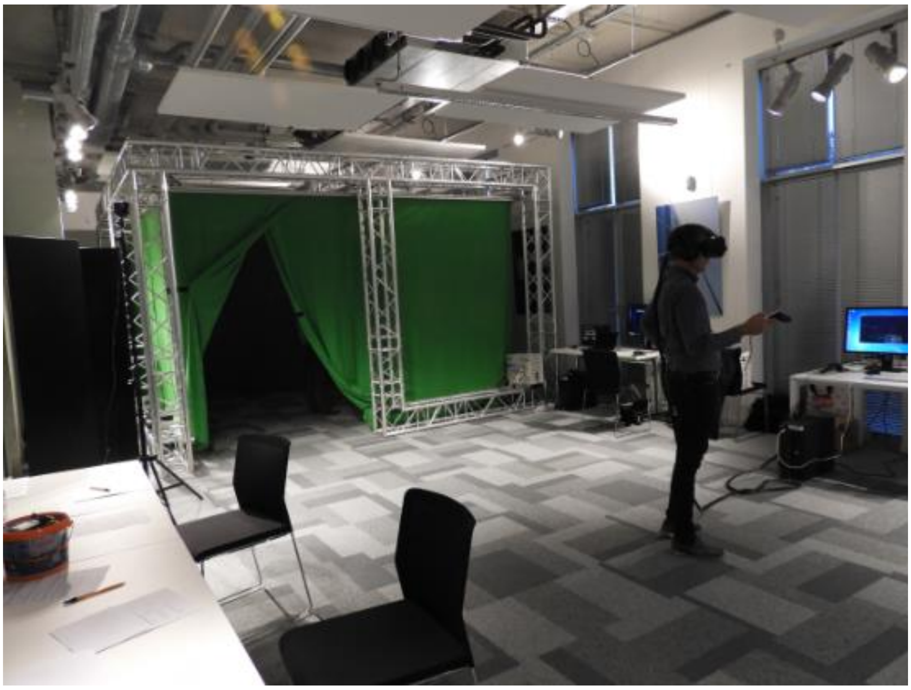


Figure 10: The experimental room with metal structure supporting the fabric sheets.

Each experimental session lasted one hour and started with a welcome and briefing phase. During this phase we explained to the participants what they were going to do in the following hour. In particular participants were made aware of the general security warning relate to the use of the HTC Vive HMD. After explaining that they were free to stop their experience at every moment, participants were request to sign the document of agreements to the collection of the experimental data.
The extract of the HTC Vive security warnings as well as the agreement form used during the experience are respectively presented in the Appendix E and F (§7.5 and §7.6).

After this introductory phase the participants fulfilled the SSQ questionnaire (used as a baseline) and were invited to take place in their experimentation area where they were equipped with the HMD and started the virtual experience.

After the experience the participants were request to go back to their table to fulfil the following questionnaires:

1) The SSQ to assess their level of VR sickness after the virtual experience
2) The IPQ to assess the perceived feeling of presence
3) The questionnaire about the perceived quality.

The actual structure of an assessment section is presented in Figure 11 .

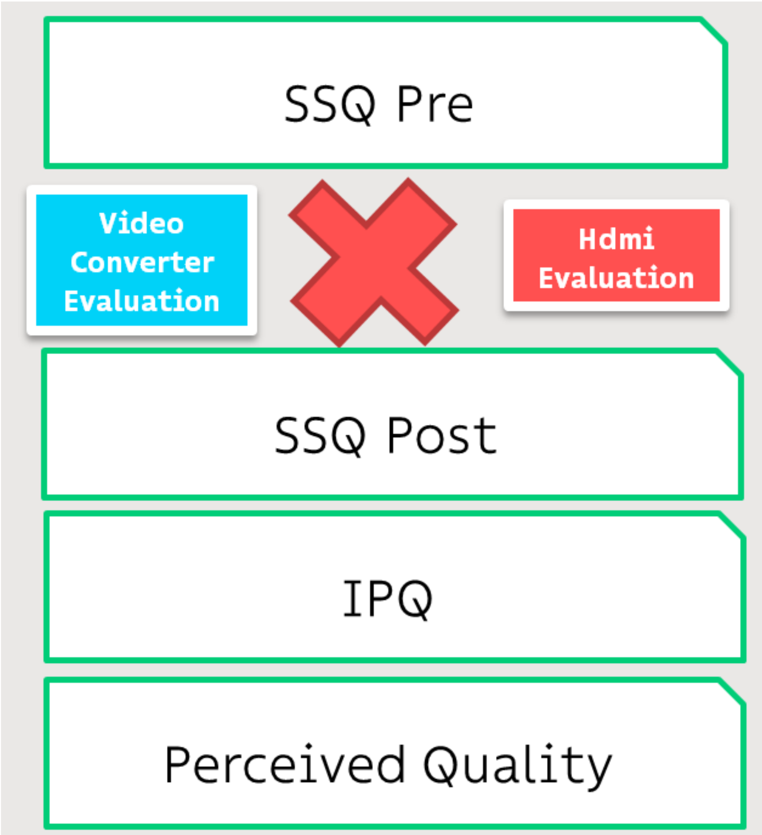


Figure 11: Questionnaires used for the evaluation

Completed the perceived quality questionnaire the participants were ready to start the second part of the experiment. In this part the participant that previously tested the set-up including the video compression module will now to test the set-up without the video compression while the other participant that in the first experience tested the set-up without the video compression now will test the set-up with the video compression module.

Once finished the second virtual reality experience, the participants were helped to take off the virtual reality device and come back to the table to fulfil the same questionnaires they completed after the first passing.

Once they completed the questionnaires a short debriefing session explained them the aim of our research. The participants were then free to pose any question about the experiment they attended and after acknowledging their participation they were invited to leave the experimentation space.

The complete timeline of the experimental session is presented in the Figure 12.

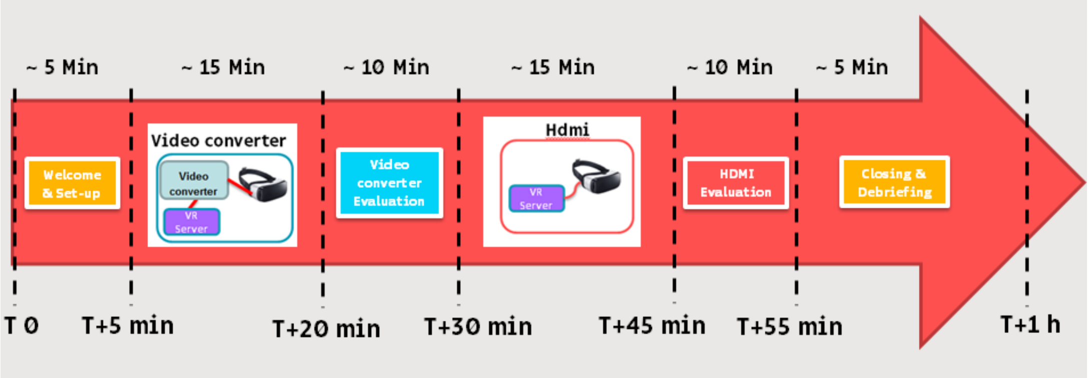


Figure 12: Example of the experimental session timeline (for participants testing the video converter in their first passing)

4.2 The virtual reality content

The content chosen for the evaluation is an interactive virtual environment named Virtual Arctic Expedition (VAE). The virtual experience allows up to 4 participants to explore the seabed of the artic regions in different epochs to observe the effects of the climate change on the arctic environment. Each participant is represented in the virtual environment via a simplified avatar.
The positions of the avatars, the movements of their hands as well as the rotation of their heads are obtained via the tracking information collected by the HTC vive Lighthouses. Equipped with virtual reality headsets (HTC Vive) users will be able to interact naturally with the oceanographic environment thanks to the Vive controllers in order to obtain information on the different species, take underwater photos, or activate animations showing the evolution of marine currents over time (see Figure 13).

Figure 13: Multi-user immersive experience in Artic Ocean.

4.2.1 The Virtual Artic Expedition scenario

The Virtual Arctic Expedition experience in his original version last around 15 minutes and is constituted by the following 4 scenes.

4.2.1.1 The underwater station

The first scene is a short tutorial explaining the participants what they are going to experience and how they can interact with the environment. Participants can for instance point their laser to an animal to obtain further information about its specie or they can use a virtual camera to take pictures (see Figure 14). This training takes place in a futuristic underwater station and ends whit the opening of the metallic gate that allows the users to see the ocean surrounding the underwater station.

Figure 14: Participant testing the functionalities inside the ocean station

4.2.1.2 The arctic sea-bed in 1950

In the second part of the experience the participants are "teleported" outside the station and found themselves in the seabed 20 meter under the Arctic Ocean in the year 1950. A voice explains them where they are and gives information about the surrounding environment. In this part of the experience the participants watch and can partially interact with different spices like seals, narwhals and whales. The participants are invited to interact with the animals and point them with the laser to obtain complementary information about the species (see Figure 15). This second part ends with the apparition of the "temporal navigation capsule" in the background.

