Master Thesis

TELECOLLABORATION BETWEEN CAVE 2 AND HTC VIVE

2016

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SUMMARY: This report shows the work which has been done during my Internship for Mechdyne and my Master project. The main subject is to evaluate the combination of the CAVE 2 and the HTC Vive to improve the collaborative task. The first part of my report will begin with my work for Mechdyne that laid the groundwork to my main project. The second part of my paper is a bibliographic review to evaluate in different ways my topic. The third part is the presentation of my experiment. The last part is the analysis of results from my experiments and validation of my hypothesis.

KEY WORD: HTC Vive, CAVE 2, Collaborative task, NASA TLX, Virtual reality, EVL, Mechdyne, HoloLens, Omegadesk, Cybercommon, Unity, Interaction, HMD, Oréal, Virtual shoper

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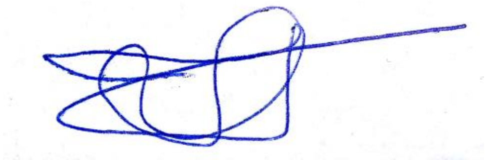

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Introduction:

We are living in a very interesting period for virtual reality (VR). The general press called 2016 “the year of the VR”. In fact, they talked about the new Head Mounted Display (HMD) being available for the first time to the general public. They manage to produce advances in HMD and making it more affordable (such as HTC, Oculus and Sony). VR exists since the 1950’s and takes different forms other than an HMD. For example, CAVE is a VR device. Its screens are not in front of the eyes of the user rather it is projected on some big screen. While HMD is the opposite. CAVE is very expensive to manufacture and requires big spaces. This type of VR is more fitting for industrial use. On the other hand, HMD is also suitable for industrial use because it has high quality engagement among participants, it is less expensive to produce, and it is at parity with CAVE’s standard. Both devices have advantages and disadvantages. Thus, it would be interesting to combine both devices to complement each other.

Indeed, the VR has a lot of applications. One of the applications that arouses great interests among companies is its collaborative application. It connects people in various locations to work together.

With the advent of globalization, many big companies have international presence and their subsidiaries are located in various countries. In order to bring them together, they need an effective network of communication. Essentially, companies such as Microsoft with Windows Holographic or MiddleVR with Improov3 are developing their own platforms and devices to connect people in various locations in more efficient way.

With this in mind, my objective is to develop a synergy among people in combining two VR devices and explore its efficiency and capability.

The first part of my paper will begin with my work for Mechdyne that laid the groundwork to my main project. The second part of my paper is a bibliographic review to evaluate in different ways my topic. The third part is the presentation of my experiment. The last part is the analysis of results from my experiments and validation of my hypothesis.

I) Internship presentation

My presentation will begin with the company and their laboratory that I worked for. I will state my objective and discuss briefly my internship. I will explain my hypothesis, methodology of collecting data, my analysis, and the conclusion of my project.

A) Industrial context

Mechdyne Corporation was founded in 1996 by Iowa State University (ISU) graduates, Dr. Chris Clover, Jim Gruening, and Kurt Hoffmeister after honing their skills at ISU's Virtual Reality Applications Center. (1)

Figure 1-Mechdyne Logo source:Mechdyne

Industry-relevant content development is a critical challenge for the active use of large VR systems. The complexity of simultaneously driving multiple displays from multiple computers requires applications that behave consistently from the users' direct interactions. Mechdyne actively utilizes the Unity game engine to provide customers with a robust solution for authoring complex, dynamic content. getReal3D is a plug-in that makes the Unity game engine compatible with VR equipment such as the CAVE(tm) and head-mounted displays for more realistic training and simulation scenarios.

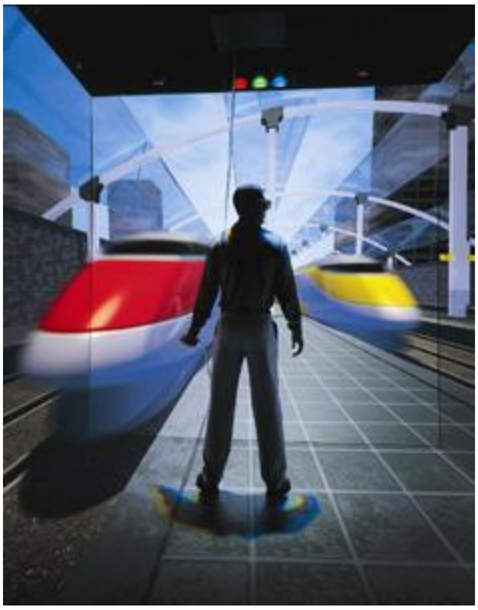


Figure 2-CAVE source:Mechdyne

getReal3D adds support for 3D stereo, tracking systems, cluster support, and synchronization. Content demonstrating relevant use cases for industrial design, manufacturing, architectural

visualization, and biomedical visualization will yield insights to the applicability of this technology to solving customers' workflows.
Mechdyne is exploring the implementations of several used cases informed by current customer conversations. These explorations will provide exposure to solving real-world problems through large-scale VR.

The objective of this internship is to assist Mechdyne on their discovery through Unity, getReal3D, and VR systems.

B) Laboratory sponsor

During my internship, I was working on new solutions for Mechdyne. I worked with one of their sponsored facilities using the equipment available at this laboratory. This laboratory is called EVL (Electronic Visualization Laboratory) in Chicago.

Figure 3-Logo EVL source: EVL

"*The Electronic Visualization Laboratory (EVL) at the University of Illinois at Chicago (UIC) is an internationally renowned interdisciplinary research laboratory whose mission is to enable scientific and engineering discoveries by designing and developing high-performance visualization, virtual reality, and collaboration systems using advanced networking infrastructure."* (2)

EVL was the first lab to be equipped with the CAVE 2 (a CAVE second generation), a virtual reality system which immerses the user in a virtual world.

Figure 4-CAVE2 source:EVL

It is a virtual-reality room with stereoscopic 3D equipment which is approximately 24 feet in diameter and 8 feet tall. It is made up of 72 seamless passive stereo off-axis-optimized 3D LCD panels and a 36-node computer cluster. The user has a 320-degree panoramic environment with a resolution of 37 megapixels in 3D experience.

EVL has also an impressive meeting room called "Cyber-Commons" which is equipped with a tactile wall of multiple high-definition display and an advanced networking to facilitate and encourage group collaboration. This is an ultra-high-resolution visualization and networking instrument for research, education, and collaborations.

Figure 5-Cyber-Commons source:EVL

The main particularity of this room is its versatility. It can transform into a lecture and meeting room, classroom, and experimental room.

OmegaDesk:

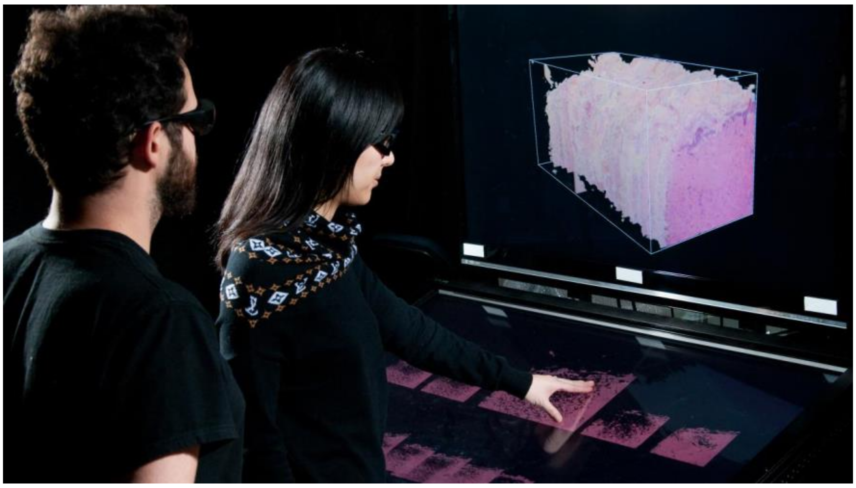


Figure 6-OmegaDesk source:EVL

This is an instrument for interactive visual data exploration and collaboration. This device enables users to view stereoscopic 3D volumes while browsing.