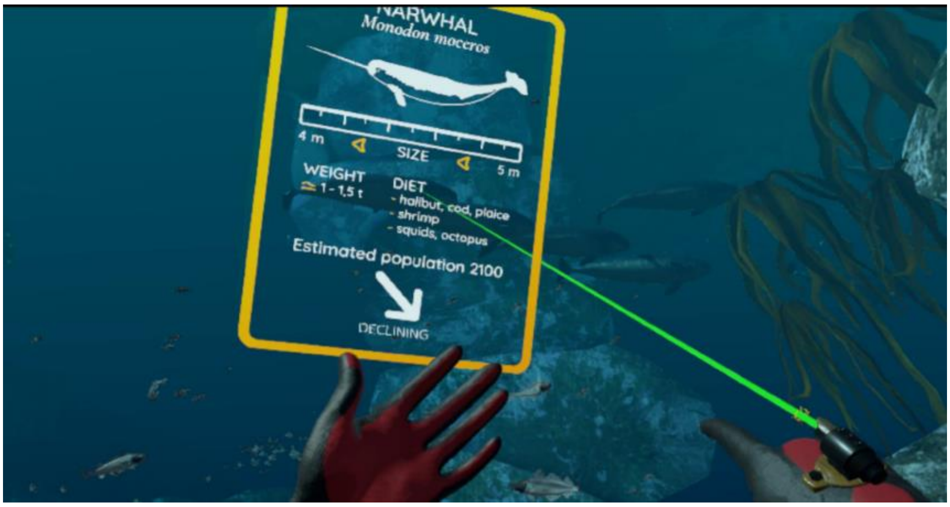


Figure 15: Participant in the 1950 pointing the laser at a narwhal to obtain more information

4.2.1.3 The temporal navigation capsule

In the third part the participants are teleported inside the "temporal navigation capsule". Here they assist to an animation explaining the evolution of the clime in the last years as well as a forecast of the consequences of the global warming in the artic region (see Figure 16). Participants can obtain further information pointing the laser to the graphical representation of the species presents inside the "temporal navigation capsule".

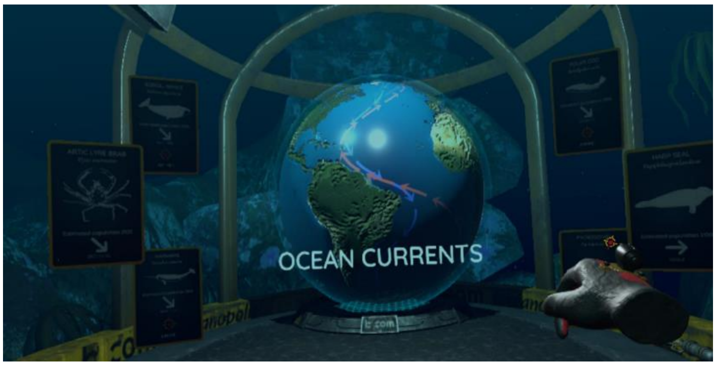


Figure 16: Presentation of the climate changes inside the temporal navigation capsule

4.2.1.4 The arctic sea-bed in 2100

In the fourth and last part the participants are teleported in the same underwater location they previously explored but this time in the year 2100. Like previously the participants are free to move around and explore the environment that now, due to the climate change, is populated by different species (see Figure 17). During the experience the participants listen to a verbal explanation of the effects of the climate change on the artic ecosystem.

Figure 17: Virtual screenshot of the sea-life in the artic sea in 2100

The experience ends with the teleportation of the participants inside the underwater station where their virtual experience started. The participants are then informed that the experience has ended and they are invited to take off their HMD.

In the frame of the WORTECS experimentation we decided to present to the users only the first three scenes of the Virtual Arctic Expedition. The last scene is in fact visually similar to the second scene and the elimination of this last scene permitted to keep the total time of each experimental session below one hour. The timeline of the scenario of the Virtual Arctic Expedition is presented in the Figure 18.

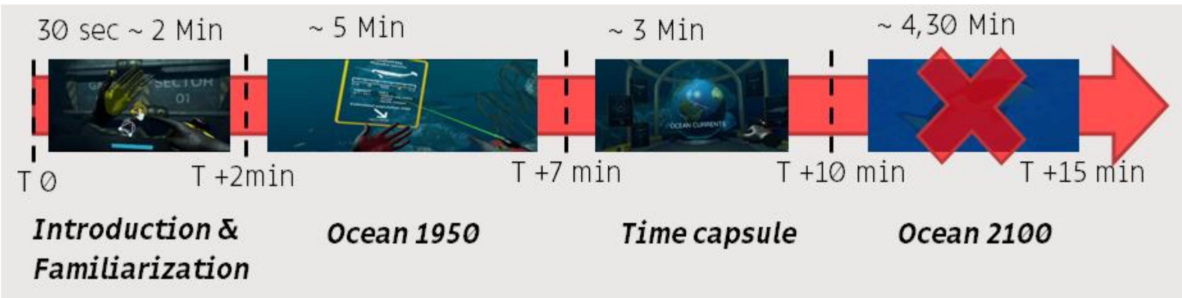


Figure 18: Timeline of the scenario of the Virtual Artic Expedition with the last scene (not presented during the WORTECS expedition) marked in red

5. Results

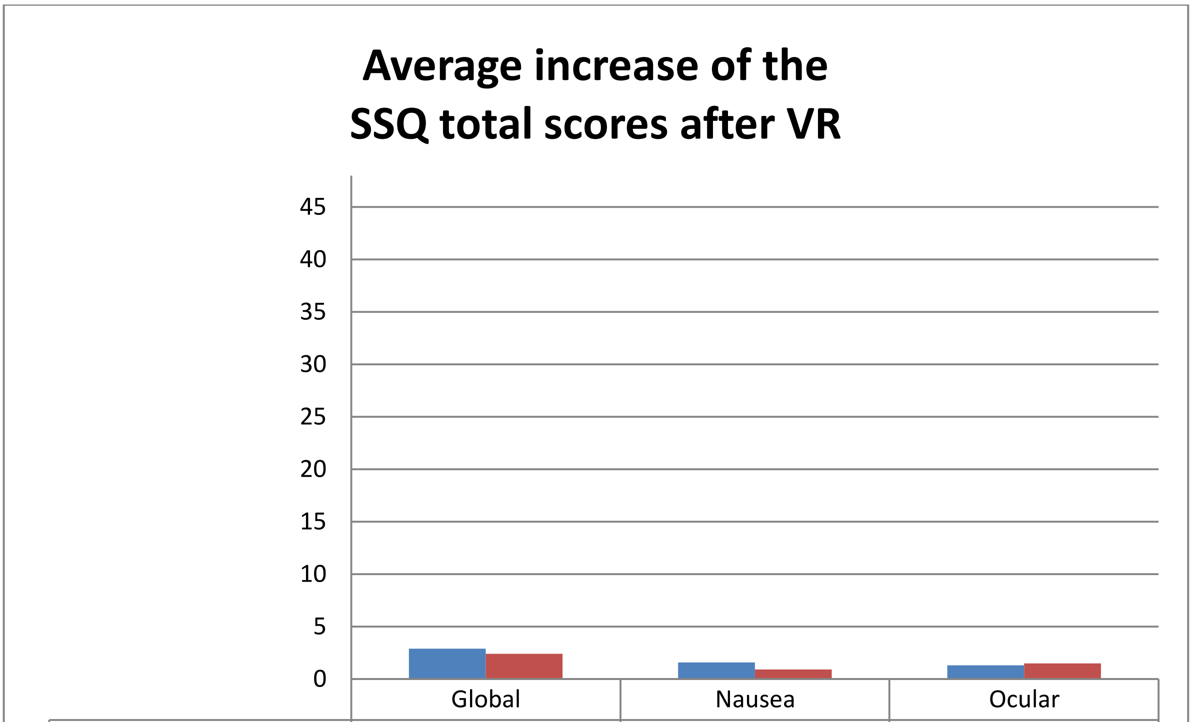
In this section we present the results of the analysis of the three questionnaires adopted for the evaluation.
Considering the reduced number of participants (10 for each experimental condition) and the nature of the questionnaires based on Likert scale we used a non-parametric statistics. Being the experimental design a Within-subject study, the statistical test adopted for our analysis is the Wilcoxon signed-rank test for paired measures. The p-value (the probability of obtaining the observed results of a test, assuming that the null hypothesis is correct) was set to the usual level of 0.05.
In the remaining of the chapter we will present for each of the assessed dimension (virtual reality sickness, presence and perceived video quality) the results obtained introducing the video converter without compression in the first part, and with compression in the second part.

5.1 Virtual reality sickness

The first aspect of the user experience we decided to assess was the virtual reality sickness. In details we wanted to verify that the integration of the video converter on top of a conventional virtual reality set-up will not increase the symptoms of VR sickness in the participants.

5.1.1 Conventional set-up vs. inclusion of the video converter without compression

The first data that we will consider are the one related to the comparison between a conventional set-up (the HTC Vive HMD is directly connected to the workstation via the Hdmi cable) and the alternative set-up (the video flux pass through the video converter placed between the workstation and the HTC Vive HMD). In this first part we will focus on the data collected during the first day when no data compression was applied.
The average values of the increase of the virtual reality symptoms are presented in the Figure 19.
As we can see the increase in the level of global sickness is minimal (the average increase is below 3 in a range going potentially up to 48) and is more relevant for the conventional set-up compared to the one induced by the integration of the video conversion modules.



	Global	Nausea	Ocular
Hdmi	2,9	1,6	1,3
VC without compression	2,4	0,9	1,5

Figure 19: Increase of the SSQ scores
HDMI vs Video Converter without compression

While there is a numerical difference in the increases of the virtual reality sickness between the two experimental set-ups, such difference is not statistically relevant according to the results of the Wilcoxon signed rank test.

As the results presented in the Table 1 shown, there isn't any statistically significant difference between the conventional set up and the set up including the video converter module in any of the three dimensions (Global sickness, Nausea and Ocular/Dizziness) of the SSQ questionnaire.

Table 1: Wilcoxon signed rank test result for SSQ in the condition video converter without compression

SSQ Dimension	V	p-value	Significant at p=0.05
Global	23	0.5261	Not Significant
Nausea	18.5	0.1058	Not Significant
Ocular	6	0.7855	Not Significant

On the basis of these results we can affirm that the inclusion of the video converter has no significant impact in the induction of the virtual reality sickness symptoms.

5.1.2 Conventional set-up vs. inclusion of the video converter with compression

A similar analysis was performed in the data collected with the second group of participants that have tested the conventional set-up as well as the set-up integrating the video converter and a data compression. The data compression was applied to simulate a maximal bandwidth at 860 Mbits per second. As previously stated this bandwidth is equivalent to the lowest bandwidth obtained using the wireless technologies developed in the WORTECS project.

The histogram in Figure 20 represents the average increases in the SSQ scores that the participants reported after the virtual experience. As we can see, like in the previous case, the increases are quite little with the average increase of the global symptoms being below 2.

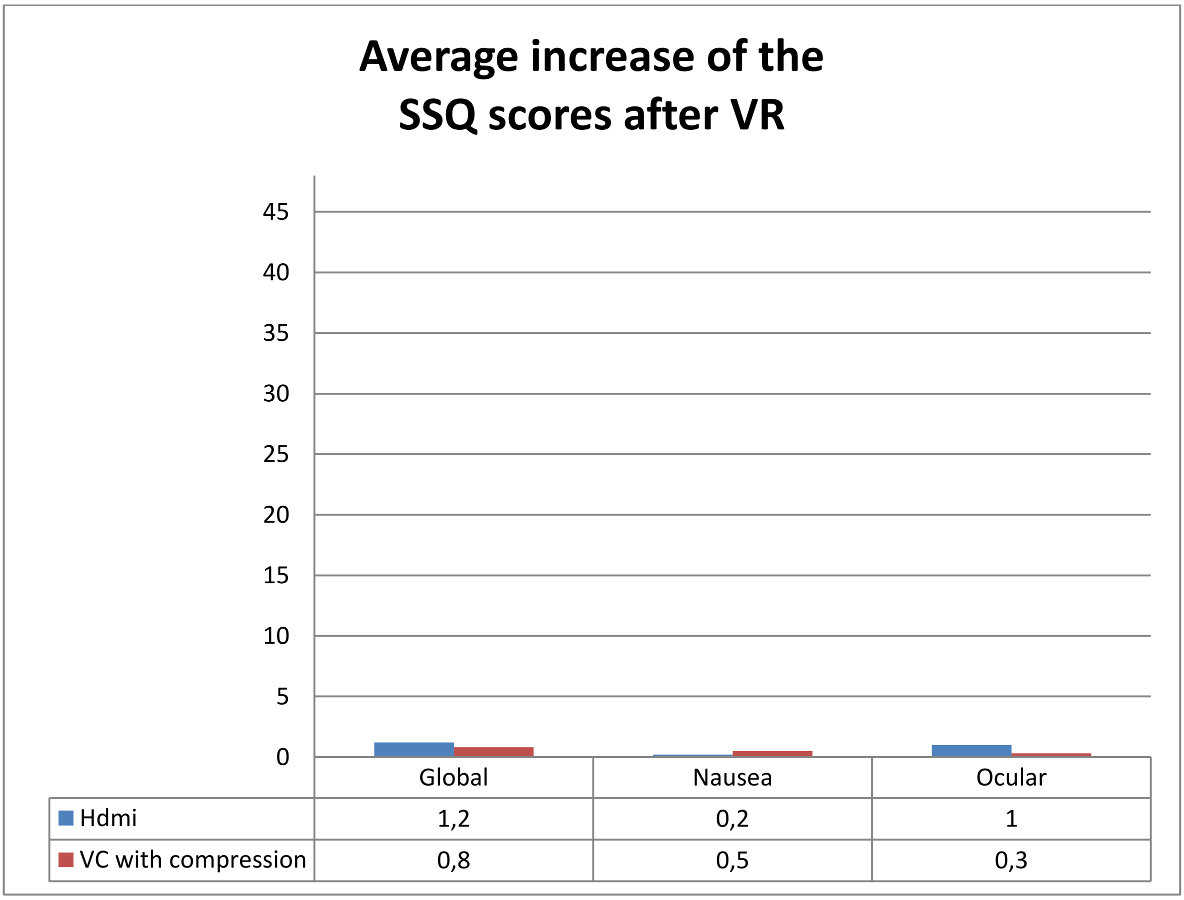


Figure 20: Increase of the SSQ scores HDMI vs Video Converter with compression

The Wilcoxon signed rank test performed on the SSQ scores shows that there isn't any statistical difference in the increase of the virtual reality sickness between the convention set up and the one integrating a data compression at 860 Mbps. The results of this statistical analysis are detailed in the Table 2.

Table 2: Wilcoxon signed rank test result for SSQ in the condition video converter with compression

SSQ Dimension	V	p-value	Significant at p=0.05
Global	11	1.0000	Not Significant
Nausea	4	0.4076	Not Significant
Ocular	8	0.3613	Not Significant

To summarize we can say that the results of the analysis of the SSQ questionnaire suggest that the integration of the video converter (without or with a compression at 860 Mbps) do not have any significant impact in the induction of the virtual reality sickness in the participants.

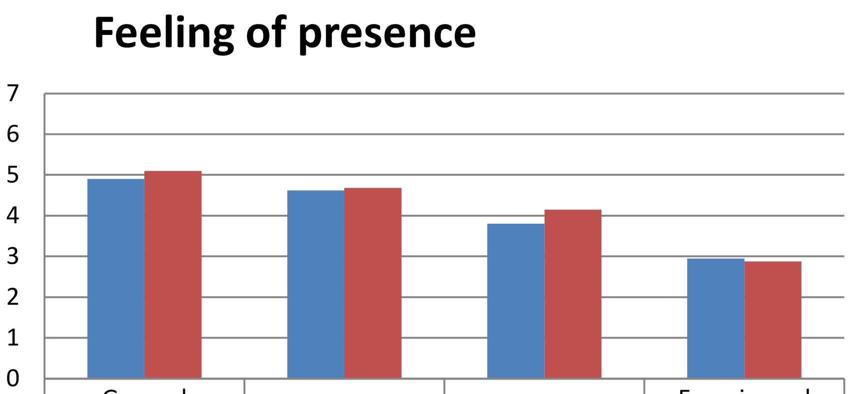
5.2 Feeling of presence

The second aspect of the user experience we decided to assess was the feeling of presence.
As previously explained, the feeling of presence is a multidimensional construct that is often considered as a reliable estimator of the general quality of the user experience in virtual reality.
For this reason we asked the participants to fulfill the IPQ questionnaire after each virtual experience.

5.2.1 Conventional set-up vs. inclusion of the video converter without compression

As for the previous analysis, we will first consider the data collected during the comparison between a conventional set-up (HTC Vive HMD directly connected to the workstation via the Hdmi cable) and the alternative set up (the video flux pass through the video converter placed between the workstation and the HTC Vive HMD) without any data compression.

The average values of the four dimensions of the feeling of presence as assessed via the IPQ questionnaire are presented in the Figure 21. As in the previous case we are not interested in the absolute values but in the difference in the scores induced by the integration of the video converter.
The results presented show a minimal numerical difference (below 0.4 in a range going up to 7) between the scores obtained with or without the video converter.



	General presence	Spatial presence	Involvement	Experienced realism
Hdmi	4,9	4,62	3,8	2,95
VC without compression	5,1	4,68	4,15	2,875

Figure 21: Histogram of the IPQ scores
HDMI vs Video Converter without compression

To assess if such numerical difference is statistically significant a Wilcoxson signed rank test was performed. The results of the test are presented in Table 3. This results show that there isn't any statistically significant difference between the conventional set up and the set up including the video converter for any of the four dimensions (general presence, spatial presence, involvement and experienced realism) of the IPQ questionnaire.

Table 3: Wilcoxon signed rank test result for IPQ in the condition video converter without compression

IPQ Dimension	V	p-value	Significant at p=0.05
General presence	7	0.4840	Not Significant
Spatial presence	18	0.6356	Not Significant
Involvement	9.5	0.2567	Not Significant
Experienced realism	23.5	0.9526	Not Significant

On the basis of these results we can affirm that the inclusion of the video converter has no significant impact on the users' feeling of presence.

5.2.2 Conventional set-up vs. inclusion of the video converter with compression

The same analysis have been performed on the data obtained during the second day of test when the participants experienced the virtual reality content using a conventional set up and the set up with the video converter and the data compression.

The histogram in Figure 22 represents the average scores obtained via the IPQ questionnaire.
Like in the previous case the numerical difference between the scores of the two set-ups is minimal.