“*The OmegaDesk unifies ultra-high-resolution computer-enhanced collaboration workspaces and stereoscopic virtual environments with multi-touch-sensitive surfaces so that users can intuitively point, write, touch and manipulate the information displayed, and communicate and share this information with remote colleagues.*” (3)

Hololens:

Figure 7- Hololens source: Microsoft

The hololens is an AR (**A**ugmented **R**eality) glasses conceived by Microsoft. It allows you to see virtual objects in the real word. The device scans the world around you to identify all surfaces. When virtual object appears, it seems to be a part of the world. There is also a finger-tracking system where your fingers directly interact with the virtual objects in front of you.

HTC Vive:

Figure 8- HTC Vive source : HTC

The HTC Vive is a new HMD (Head-Mounted Display) similar to Oculus Rift. However, the device is furnished with two controllers which allow the hand tracking. It also allows room-scale set up to move in a room of 25m² maximum thanks to the lighthouse system which are the two cubs furnished with the Vive. There is also a front camera which able to see the reality without removing the HMD. It has two screens and two lens Fresnel to allow an immersion to virtual world.

The laboratory has many interesting equipment. However, I only discussed about main devices that equipped this laboratory.

C) Project presentation

In the first three months of my internship, Mechdyne had assigned me with several projects to work on before the main project. As my work on these projects progressed, it aroused my curiosity on these two devices that I was using.

Village Viking:

Village Viking is a scene made by Unity to demonstrate their new engine. You can download the scene on the Unity store for free. Mechdyne became interested and proposed that I adapt this scene for the CAVE and add some interactions.

This demo demonstrates the scope and power of the CAVE. You will notice that I enhanced the sceneries and made it compatible with CAVE 2.

Figure 9-Unity scene Village Viking Project

I also augmented the interactions to create new immersion or engagement to users. I added a hand to interact with objects. For example, when you grabbed an object, the hand will automatically disappears leaving only the user and the object. It makes the interaction more spontaneous and unscripted.

CAVE2 has no floor grid and thus, to pick up an object on the floor is very difficult. To resolve this issue, I added a feature (or interaction) that allows users to attract an object from a distance by using the controller. This feature requires users to direct the controller stick to the target object and press the button. When users pressed the button, a 3D sound will occur to signal that target object has been captured or held.

The 3D sound is very important because CAVE is equipped with 20-speaker surround audio sound system. The sound increases excitement among users. This audible feature stimulates the auditory sensor and enhances the experience of the user. With this in mind, I also added various acoustic tones such as footsteps, wind, fire sound for the torch, sea waves, and others. I have also customized function wherein each time the user moves away from the object the sound reduces accordingly. For example, interior of some houses (buildings or structures) produces sounds or tones. To visit some of them, I have implemented a new way of moving the “teleportation.” You target the place where you want to go, thanks to a circle, with your hand. As compared to the movement with joystick, this system of movement normally reduces the motion sickness that users might experience.

Virtual Shop for L’Oréal Paris:
The main purpose of this project was to make a Virtual Shop. In this virtual shop, user or pretend customer will shop, buy, or peruse like in a real shop.
L’Oréal give us only a 3D model of the shop. From this model, I created two versions of application. I made one for CAVE 2 and another one for Vive. The principle of this application is for users to approach the shelf and browse L’Oréal products on display. Users act as customers choosing, examining product contents and browsing shelves. Users also can buy L’Oréal products and add to basket or inventory.

_ CAVE 2 and Smartphone:
In this version, a green stick will select an object. The object appears in front of a view like a HUD (head-view display) where you can manipulate the object by using the joystick.

Figure 10-Virtual Shoper CAVE 2 application

The user carries a smartphone in the CAVE 2 which represents as a shopping basket where user will stock all the objects he wants.

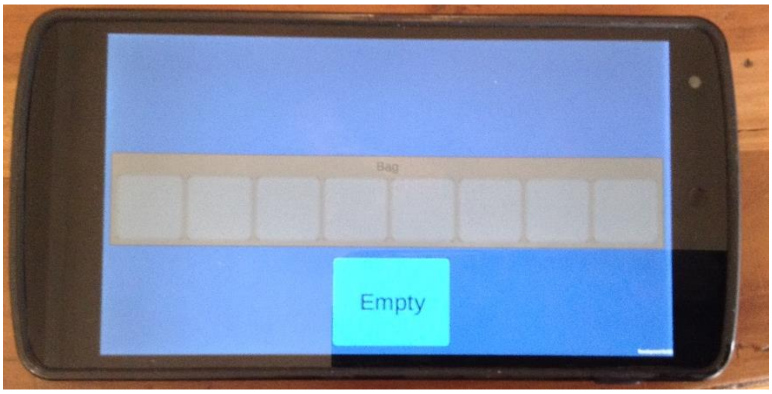


Figure 11-Inventory on Smartphone

Interestingly, when user selects an object a menu appears on the smartphone above the slots which represents as the shopping basket. This menu provides two choices “Accepted” or “Rejected.” If the user press “Accepted” on his smartphone the object will disappear from the shelf and an image of the object will appear in the first slot of the shopping basket on the smartphone. If the user press “Rejected” the object will be replaced in the shelf. The user can press the button “Empty” on his phone when he wants to replace all objects on the shelf and empty his shopping basket.
This application is made for Android.

After these applications, I made another version with the HTC Vive.

_ HTC Vive:
The challenges encountered were different because the reality around us is not visible. So we cannot use an external tool like smartphone. Contrary to the CAVE, we have also a second wand.

Figure 12-Virtual Shoper Vive application

To resolve it, I replaced the smartphone with a real shopping basket. Left wand was modelled by the shopping bag and the right hand was modelled by a virtual hand. When the user wants an object he can teleport in front of the shelf and grab the object with his hand (which is right wand). He can examine the object like he has the actual object in front of him. If he wants to keep the object, he does the same as he was in a real shop. He will put the object inside his shopping bag with his hand. If he wants to replace the object, he can get grab the object in his shopping bag with his virtual hand and replaces it with another object from the shelf. This is not automatic but close enough to mimic the action in real life. This way, user will have a sense of shopping in real shop.
Upon completion of these projects, I started my main project.

Main Project: Collaboration between CAVE and Vive

This project is about collaborative tasks in virtual reality. Prior, Mechdyne has already made a concerted project between two CAVEs but neither with a Vive. Compared to current Oculus rift, Vive is more exciting because it has a "room scale" technology that provides the user more versatility in navigating the virtual world.
The purpose of the project is to enable people around the world to work together without travelling physically to the same place. As we all know, we can do this with several CAVE 2 but this device is expensive and requires big space. In addition, company can invest in one CAVE 2 but it cannot provide CAVEs for each participant in distant places. Vive is an excellent option to achieve the same purpose. Vive is less expensive, easy to set up and user friendly. Host company can still use CAVE2, and can provide each participants with Vive device that can connect to the Host.