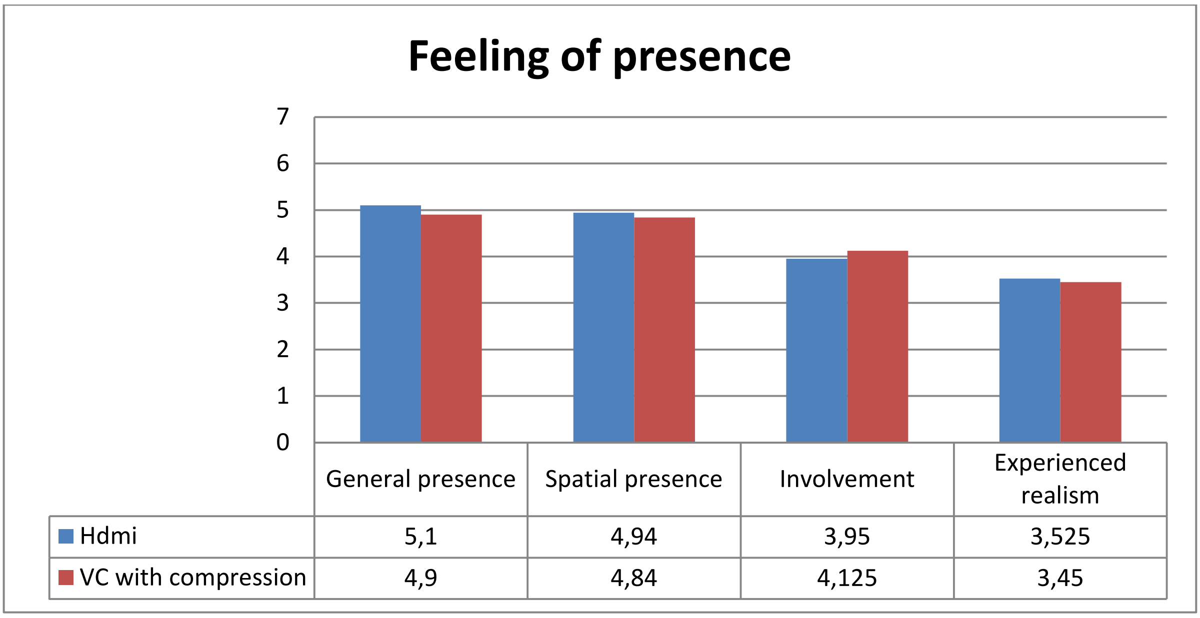


Figure 22: Histogram of the IPQ scores HDMI vs Video Converter with compression

The Wilcoxon signed rank test performed on the IPQ scores shows again a lack of statistical difference between the two conditions in the assessed dimensions of the feeling of presence.
The results of this statistical analysis are detailed in Table 4

Table 4: Wilcoxon signed rank test result for IPQ in the condition video converter with compression

IPQ Dimension	V	p-value	Significant at p=0.05
General presence	3	0.3458	Not Significant
Spatial presence	19	0.4428	Not Significant
Involvement	19	0.7197	Not Significant
Experienced realism	17.5	0.6049	Not Significant

The results of the two studies confirm the lack of impact of the integration of the video converter in the feeling of presence even when a data compression is applied to simulate a bandwidth limit of 860 Mbps.

5.3 Perceived video quality

After assessing the innocuity of the integration of the WORTECS technologies via the virtual reality sickness questionnaire and after assessing the lack of impact of the WORTECS technologies over the general quality of

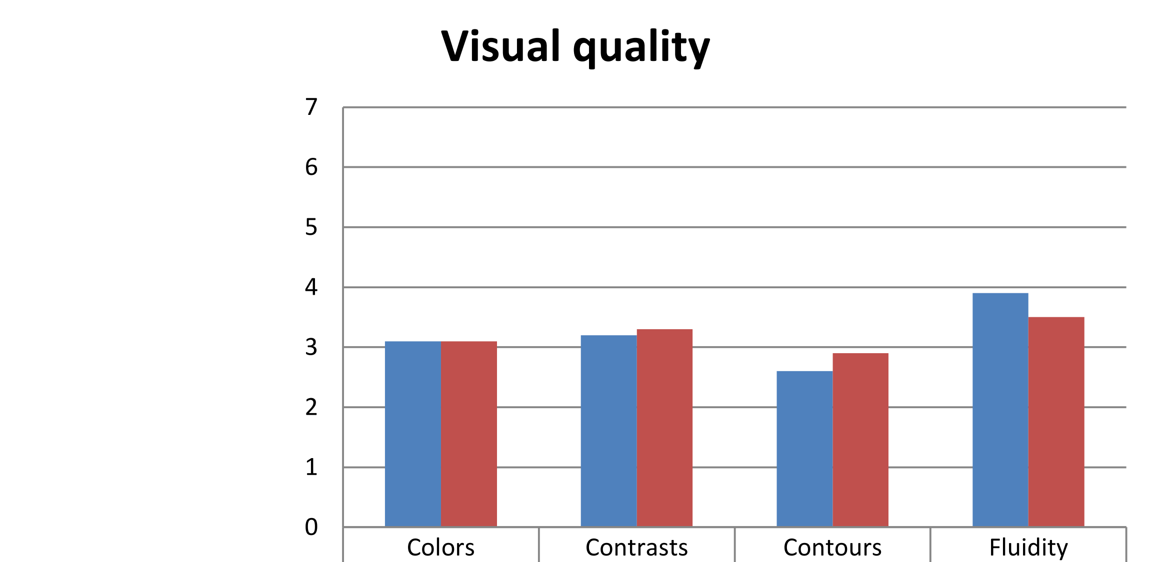
the user experience via the IPQ questionnaire, we decide to focus our study on the impact of the video converter (with and without compression) over the perceived video quality.
To do this we asked the participants to fulfill our perceived video quality questionnaire after each virtual experience. The adopted questionnaire includes two categories of questions. The first category is constituted by four questions that concerns different qualitative aspects of the visual experience (like colors and contrasts). The second category is constituted by five questions that focus on the identification of specific artifacts.
In the rest of this paragraph we will first present the results of the video quality questions and then the results of the questions concerning the visual artifacts.

5.3.1 Assessment of the video quality

The assessment of the general video quality is based on a non-standardized questionnaire that is constituted by four questions assessing the following aspects of the video quality: the colors, the contrast, the definition of the contours and the fluidity.
The participants were request to fulfill the questionnaire after each virtual reality experience.

5.3.1.1 Conventional set-up vs. inclusion of the video converter without compression

Concerning the experimental session comparing the conventional virtual reality set-up with the set-up incorporating the video converter without data compression, the histogram in Figure 23 shows that there is not a general preference for one of the two set-ups. While for instance on average the participants consider the classical set-up to have a slightly better fluidity, they consider the contours being better defined in the set-up incorporating the video converter.



	Colors	Contrasts	Contours	Fluidity
Hdmi	3,1	3,2	2,6	3,9
VC without compression	3,1	3,3	2,9	3,5

Figure 23: Histogram of the scores of the perceived visual quality questionnaire HDMI vs Video Converter without compression

Such difference is actually quite little and the results of the Wilcoxon singed rank test presented in the Table 5 show that these numerical differences are not statistically significant.

Table 5: Wilcoxon signed rank test result for the perceived video quality in the condition video converter without compression

Video Quality	V	p-value	Significant at p=0.05
Colors	1.5	1.000	Not Significant
Contrast	0	1.000	Not Significant
Contours	9.5	0.4821	Not Significant
Fluidity	17	0.6698	Not Significant

5.3.1.2 Conventional set-up vs. inclusion of the video converter with compression

In the case of the comparison between the conventional set-up and the set-up with the video converter and data compression, the histogram presented in Figure 24 shows a different scenario. In this case in fact the average quality of the conventional set-up is perceived slightly superior than the one of the set-up with the video conversion and data compression.

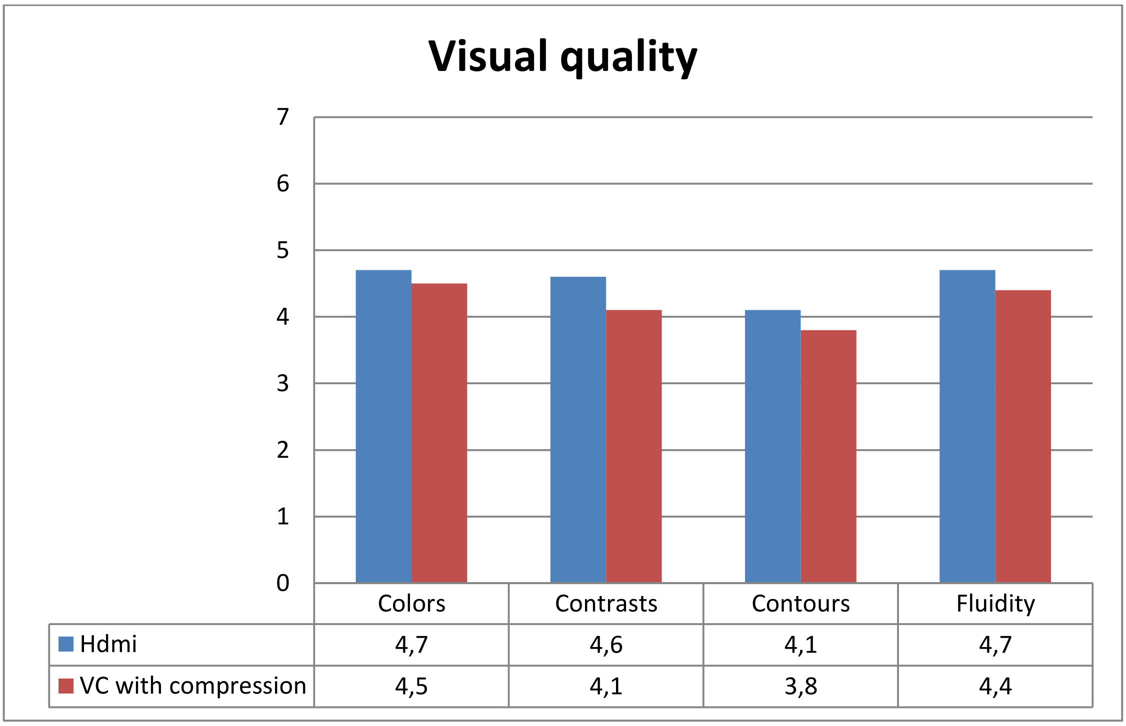


Figure 24: Histogram of the scores of the perceived visual quality questionnaire HDMI vs Video Converter with compression

As previously, to evaluate if this numerical difference is statistically relevant we performed a Wilcoxon signed rank test. The results of this tests presented in Table 6 shows that these differences aren’t statistically significant.

Table 6: Wilcoxon signed rank test result for the perceived video quality in the condition video converter with compression

Video Quality	V	p-value	Significant at p=0.05
Colors	7.5	0.4237	Not Significant
Contrast	24	0.0726	Not Significant
Contours	22	0.6082	Not Significant
Fluidity	15	0.3741	Not Significant

To conclude, the analysis of the questionnaire concerning the video quality support the hypothesis that the integration of the video converter, even when associated with a data compression, do not impact the perceived video quality.

5.3.2 Perceived video artefacts

Our last analysis of the user experience aims to assess if the integration of the video converter (with or without compression) has an impact on the presence (and degrees of annoyance) of video artifacts common in virtual reality.
The five artifacts assessed during our evaluation are:

1. Flickering
2. Ghosting
3. Lack of reactivity
4. Presence of macroblocks
5. Freezing of the images

5.3.2.1 Conventional set-up vs. inclusion of the video converter without compression

The histogram presented in the Figure 25 gives the responses of the participants at the five questions concerning the presence (and level of annoyance) of the video artefacts. Form the histogram we can notice that the most disturbing artefact was the flickering with an average value of annoyance around 2 on a scale reaching the maximum at 7. This data is not surprising considering that the flickering is a main video artifact in virtual reality. Considering the comparison between the two set-ups, the histogram didn't show a clear difference in performances between the two configurations, with some artifacts like the flickering being more present in the conventional set-up while others, like the ghosting, being more frequent in the set-up including the video converter.

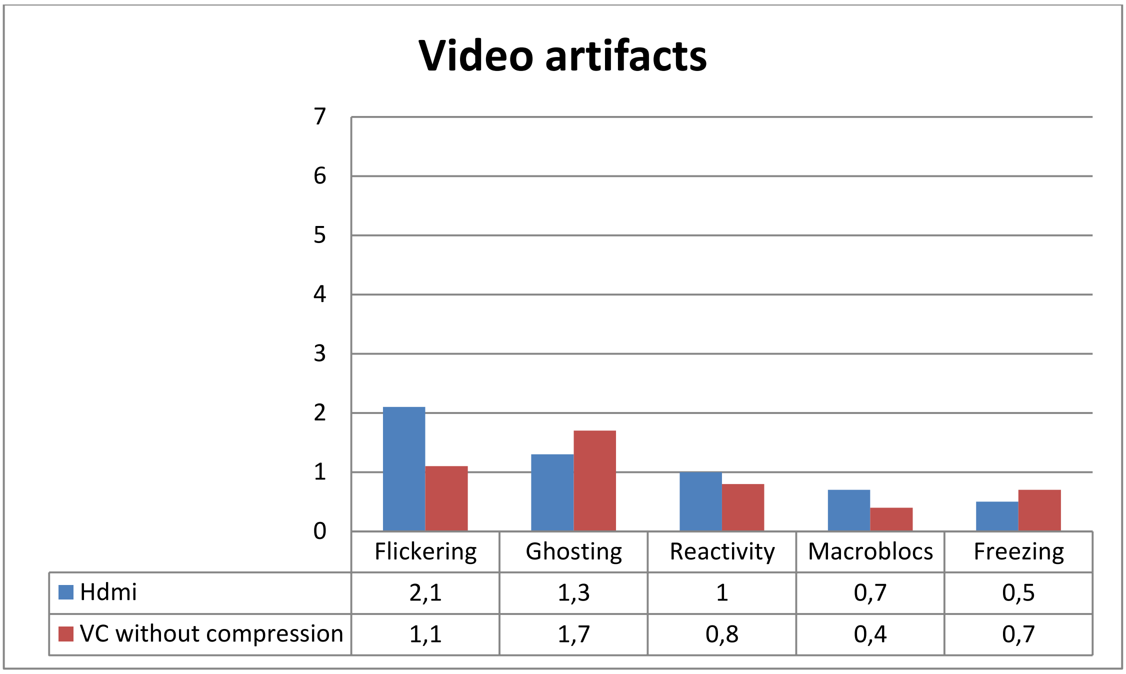


Figure 25: Histogram of the scores of the perceived video artifacts questionnaire HDMI vs Video Converter without compression

These considerations are supported by the results of the Wilcoxon signed rank test presented in Table 7 that didn't show any statically significant difference between the two conditions.

Table 7: Wilcoxon signed rank test result for the perceived artifacts in the condition video converter without compression

SSQ Dimension	V	p-value	Significant at p=0.05
Flickering	10	0.1003	Not Significant
Ghosting	1	1.0000	Not Significant
Reactivity	5	1.0000	Not Significant
Macroblocks	4.5	0.5862	Not Significant
Freezing	3.5	0.7127	Not Significant

5.3.2.2 Conventional set-up vs. inclusion of the video converter with compression

The last analysis we are going to present concerns the assessment of the perceived video artifacts in the experimental session comparing the conventional set-up with the set-up including the video converter and the data compression.
The results show that, as illustrated in the histogram in Figure 26, the compression doesn't introduce a relevant amount of artifacts considering that the highest reported annoyance for the artifacts in the set-up adopting the data compression is 1.3 and that this value is lower than the score of 1.7 that concerns the reactivity of the conventional set-up.

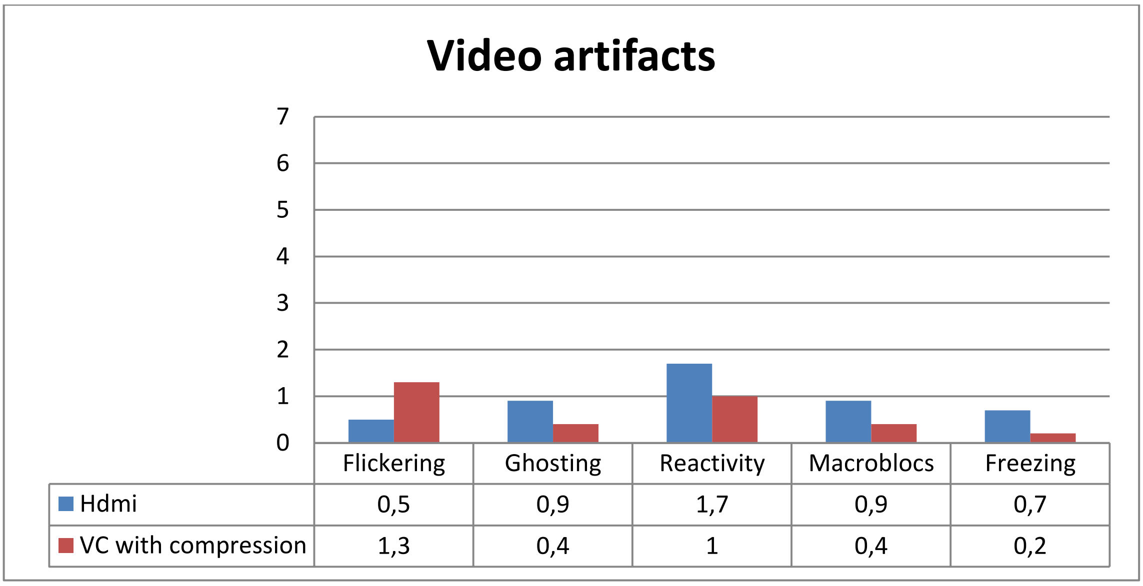


Figure 26 : Histogram of the scores of the perceived video artifacts questionnaire HDMI vs Video Converter without compression

The Wilcoxon singed rank test confirms that there isn't any statistically significant difference in the level of annoyance induced by the video artifacts between the conventional set-up and the set-up including the video converter and the data compression. The results of the test are detailed below in Table 8.