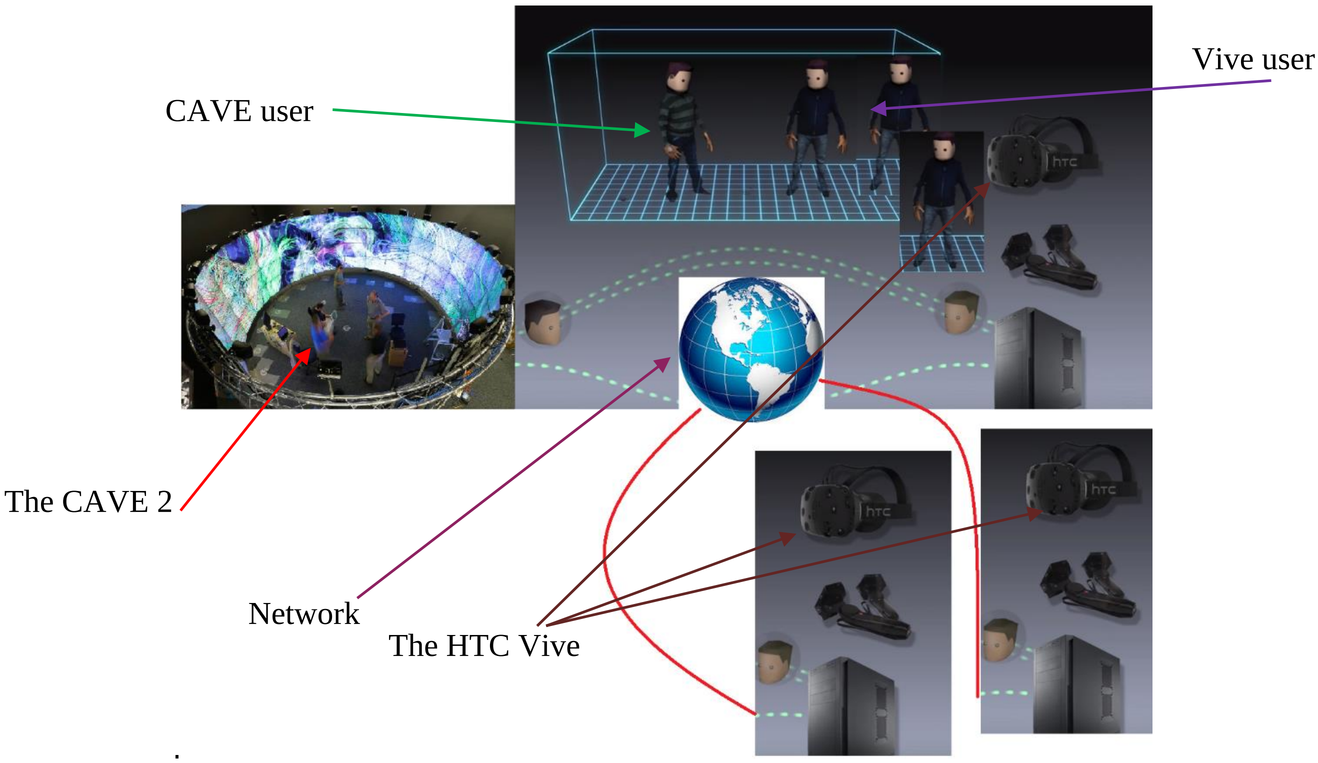


Figure 13-scheme of the project

There are two questions to consider. Can we replace CAVE 2? Is HMD the best choice to replace CAVE 2? In fact, CAVE 2 and HMD has advantages and disadvantages.
Below is an example of chart showing comparison between HMD (Oculus rift) and CAVE.

	Oculus Rift HMD	VisCube CAVE
Resolution	~1 Mpixel per eye	~2-8 Mpixels per screen
Image Quality	requires distortion and color correction	pixel perfect
Immersion	completely immersive	immersive
Field of View	100 degrees	170 degrees
Presence	disembodied, isolating	excellent, see your own body
User Volume	movement limited due to isolation, tether, and small tracked volume	completely wireless, precise tracking, move around freely in user volume

	Oculus Rift HMD	VisCube CAVE
Users	single user	multiple viewers, one tracked user
Comfort	bulky, tethered, sweaty	lightweight glasses, wireless
Small Group Collaboration	not well suited	ideal for face-to-face meetings
Tracking Error/Latency	sensitive, simulator sickness more likely	much less sensitive, simulator sickness less likely
Accomodation	close screens cause eye discomfort over time	large, fixed screens comfortable with extended use
Cost	very low cost	high cost

Figure 14-HMD vs CAVE source:visbox.com

Combination of HMD and CAVE can provide cheaper solution and can improve collaboration among participants.
In our case, I have chosen the HTC Vive as HMD which is the most advance HMD for consumer market.

Therefore, I have decided to test my hypothesis and inquire the problematic.

<u>Hypothesis:</u>
Combination of HTC Vive and CAVE improves the user’s performance in collaborating with other users.

<u>Problematic:</u>
Does collaboration between a CAVE system and an HMD improve task performance?

I begin my study with a bibliographic review of what the VR community

II) Bibliographic Review

Before we begin this project, we need to review what has already done about the collaborative work and virtual reality. In this purpose, I have reviewed different articles, papers and projects.

The RAVE, CAVE, and Collaborative Virtual Environments (4)**:**

This paper tried to answer some questions about RAVE, CAVE and other immersive devices using the CVEs (Collaborative Virtual Environments). A good summary can be find at the end of the paper with main questions and concise answers.

*"**What is a collaborative virtual environment (CVE)?** Collaborative Virtual Environments (CVEs) involve the use of networked virtual reality systems to support cooperation between groups of people. (Workshop on CVEs in Higher Education, 1997)*

What/where are some current research projects being conducted involving immersive projection systems, such as the RAVE, CAVE, and ImmersaDesk(TM) and collaborative virtual environments? *Research in this area is being conducted in a number of facilities around the world.*

What are some current applications using immersive projections systems in collaborative virtual environments? *Typical applications include collaborations between researchers at universities and between employees of corporations.*

What is needed to enable the RAVE to be linked to CAVEs and similar immersive projection systems, so that users geographically separated can work together in realtime? *Needed are connections to one or more network systems, software, knowledgeable RAVE personnel, and willing collaborators*." (4)

This paper describes an important interesting number of application using the CAVE first generation and the CVEs. In particular, some experiments are led by EVL. However, this paper is too old (2000) and obsolete. We are now at EVL a second generation CAVE. We have also some new free system of communication (for example, skype, video conferencing, Google Hangouts) which was a problem encountered by Tohwa University (Japan) at this time because a call between them was too expansive.

The AR-CAVE: Distributed Collaborative Augmented Reality and Immersive Virtual Reality System (5)**:**

This paper tried to combine an augmented reality (AR) environment with immersive virtual environment. In this purpose, they combine a CAVE first generation with the AR-CAVE (Augmented Reality connected CAVE). This last device is independent from the CAVE. It allows physical activity and expand the virtual space and collaboration between two different geographic areas.

The experiment:

Two users play together a simple hitting ball game called Ting Ting Together. One is in the CAVE and the other is in the AR-CAVE.

(c) Playing T3 in the AR (d) Playing T3 in the VT-CAVE

Conclusion:

The idea to use AR to integrate new interactions is very interesting. However, the immersion in the AR isn't satisfying. I prefer using another VR device such as VIVE which brings new interactions in a fascinating way. On top of this, feedback received is not enough contrary to the combination of the VIVE and the CAVE where you can directly see what the other user is doing.

Immersive Collaborative Analysis of Network Connectivity: CAVE-style or Head-Mounted Display? (6)**:**

This paper is a study "*of collaborative abstract visualisation of 3D network diagrams in CAVE-style and HMD platforms*." (6) They want to analyse the effects of these platforms on "*task performance, collaboration and user experience for some representative abstract visualisation"* (6).

Moreover, they want to check if we can replace the expensive device CAVEs to the lost cost HMD.

The experiments:

We have two different groups (HMD and CAVE). Each group have two collaborative visualisation tasks.

CAVE:

We have two users in the CAVE 2 (2nd generation) viewing the 3D network.