Table 8: Wilcoxon signed rank test result for the perceived artifacts in the condition video converter with compression

SSQ Dimension	V	p-value	Significant at p=0.05
Flickering	3.5	0.3430	Not Significant
Ghosting	5	0.4227	Not Significant
Reactivity	3	0.3711	Not Significant
Macroblocks	5	0.4227	Not Significant
Freezing	4	0.7893	Not Significant

To summarize the analysis performed on the perceived video quality questionnaires supports the hypothesis that the integration of the video converter as well as the application of a data compression to simulate a maximal bandwidth of 860 Mbps does not impact the perceived visual quality of the virtual experience. This lack of impact concerns both the general perception of the visual quality as well as the presence of specific video artifacts.

6. Conclusions

In this study we assessed the impact of two of the WORTECS technologies (the video converter module and the data compression algorithm) on three aspects of the user experience during a virtual reality experience.

The three chosen aspects of the user experience were the virtual reality sickness, the feeling of presence and the perceived visual quality.

The data concerning the user experiences have been collected using three questionnaires. The virtual reality sickness and the feeling of presence were assessed using standardized questionnaire like the SSQ and the IPQ, while the visual quality was assessed using a custom questionnaire due to the lack of a standardized questionnaire applicable to virtual reality content.

The study takes place in two independent sessions, one to assess the impact of the video converter without compression, and the other to assess the impact of the video converter and the data compression.

The study was conducted adopting a within-subject design and, due to the reduced number of participants and the nature of the questionnaire, the collected data were analysed using non-parametric statistics (Wilcoxon signed rank test for paired measures).

Within the limit of the reduce number of participants (ten for each independent session) the results of this study support the hypothesis that the tested technologies (with or without compression) do not impact in a statistically significant way any of the investigated aspects of user experience.

6.1 Future developments

This first evaluation allowed us to assess that the video converter as well as the data compression (to simulate an 860 Mbps maximal bandwidth) have no negative impact on the user experience.

This evaluation was a mandatory prerequisite to assess that impact of a technology that is at the core of the WORTECS wireless set-up. The video converter as well as the compression algorithm are in fact two of the components toward which the video stream will pass regardless to which of the wireless technology will be used.

The future evaluations will focus on the comparison of the three wireless technologies (fiber without fiber, radio frequency and optical wireless communication) as presented in Figure 27.

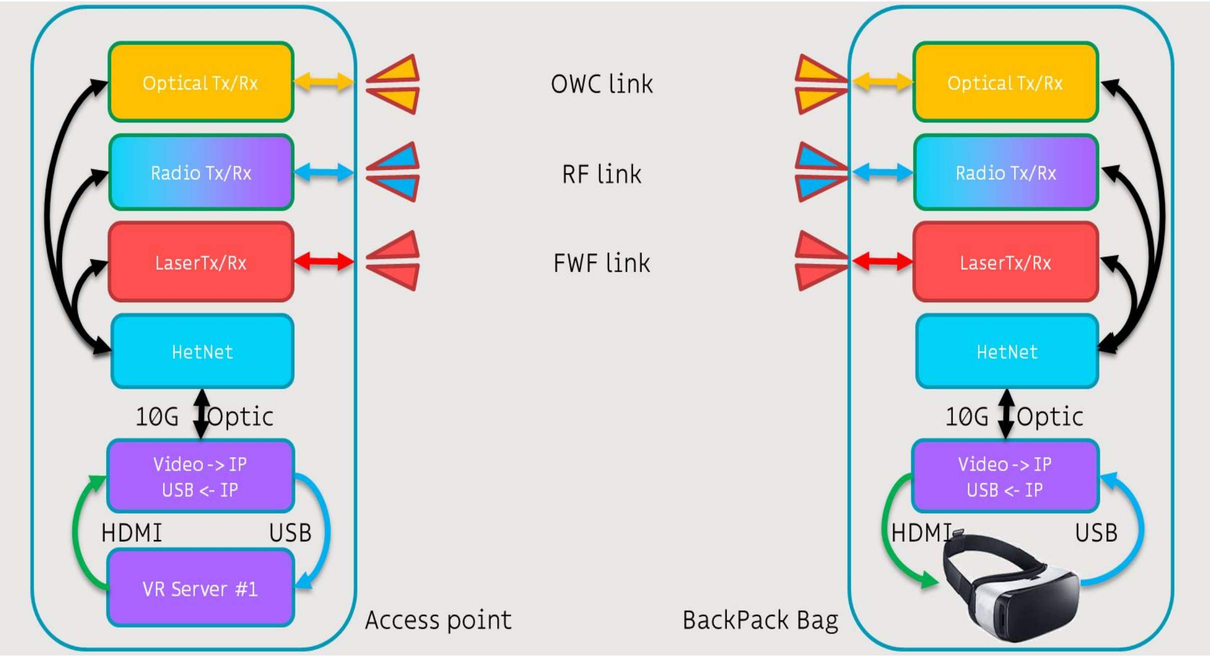


Figure 27: The three wireless technologies developed in the frame of the WORTECS project

This next evaluation will focus on various aspects of the wireless technologies, like for instance: the reactivity of the system, its reliability and robustness to the interferences. For this reason the next use case will target a multiuser scenario with different participants physically present in the same space, sharing simultaneously the same virtual experience but using different wireless technologies as presented in Figure 28.

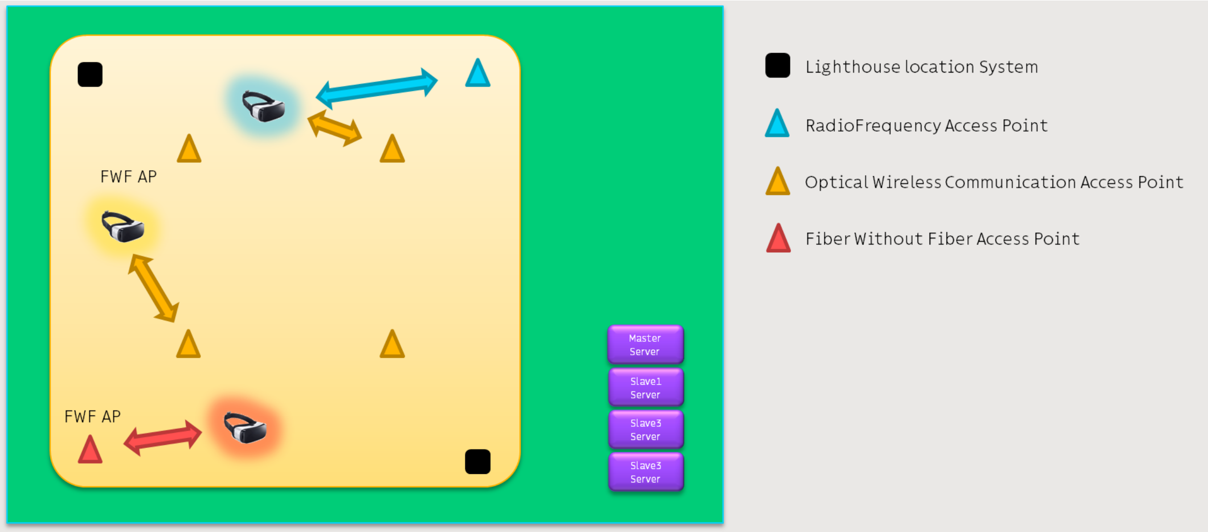


Figure 28: Graphical representation of the multiuser environment using different wireless technologies

7. Appendixes

7.1 Appendix A. French Cybersickness Questionnaire

Questionnaire sur les cybermalaises*

Laboratoire de Cyberpsychologie de l'UQO

(Traduit de Kennedy, R.S.et al., 1993)

Numéro_____________________________ Date____________________

Consignes : Encerclez à quel point chaque symptôme ci-dessous vous affecte présentement.

1. Inconfort général	Pas du tout	Un peu	Modérément	Sévèrement
2. Fatigue	Pas du tout	Un peu	Modérément	Sévèrement
3. Mal de tête	Pas du tout	Un peu	Modérément	Sévèrement
4. Fatigue des yeux	Pas du tout	Un peu	Modérément	Sévèrement
5. Difficulté à faire le focus	Pas du tout	Un peu	Modérément	Sévèrement
6. Augmentation de la salivation	Pas du tout	Un peu	Modérément	Sévèrement
7. Transpiration	Pas du tout	Un peu	Modérément	Sévèrement
8. Nausées	Pas du tout	Un peu	Modérément	Sévèrement
9. Difficulté à se concentrer	Pas du tout	Un peu	Modérément	Sévèrement
10. Impression de lourdeur dans la tête	Pas du tout	Un peu	Modérément	Sévèrement
11. Vision embrouillée	Pas du tout	Un peu	Modérément	Sévèrement
12. Étourdissement les yeux ouverts	Pas du tout	Un peu	Modérément	Sévèrement
13. Étourdissement les yeux fermés	Pas du tout	Un peu	Modérément	Sévèrement
14. *Vertiges	Pas du tout	Un peu	Modérément	Sévèrement
15. **Conscience de l'estomac	Pas du tout	Un peu	Modérément	Sévèrement
16. Rots	Pas du tout	Un peu	Modérément	Sévèrement

* Les vertiges sont vécus comme une perte de l'orientation par rapport à la position verticale.
** L'expression « conscience de l'estomac » est habituellement utilisée pour désigner un sentiment d'inconfort sans nausée.

Dernière version : Mars 2013

***Version originale : Kennedy, R.S., Lane, N.E., Berbaum, K.S., & Lilienthal, M.G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology*, *3*(3), 203-220

Questionnaire sur les Cybermalaises

Laboratoire de Cyberpsychologie de l'UQO

Cotation de la version canadienne-française du Questionnaire sur les cybermalaises :

- Faire le Total des items 1 à 16 : échelle de 0 (pas du tout) à 3 (sévèrement).
  - Sous-échelle « *Nausée* » : items 1 + 6 + 7 + 8 + 12 + 13 + 14 + 15 + 16.
  - Sous-échelle « *Oculo-moteur* »: items 2 + 3 + 4 + 5 + 9 + 10 + 11.

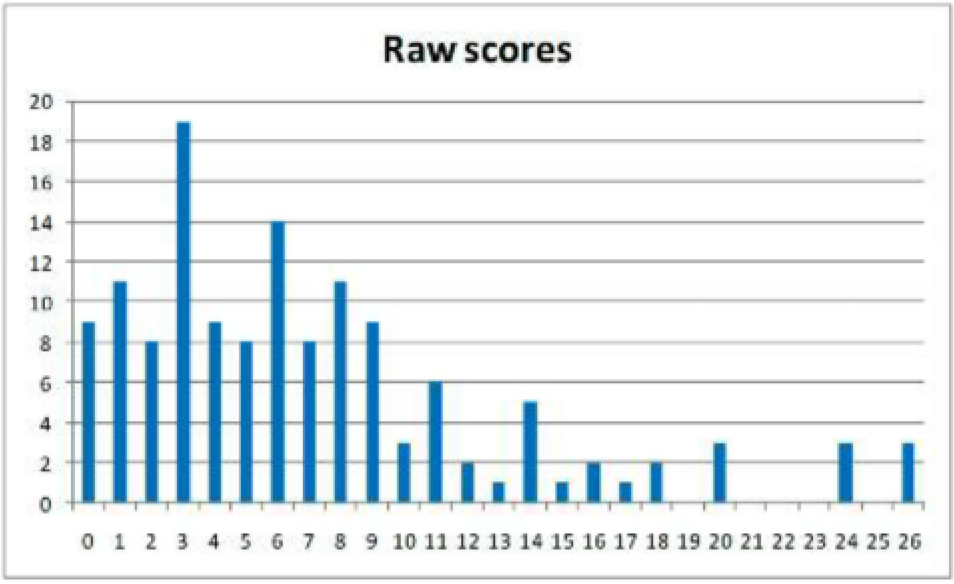
Pour consulter les articles scientifiques sur la validation canadienne-française de ce questionnaire, veuillez-vous référer aux articles suivants :

BOUCHARD, S., Robillard, & Renaud, P. (2007). Revising the factor structure of the Simulator Sickness Questionnaire. Acte de colloque du *Annual Review of CyberTherapy and Telemedicine*, *5*, 117-122.

BOUCHARD, S., St-Jacques, J., Renaud, P., & Wiederhold, B.K. (2009). Side effects of immersions in virtual reality for people suffering from anxiety disorders. *Journal of Cybertherapy and Rehabilitation*, 2(2), 127-137.

BOUCHARD, S. Robillard, G., Renaud, P., & Bernier, F. (2011). Exploring new dimensions in the assessment of virtual reality induced side-effects. *Journal of Computer and Information Technology*, *1*(3), 20-32.

Basée sur les résultats de l'étude de Bouchard, St-Jacques, Renaud, & Wiederhold (2009), voici la moyenne des scores reportés dans l'étude de validation:



Note. Pour la cotation et validation de la version originale anglaise, veuillez consulter l'article suivant : Kennedy, R.S., Lane, N.E., Berbaum, K.S., & Lilienthal, M.G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology, 3*(3), 203-220.

7.2 Appendix B. French version of the IPQ presence questionnaire

Voici plusieurs propositions qui peuvent s'appliquer à l'expérience que vous venez d'avoir. Indiquez, s'il vous plait, si chacune de ces propositions s'applique ou non à votre expérience. Vous pouvez utiliser n'importe quelle graduation. Il n'y a pas de bonne ou de mauvaise réponse, seule votre opinion est importante.
Vous remarquerez que certaines questions se ressemblent. Ceci est nécessaire pour des raisons statistiques. Rappelez-vous que vous devez répondre à ces questions en vous référant seulement à l'expérience que vous venez juste d'avoir.

A quel point étiez-vous conscient du monde réel environnant alors que vous étiez en train de naviguer dans le monde virtuel ? (par exemple : sons, température de la pièce, présence d'autres gens, etc.) ?

Extrêmement conscient — Pas conscient du tout

-3 -2 -1 0 +1 +2 +3

Modérément conscient

Comment le monde virtuel vous a-t-il semblé?

Complètement réel — Pas du tout réel

-3 -2 -1 0 +1 +2 +3

J'ai eu la sensation d'agir dans l'espace virtuel plutôt que d'agir sur un quelconque mécanisme à l'extérieur de celui-ci.

Pas du tout d'accord — Complètement d'accord

-3 -2 -1 0 +1 +2 +3

A quel point votre expérience dans l'environnement virtuel vous a-t-elle semblée cohérente avec votre expérience dans le monde réel ?

Pas cohérente — Très cohérente

-3 -2 -1 0 +1 +2 +3

Modérément cohérente

A quel point le monde virtuel vous a-t-il semblé réel ?

A peu près aussi réel qu'un monde imaginé — Indistinguable du monde réel

-3 -2 -1 0 +1 +2 +3

Je ne me suis pas senti présent dans l'espace virtuel.

Pas senti présent — Senti présent

-3 -2 -1 0 +1 +2 +3

Je n’étais pas conscient de mon environnement réel.

Pas du tout d’accord -3 -2 -1 0 +1 +2 +3 Tout à fait d’accord

Dans le monde généré par l’ordinateur, j’ai eu le sentiment “d’y être ”.

Pas du tout -3 -2 -1 0 +1 +2 +3 Beaucoup

D’une certaine façon, j’ai eu l’impression que le monde virtuel m’entourait.

Pas du tout d’accord -3 -2 -1 0 +1 +2 +3 Tout à fait d’accord

Je me suis senti présent dans l’espace virtuel.

Pas du tout d’accord -3 -2 -1 0 +1 +2 +3 Tout à fait d’accord

Je faisais toujours attention à l’environnement réel.

Pas du tout d’accord -3 -2 -1 0 +1 +2 +3 Tout à fait d’accord

Le monde virtuel semblait plus réaliste que le monde réel.

Pas du tout d’accord -3 -2 -1 0 +1 +2 +3 Tout à fait d’accord

J’avais l’impression que j’étais juste en train de percevoir des images.

Pas du tout d’accord -3 -2 -1 0 +1 +2 +3 Tout à fait d’accord

J’étais complètement captivé par le monde virtuel.

Pas du tout d’accord -3 -2 -1 0 +1 +2 +3 Tout à fait d’accord

7.3 Appendix C: English (WEB) version of the IPQ presence questionnaire

How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?

extremely aware	-3	-2	-1	0	+1	+2	+3	not aware at all
				moderately aware				64/inv1/0

How real did the virtual world seem to you?

completely real	-3	-2	-1	0	+1	+2	+3	not real at all
								48/real1/1

I had a sense of acting in the virtual space, rather than operating something from outside.

fully disagree	-3	-2	-1	0	+1	+2	+3	fully agree
								31/sp4/2

How much did your experience in the virtual environment seem consistent with your real world experience ?

not consistent	○	○	○	○	○	○	○	very consistent
	-3	-2	-1	0	+1	+2	+3	
				moderately consistent				7/real2/3

How real did the virtual world seem to you?

about as real as an imagined world	○	○	○	○	○	○	○	indistinguishable from the real world
	-3	-2	-1	0	+1	+2	+3	59/real3/4

I did not feel present in the virtual space.

did not feel	○	○	○	○	○	○	○	felt present
	-3	-2	-1	0	+1	+2	+3	28/sp3/5

I was not aware of my real environment.

fully disagree	○	○	○	○	○	○	○	fully agree
	-3	-2	-1	0	+1	+2	+3	37/inv2/6

In the computer generated world I had a sense of "being there"

not at all	○	○	○	○	○	○	○	very much
	-3	-2	-1	0	+1	+2	+3	62/g1/7

Somehow I felt that the virtual world surrounded me.

fully disagree	○	○	○	○	○	○	○	fully agree
	-3	-2	-1	0	+1	+2	+3	44/sp1/8

I felt present in the virtual space.

fully disagree	○	○	○	○	○	○	○	fully agree
								33/sp5/9
	-3	-2	-1	0	+1	+2	+3	

I still paid attention to the real environment.

fully disagree	○	○	○	○	○	○	○	fully agree
	-3	-2	-1	0	+1	+2	+3	40/inv3/10

The virtual world seemed more realistic than the real world.

fully disagree	○	○	○	○	○	○	○	fully agree
	-3	-2	-1	0	+1	+2	+3	47/real4/11

I felt like I was just perceiving pictures.

fully disagree	○	○	○	○	○	○	○	fully agree
	-3	-2	-1	0	+1	+2	+3	30/sp2/12

I was completely captivated by the virtual world.

fully disagree	○	○	○	○	○	○	○	fully agree
	-3	-2	-1	0	+1	+2	+3	38/inv4/13

7.4 Appendix D: Perceived video quality questionnaire

1. Comment évalueriez-vous les **couleurs** de l'image ?

Mauvais Excellente

-3 -2 -1 0 +1 +2 +3

2. Comment évalueriez-vous le **contraste** de l'image ?

Mauvais Excellente

-3 -2 -1 0 +1 +2 +3

3. Comment évalueriez-vous les **contours** de l'image ?

Mauvais Excellente

-3 -2 -1 0 +1 +2 +3

4. Comment évalueriez-vous la **fluidité** des mouvements ?

Mauvais Excellente

-3 -2 -1 0 +1 +2 +3

5. Avez-vous remarqué un **scintillement** dans la séquence ?

☐ **OUI** ☐ **NON**

Si vous avez remarqué un scintillement, veuillez l'évaluer sur l'échelle ci-dessous.