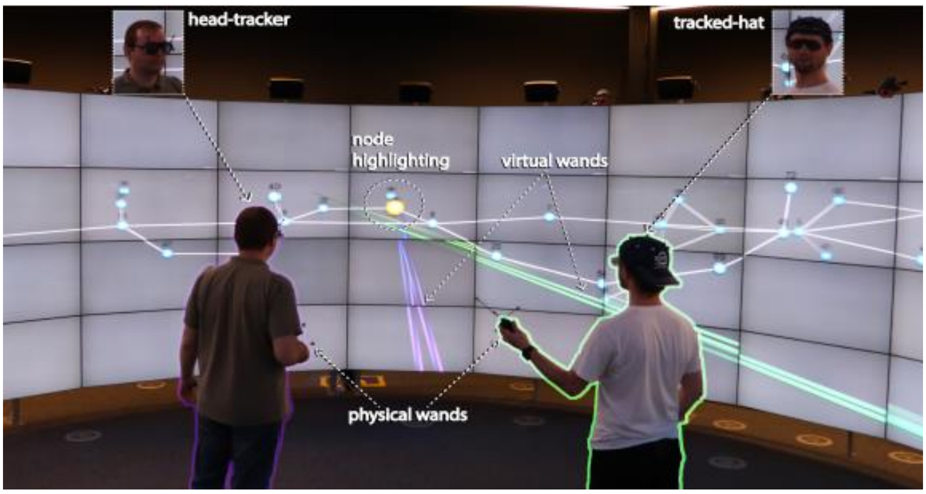


Figure 15-Two users in the CAVE2

The purple one carry a head tracker and the green one has no head tracker. The scene is rendered from the purple one.

HMD:

“Minimal set-up for a collaborative environment using two OR DK2+Leap motion, connected on LAN. Each user has an independent view of the visualisation in a Unity client, and sees each other’s view frustum and wands” (6)

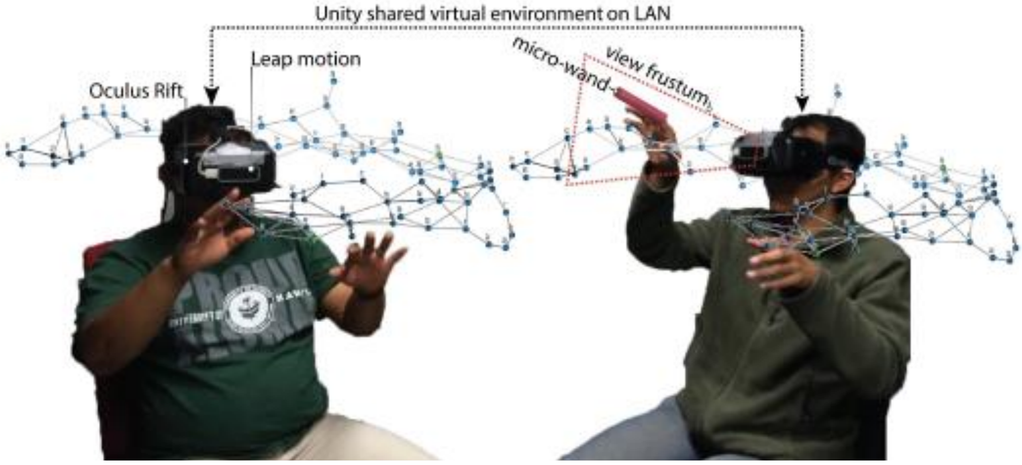


Figure 16-Two users with the two HMD

Conclusion:

At the end of this study they concluded that HMDs provide “*a comparable experience for collaborative abstract data*” (6). Contrary to them, I did not compare CAVE and HMD. My purpose is to validate that the combination of these two devices is better than individually. In fact, they did not try this combination and had said that both devices have different quality. In my experiment we try to solve a puzzle task and not abstract data. These experiments are very interesting because I intend to analyse another aspect.

<u>Tele-Immersive Collaboration in the CAVE Research Network</u> (7):

This paper demonstrates different application of tele-immersive with the CAVE and ImmersaDesk2.

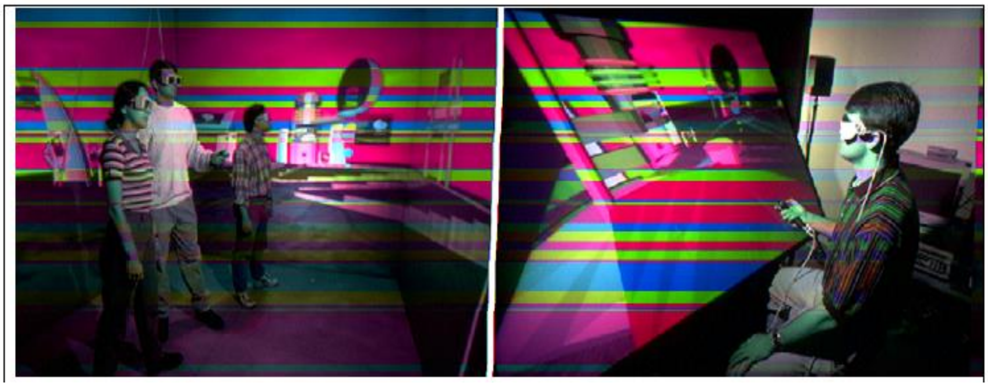


Figure 1: The CAVE and ImmersaDesk. The left image shows three people in the CAVE. All three wear shutter glasses to see the virtual world in stereo, but only one has a tracked pair of glasses and carries the wand. The right image shows a single user sitting in front of the ImmersaDesk wearing the same tracked glasses and carrying the same wand as in the CAVE. The CAVE and ImmersaDesk users can interact with the same virtual worlds from different perspectives.

These experiments are very interesting because they show different field of applications like climatological data, architecture, automobile….
They focused on the avatar and how we perceived the other user. So, it's easier for several users to work in the CAVE on the same application. In this experiment, they used two expensive devices which are not affordable to everybody. Furthermore, they underlined the advantages of these devices contrary to an HMD which is inexpensive and to be opened with the real world.

Evaluating Collaboration in Distributed Virtual Environments for a Puzzle-solving Task (8)**:**

"The purpose of the paper is to discuss the benefits and limitations of different methods for evaluating the effectiveness and experience of collaboration in distributed VEs or a puzzle-solving task. (8)*"*

The experiment:

They used different combinations of different devices:

Table 1: Abbreviations and settings

	The Five Settings
FtF	Face to face collaboration with cardboard blocks
I – I	Gothenburg IPT connected to London IPT
I – HMD	IPT connected to HMD
I – D	IPT connected to Desktop system
D – D	Two connected Desktop systems

The two users in each setting have to solve a puzzle involving 8 separate blocks with different colours on different sides. The objective of the pair is to set 4 blocks of the same colour on each of the six sides.

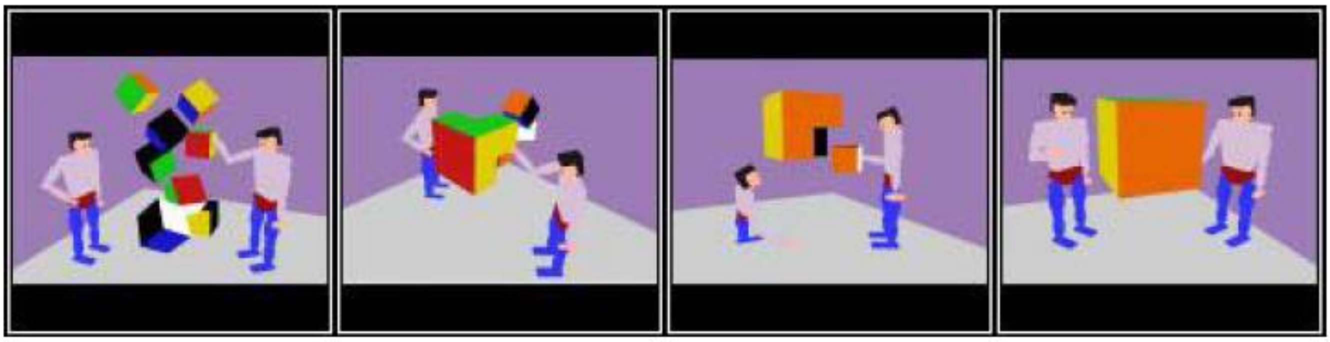


Figure 1: Four stages of solving the Rubik's Puzzle

Conclusion:

This paper demonstrates the performance of collaborative tasks with different devices and its attempt to improve it. However, they did not try to compare with single person. They only analysed the result of pair. Though we used a new generation of CAVE (2nd generation), we did not take into account the price of different devices. If we have restrained our choice with one pair it is on purpose and not by default.

<u>Studying the Features of Collaboration in the VirCa Immersive 3D Environment (9)</u>:

In this paper, they wanted to demonstrate that virtual reality *"can appropriately support collaborative information interpretation and sharing activities.* (9)*"*

The experiment:

There are three elements that composed the 3D Environment:

1) physical representation of information in posters
2) user actions to manage these posters
3) collaborative editing surface to create a new document based on the interpretation of the information contained in the posters.

Hence, the interpretation will be encouraged by reading, structuring and organizing, highlighting, commenting, and creating new content.

We place everything in a 3D room model that was accessed by two collaborating participants. One participant was placed in a 3D Cave to experience an immersive environment. The other participant's computer (equipped with a Tobii T120 eye-tracker for further analyses not reported here) joined the partner through a desktop computer that provided a less immersive environment.

Figure 1. Collaborative review of the posters in the VirCA 3D cave.

Figure 2. Avatars in the VirCA 3D cave

Figure 3. A sticky note in the VirCA 3D cave.

Figure 4. Collaborative editing in the VirCA 3D cave.

Conclusion:

The experiment determines new information for the collaborative tasks (in particular the usage of eye tracking). Even in this case of combining VR device with a non VR device, the result is not as good as a HMD. It demonstrates that even if the interactions and the actions are very good, the second device (a desktop) is insufficient for superior immersion.

Collaborative tasks with only HMD (10)**:**

This experiment used only HMD and no CAVE to execute a collaborative task. They used two HTC Vive and a Kinect.
They attempted to build something together with some cubes using the controller of the Vive to interacts with them. The Kinect allows to model their actual body in the virtual world with a cloud of pixels.

Figure 17- Two Vive users working together

New platforms:

With new inexpensive HMD, there are new collaborative platforms which combine the CAVE and HMD which can eventually replace the CAVE with inexpensive HMD for economic reason.

MiddleVR:

Improov3 created by MiddleVR is a virtual co-working space and discussion room. According to MiddleVR, multiple users in different locations can join the virtual meeting room with or without a VR system.

Each user will have his own avatar and each participant can partake in a virtual room with various VR devices (Oculus Rift (DK1, DK2, CV1 & touch controllers), HTC Vive (DK1, Pre), CAVEs, Power walls, 3D TVs, and any VR systems supported by MiddleVR for Unity) and also with non-VR application (Gmail...).

"Improov3 allows users to review one or multiple 3D models in Virtual Reality in multiple monitors and discuss using virtual keyboard floating inside the virtual space. " (11)

"The product review can be collaborative; it is a solution for colleagues from the same company to work while travelling in different locations." (11)

Dassault Systèmes:

Dassault Systèmes intends to replace the CAVE which is considerably too expensive. However, the main default with the HMD is the isolation. As matter of fact, you cannot see your partner physically next to you. So it "*began its "Never Blind in VR" project two years ago to solve*" (12) this problem.

In the original project, they used Kinect to scan the real world around the user to allow him to see it. But the HTC Vive has his own front camera which prompted them to integrate it and to replace the Kinect.

III) The experiment

We will see now in detail the conduct of the experiment. I will begin with the presentation of the application used during my experiment and the methodology. Finally, I will detail my experiment plan.

A) The application

I made my application using Unity which is a game engine. Unity has its own physic engine and graphic engine. There are plenty of game engines but I have chosen this one because it is free and compatible with CAVE 2 and HTC Vive.

Figure 18-Official Unity Logo source: wikipedia

My application is made up of two components: a client and a server. This is a multi-users application using UNET which is the networking module of unity integrated into the engine that is allowing someone to work with components and visual aids to build its multi-users application.

The concept of my project is to use HTC Vive to complement the functionality of CAVE 2. Rather than having several CAVE 2 which is too expensive, HTC Vive will fill-in for other required elements of my project.

My project only requires one CAVE to use. Thus, a company, for example, can set one CAVE 2 in their headquarter and works with other collaborators throughout the world without needing to build another CAVE for another location. They just need an HTC Vive which is inexpensive. Consequently I have decided that CAVE 2 will be the server that will host clients who will be using HTC Vive.

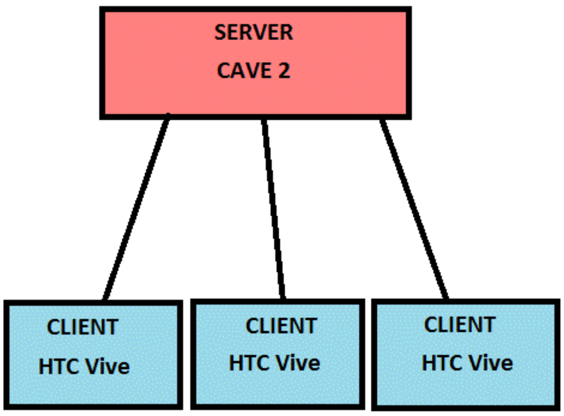


Figure 19-Networking Client_Server

I have chosen to make a puzzle game to underline the benefits of the collaborative work between a Vive and a CAVE 2. The purpose of the experiment is to build a figure with cubes of different colours in a limited time. I have made three different versions of this application: a demo, a second application where the user is alone (single version), and a third application where the user works with another user (collaborative version). For each version, we have one for the user of

Vive and one for the user of the CAVE2. The only difference among these versions is the figure which has to be made. In a demo, we have only one to help the user to be aware with the application and his device (Vive or CAVE 2). In the single and collaborative versions, we want to evaluate if the user performs better alone or with someone. We keep the same instruction (same figure) between these two versions. However, to avoid the learning effect between these two applications we have chosen to put different instructions (figures) and maintain the same level.

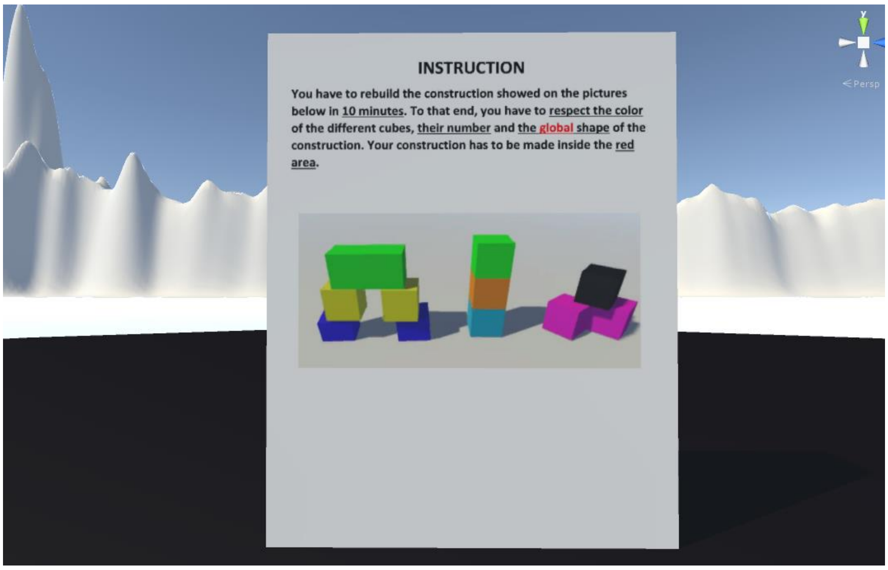


Figure 20-The big sign with the instructions (Demo application)

These three versions share the same functionalities. There are 56 cubes of 8 different colours distributed randomly in all the playable area. This area is divided into three zones: a red circle, a black circle and a white zone. The red circle is the delimited zone where you have to execute the task requested. The black and white area serves as a marker to the users for the distance from the red circle. You have also a big sign next to the red circle where the instructions are written.