Très ennuyant/dérangeant Pas ennuyant/ dérangeant

-3 -2 -1 0 +1 +2 +3

6. Avez-vous remarqué des **images fantôme** (effet de trainage) dans la séquence?

☐ **OUI** ☐ **NON**

Si vous avez remarqué des images fantôme (effet de trainage), veuillez l'évaluer sur l'échelle ci-dessous.

Très ennuyant/dérangeant Pas ennuyant/ dérangeant

-3 -2 -1 0 +1 +2 +3

7. Avez-vous remarqué un manque de réactivité du système ?

☐ **OUI** ☐ **NON**

Si vous avez remarqué un manque de réactivité du système, veuillez l'évaluer sur l'échelle ci-dessous.

Très ennuyant/dérangeant Pas ennuyant/ dérangeant
-3 -2 -1 0 +1 +2 +3

8. Avez-vous remarqué des **« pavés de pixel »** (macro blocs) dans l'image ?
   □ **OUI** □ **NON**

Si vous avez remarqué un manque des « pavés de pixel », veuillez l'évaluer sur l'échelle ci-dessous.

Très ennuyant/dérangeant Pas ennuyant/ dérangeant
-3 -2 -1 0 +1 +2 +3

9. Avez-vous remarqué des **images figé ou des « écrans noirs »** pendant votre expérience ?
   □ **OUI** □ **NON**

Si vous avez remarqué des **images figées ou des « écrans noirs »**, veuillez l'évaluer sur l'échelle ci-dessous.

Très ennuyant/dérangeant Pas ennuyant/ dérangeant
-3 -2 -1 0 +1 +2 +3

7.5 Appendix E: French version of HTC vive security warnings

Consigne de sécurité HTC VIVE.

Crises Photosensibles

Comme d'autres produits qui produisent des effets visuels (y compris des éclairs lumineux), le produit peut déclencher des crises d'épilepsie, des convulsions, des évanouissements ou des étourdissements graves, même chez les personnes qui n'ont pas d'antécédents de ces conditions. Si vous avez des antécédents d'épilepsie ou de convulsions, de perte de conscience, ou d'autres symptômes liés à l'épilepsie, consultez votre médecin avant d'utiliser le produit. Pour réduire la probabilité d'une crise, n'utilisez pas le produit si vous êtes fatigué ou avez besoin de sommeil.

Interférence de Radiofréquences

Le produit peut émettre des ondes radio qui peuvent interférer avec le fonctionnement des appareils électroniques à proximité. Si vous avez un stimulateur cardiaque ou autre appareil médical implanté, n'utilisez pas le produit avant d'avoir consulté votre médecin ou le fabricant de votre appareil médical. *Pour minimiser les interférences de fréquence radio, utilisez uniquement des accessoires approuvés par le fabricant original ou des accessoires qui ne contiennent pas de métal. L'utilisation d'accessoires non approuvés par le fabricant original pourrait transgresser vos règles locales d'exposition aux radiofréquences et doit donc être évitée.*

Arrêter l'utilisation si vous ressentez une gêne

Arrêtez d'utiliser le produit et consultez votre médecin si vous ressentez un des symptômes suivants :

- Attaques, perte de conscience, convulsions, mouvements involontaires, vertiges, désorientation, nausées, étourdissements, somnolence ou fatigue ;
- Douleur ou inconfort oculaire, fatigue oculaire, tics des yeux, ou anomalies visuelles (comme la vision modifiée, floue, ou double) ;
- Transpiration excessive, salivation accrue, troubles du sens de l'équilibre, coordination œil-main avec facultés affaiblies, ou autres symptômes similaires au mal des transports.

Jusqu'à récupération complète de ces symptômes, ne conduisez pas, n'utilisez pas de machines, ou ne prenez pas part à des activités qui peuvent avoir des conséquences potentiellement graves.
Avant de reprendre l'utilisation du produit, assurez-vous qu'il est correctement configuré.
Le type de contenu que vous utilisiez peut avoir causé vos symptômes. Continuer à utiliser un tel contenu peut vous conduire à éprouver les mêmes symptômes.

Utilisation par les Enfants

Le produit n'a pas été conçu pour être utilisé par les enfants. Ne laissez pas ce produit à la portée des jeunes enfants et ne les laissez pas l'utiliser ou jouer avec lui. Ils pourraient se blesser ou blesser d'autres personnes, ou risqueraient d'endommager accidentellement le produit.

Le produit peut contenir de petites pièces aux bordures coupantes qui pourraient causer une blessure ou qui pourraient se détacher et présenter un risque de suffocation pour les jeunes enfants. Consultez immédiatement votre médecin si des pièces du produit ou des accessoires sont avalés.

Si les enfants plus âgés sont autorisés à utiliser le produit, alors des adultes doivent les surveiller de près pour déceler des effets négatifs pendant et après leur utilisation du produit. Ne laissez pas les enfants âgés utiliser le produit si des effets négatifs sont observés. Les adultes doivent aussi veiller à ce que les enfants plus âgés évitent l'utilisation prolongée du produit.

7.6 Appendix F: French version of the participants agreement

FORMULAIRE DE CONSENTEMENT

Je soussigné(e) :

Volontaire participant au test		**Ou représentant légal (e.g. si le volontaire est mineur)**	
Prénom		Prénom	
Nom		Nom	

certifie avoir donné mon accord pour participer à une expérimentation de l’usage de technologies / à un test d’expérience utilisateur consistant en l’évaluation d’un expérience en RV (« Test »),sous supervision du ou des expérimentateur(s), organisé par **la Fondation de Coopération Scientifique b<>com dont le siège social est situé 1219 avenue des Champs Blancs, (35510) CESSON-SEVIGNE (SIREN 751 468 943)** dans le contexte suivant :

Date	
Lieu	Cesson-Sevigne
Expérimentation	WORTECS

J’accepte volontairement de participer à ce Test et je comprends que ma participation n’est pas obligatoire et que je peux la stopper à tout moment sans avoir à me justifier ni encourir aucune responsabilité. Mon consentement ne décharge pas les organisateurs du Test de leurs responsabilités et je conserve tous mes droits garantis par la loi.

Au cours du Test, j’accepte que soient recueillies les données suivantes :

- mon nom, prénom, âge, sexe,
- mes réponses aux questions des expérimentateurs

La réponse aux questions est entièrement libre et je suis informé que je peux refuser de répondre à toute question.

Les données sont collectées afin de conduire le Test et de permettre aux expérimentateurs de créer à partir d’elles des statistiques anonymes à usage de recherche et développement, sous la responsabilité de la Fondation de Coopération Scientifique b<>com. J’accepte pour ce faire que les données enregistrées à l’occasion du Test puissent être conservées dans une base de données confidentielle et faire l’objet d’un traitement informatisé interne à b<>com.

Mon identité n’apparaîtra dans aucun rapport ou publication et toutes les données me concernant sont destinées à être anonymisées ou supprimées par b<>com dans un délai maximum de 1 mois à compter de la fin du Test. Ce formulaire contenant mes noms et prénoms ne sera plus corrélé au reste des données après ce délai de 1 mois et sera archivé par b<>com pendant 5 ans à compter de la fin du Test.

J’ai bien noté que, conformément à la législation informatique et liberté en vigueur, je dispose d’un droit d’accès, de rectification, d’opposition, de limitation et d’effacement de mes données personnelles que je peux exercer auprès de b<>com à tout moment avant l’anonymisation ou la suppression des données, en m’adressant aux expérimentateurs par voie postale ou téléphonique grâce aux coordonnées en bas de page, ou par email à *personal-data@b-com.com*. La collecte et l’utilisation de mes données personnelles par b<>com dans le cadre du Test repose légalement sur mon consentement, que je peux retirer à tout moment. En outre, j’ai été informé qu’en cas de manquement de b<>com à ces droits, je peux déposer une réclamation postale ou en ligne auprès de la CNIL (Commission Nationale Informatique et Libertés).

Par ailleurs, j'ai été informé que la participation au Test nécessite un bon état de santé général. Par conséquent, je déclare par la présente être en bon état de santé, ne pas avoir d'antécédents médicaux particuliers, et ne pas avoir débuté de traitement médical de longue durée durant les 12 derniers mois. b<>com ne saurait être tenu pour responsable en cas de fausse déclaration de ma part.

Noms et signature
de(s) expérimentateur(s) :

Signature du volontaire (ou de
son représentant légal) :
(Précédée de la mention « lu et approuvé »)

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