Vive Interaction:

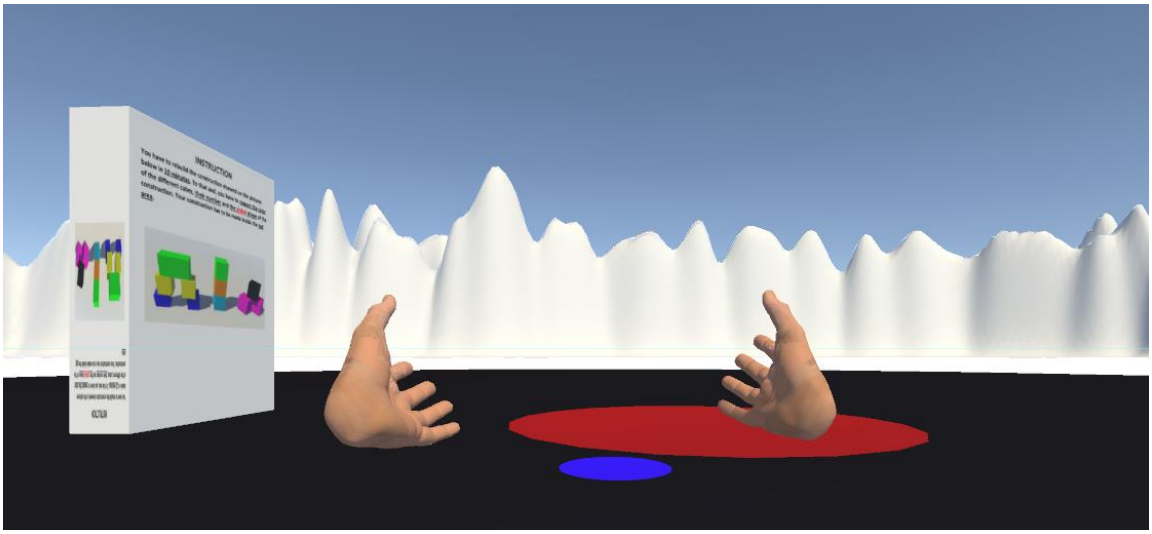


Figure 21-Vive application

Grabbing:

The Vive has two wands which are modelled by two virtual hands. You can grab a cub with each hand. Then, it becomes blue, when you touch it. This is your visual feedback. The hand will also disappear when grabbing an object which leaves only the object being visible. You have to drop the object to see your hand gain. This process improves immersion and interaction between user and object.

Movement:

We have two different ways to move in virtual world. We can teleport ourselves everywhere we want to go. We have a blue circle on the floor which represents the destination and we can move this circle in moving our wands. This is a good alternative contrary to the classic way of moving with joystick aim to reduce motion sickness. The Vive has also room-scale technology which makes it possible to walk naturally in a zone restricted by the room. Hence, when you can combine these two features: you move naturally for limited space and use teleportation to increase your distance.

Cave Interaction:

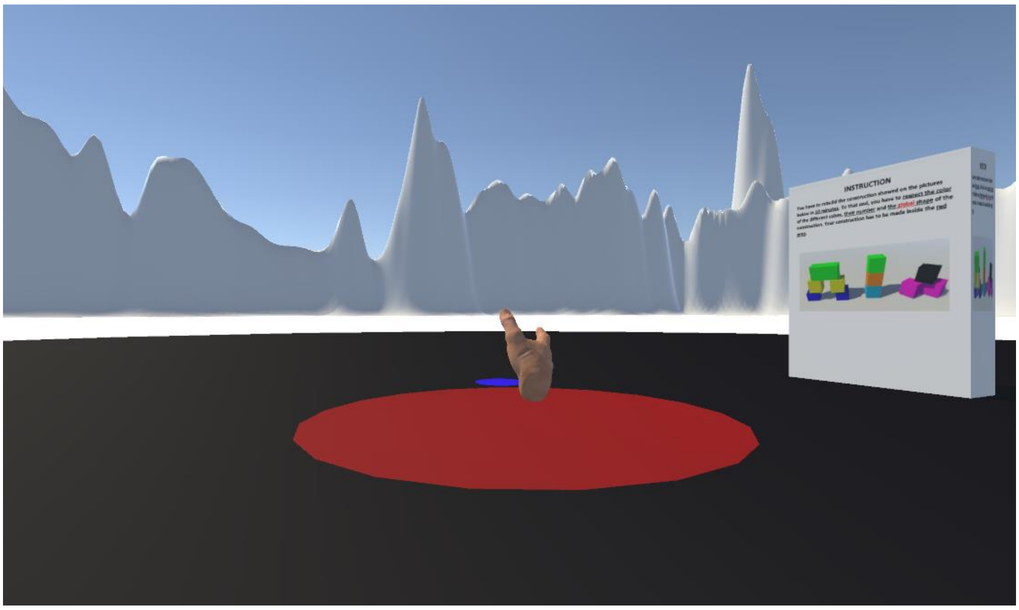


Figure 22-CAVE application

Grabbing:

The system of grabbing is the same as the Vive. The only difference is the number of the hand. Here, there is only one wand. We will have only one hand to interact in the virtual world. This restriction isn't technical. Our sponsor company imposed to use only one hand because CAVE 2 that they sell to its clients uses only one wand.

Movement:

We have three different capabilities to show mobility inside the virtual world. We can do teleportation similar to Vive's feature. We can do also something similar to room-scale but very limited because we have no floor grid. And we can do the classic way of using joystick to manipulate our movements. Unlike Vive, user will be free to use either teleportation, joystick or both.

Problem encountered:

-The first solution was to restrict the CAVE and the Vive with only one way of moving: the natural walking to prevent motion sickness. But if you restrict the play area of the size of the CAVE 2, the user in the CAVE 2 would not be able to see the cubs. The reason for this is that the CAVE 2, contrary to the CAVE (first generation) has no floor. Therefore, everything inside the CAVE 2 is not visible.

-In order to grab the cub, the cub has to be in front of the user's view. To improve this immersion, I added a virtual hand at the same exact position of the wand. In this way, it will provide the user a sense of actual hand with his virtual hand.

As we continue, the user has to be next to the cub to grab it. The user will have to come close to the screen where he can see and touch the cub but not too close to the screens or else tracking will disappear. Finally, I put the virtual hand far enough in front of the user to allow him to grab his cub without losing the grabbing component. Eventually, some interactions were compromised because the arm became too long for its purpose.

-I have to limit my play area and establish grids using mountains all around it. This is a cautionary move to avoid people who teleport themselves at the extremity of the terrain to fall into a void or crevices.

-Unlike Vive, the text in CAVE is bigger. It required me to adjust it.

Each time, the user has to complete all tasks within 10 minutes. The single and collaborative versions was designed not to be completed within 10 minutes in order for us to be able to measure what we want. Now we are going to discuss our methodology.

B) Methodology

My hypothesis states "the combination of HTC Vive and CAVE improves significantly the user's performance". With this in mind, I have to undertake the proper measures. Hence, I have chosen to use objective and subjective measures to best evaluate the performances of the users in each case.

Subjective measure:

<u>Virtual reality personal history survey:</u>

At the beginning of the experiment, a survey was provided to each user to be filled out before starting. This survey shows the background of the user about his experience with the VR devices and video games in general. The survey gives information for any impairments or health issues the user might have (for example, poor eyesight, history of vertigo or dizziness, claustrophobia, migraines or headaches) that would affect the performance and the experiment.

<u>Feedback survey:</u>

We give this survey to each user at the end of the experiment. This survey assisted us to determine if users have encountered some issues during the experiment which interfered with their performances. It gathered information on how to efficiently reduce motion sickness on various ways of moving. We used it also to compare the experience of users on single and collaborative tasks to evaluate which one produces high quality performance. Finally, this survey gave us the users reactions towards the experiment and the VR in general, including their suggestions on how to improve future experiments.

NASA-TLX (Task Load Index):
"*The NASA Task Load Index is a multi-dimensional rating procedure that provides an overall workload score based on a weighted average of ratings on six subscales: Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort and Frustration.*"

"*It was designed to reduce between-rater variability by using the a priori workload definitions of subjects to weight and average subscale ratings.*"

"*This procedure for collecting workload rating was developed by the Human Performance Group at NASA Ames Research Center during a three year research effort that involved more than 40 laboratory.*"
This survey allows the users to evaluate their own performance. So we give one at each user after each task (Demo, Single, Collaborative). We will give a total of three of it during the experiment for each user.

.

Objective measure:
Completion Rate:
I completed this survey at the end of each experiment. I counted the number of cubs the user abled to place during the 10 minutes time. I know the total number of cubs per each figure. This number allows me to know the completion rate per user per experiment to evaluate their performance. Normally, the figure is designed not to be completed in 10 minutes except the demo task to facilitate their performance evaluation. If user finishes before the end of the time I noted the time next to this rate.
These surveys were given during the experiment to every user. We will see now exactly the organisation and the material used during an experiment.

C) Experimental plan

The purpose of this experiment is to test our hypothesis. We need to have two users in a different geographical area (not to be seen or heard by the other). I placed the first user in the CAVE 2 and the second in the cyber common. Then, I arranged the Vive in the cyber common because to isolate these two users from each other. Cyber common is a big and versatile area which is perfect for the room scale. Hence, I will begin to present these two installations:

Vive installation:
We can see in detail the installation of VIVE in cyber common:

Figure 24-Stations lighthouse

Figure 23-Workstation (Computer)

Figure 25-User with the Vive

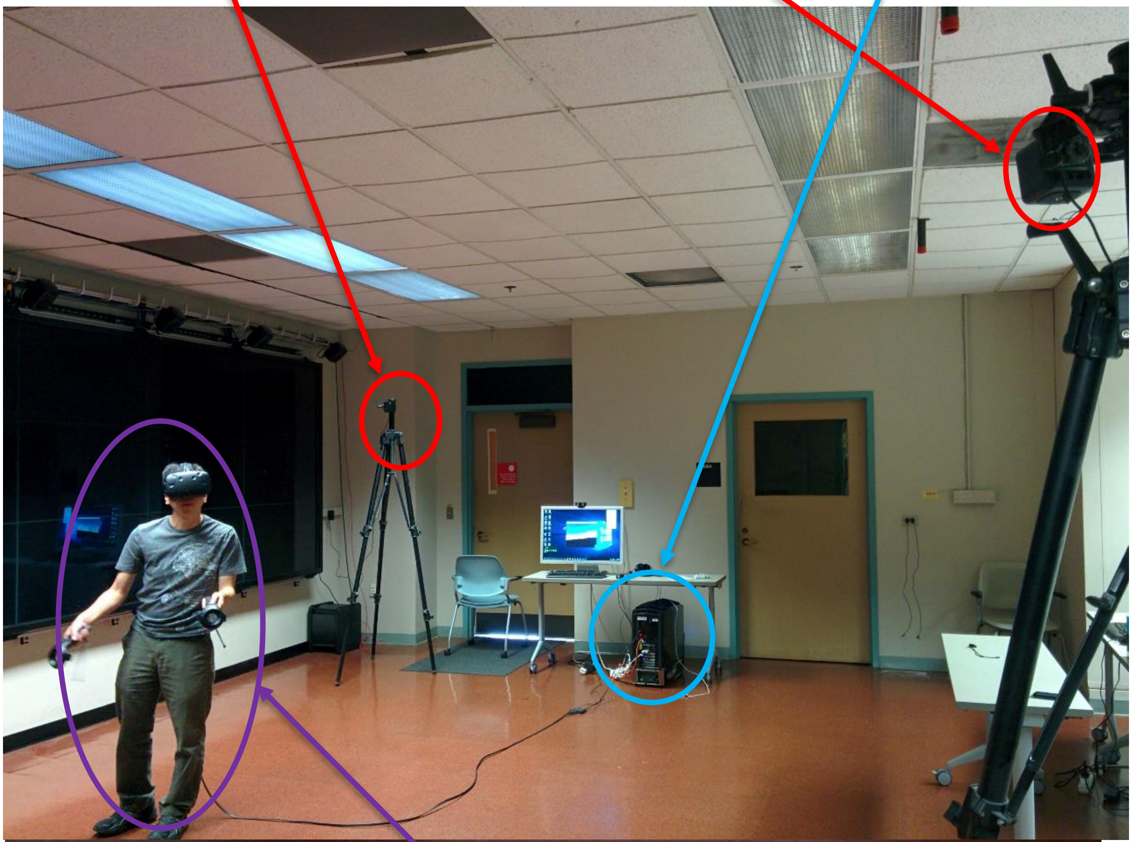


Figure 26-HMD +Wands + headphone

The user carries an HMD and two wands to interact in the virtual world. He carries also a headphone to hear the other user during the collaborative task. He can talk with the other user because of the microphone integrated in the HMD and Skype. The HMD needs to be plugged into a powerful computer.

Positional tracking becomes feasible due to lighthouse system.

The lighthouse system:

The lighthouse system is made up of two base stations which are in opposite corner of the room facing each other.

Figure 27-Lighthouse system

In fact, stations lighthouse emits laser rays (two green point on the left picture) through the room. The HMD and the wands are equipped with little LEDs (right picture below) that receives these laser rays which eventually sends their positions to the computer.

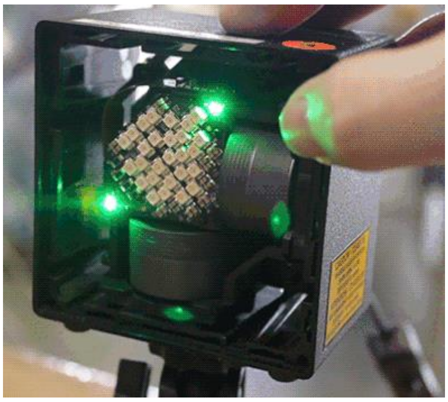


Figure 28-Inside a lighthouse with the laser
source: Gizmodo

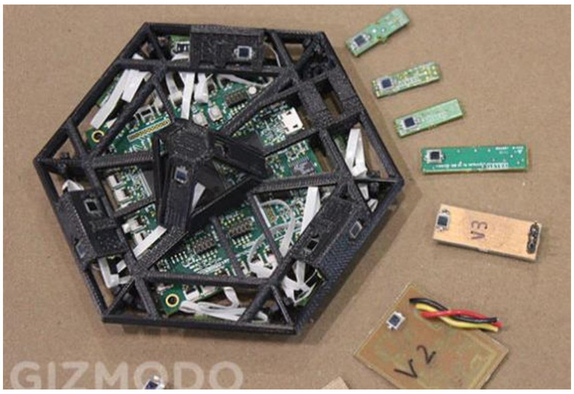


Figure 29-Inside a wand with the led around
source: Gizmodo

The lighthouse connects to the computer because they are passive so users do not need to connect. Unlike the LED on the HMD which are active and continuously sending information to the computer through its lasers.

Cave installation:

We can see in detail the installation in CAVE 2:

Figure 30-camera optical tracking system

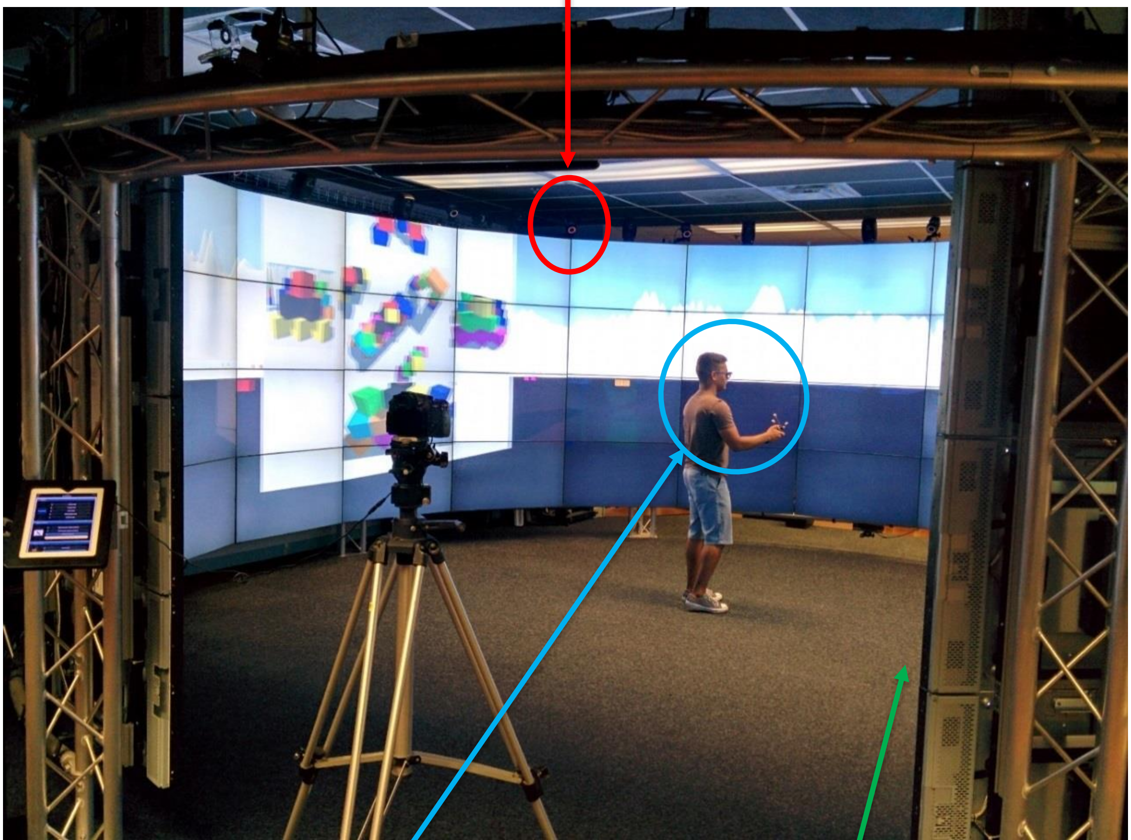


Figure 31-the CAVE 2

Figure 33-3D passive glasses with tracker+ Wand with trackers

Figure 32-Speakerphone

The user carries a pair of glasses for passive 3D and a wand. Both are equipped with trackers. The positional tracking consists of camera optical. These cameras use Infra-red (IR) LED's mounted around the camera lens, along with IR pass filters placed over the camera lens. They measure the Infra-red light reflected from markers. During this time the cameras are active and needed to be connected to the computer. However, the trackers are passive and do not need to be connected.

It can talk and hear other users due to a speakerphone placed on the floor in CAVE 2 and Skype.

Below is a detailed progress of one session following the experiment's time table:

Experiment Time Schedule:

Duration	Task (Descriptive)
5 min	_Presentation _ Form « Background VR » (one copy per user)
10 min	_Experiment: Demo (Cave and Vive) (to be aware with the devices and the application) _Start a stopwatch for each _Start a camera for each _Count the number of cubs disposed
10 min	_Form TLX (explanation of the way to fill it) (one copy per user)
10 min	_Experiment: Single (Cave and Vive) (the user completes the task alone) _Start a stopwatch for each _Start a camera for each _Count the number of cubs disposed
5 min	_ Form TLX (one copy per user)
10 min	_ Experiment: Collaborative (Cave and Vive) (both user completes the task together) _Start a stopwatch for each _Start a camera for each _Count the number of cubs disposed _Start Skype _Start speakerphone for Cave 2 _Start the microphone integrated and plug Vive's headphone.
5 min	_ Form TLX (one copy per user)
5 min	_ Form Feedback (one copy per user)

Notice that the assignment of the user for each device is made randomly. Notice also that each survey is filled anonymously to maintain confidentiality.

Problem encountered:

_The user using the Vive has to be monitored most the time during experiment because of wires. In fact, user can walk on wires and pull it unwittingly. There is a high risk that the user may unplug the wire from the computer by mistake and stop the application. If this happens, it could ruin or interfere the experiment.

Supervision is required to prevent users to entangled themselves from these wires or from colliding onto some physical objects in the room. Thus, a solution was implemented in the Vive to avoid users from colliding or bumping into physical objects.

Figure 34-Illustration of the "Chaperone system" source:ETR.fr

In fact, when we made an adjustment on Vive, we implemented a blue grid which serves as boundaries for the user. It reminds the user that he is too close to the grid. This system is called "Chaperone system." Despite this system is in place, there were some people who crossed the blue grid and bumped into physical objects inadvertently.

_Another problem occurred when some users could not distinguish some colours (for example, between light yellow and light green). Proper attention was required to choose the proper colours for the application. This issue has been encountered in particular with the Vive.

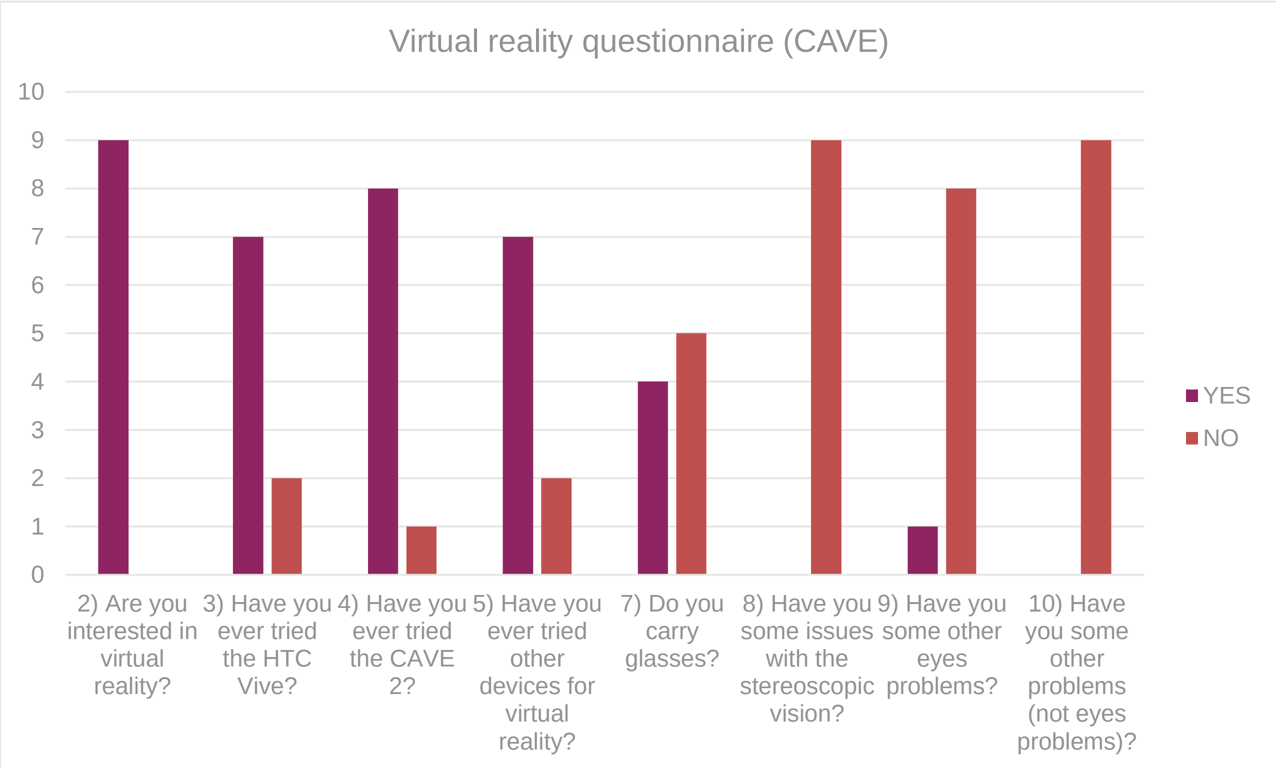
I managed to test 18 persons per group of 2 with my experiment. One was in CAVE 2 and the other one was with the Vive. Each session lasted 1 hour. So now we have to analyse the results from the surveys filled out by the users to test our hypothesis.

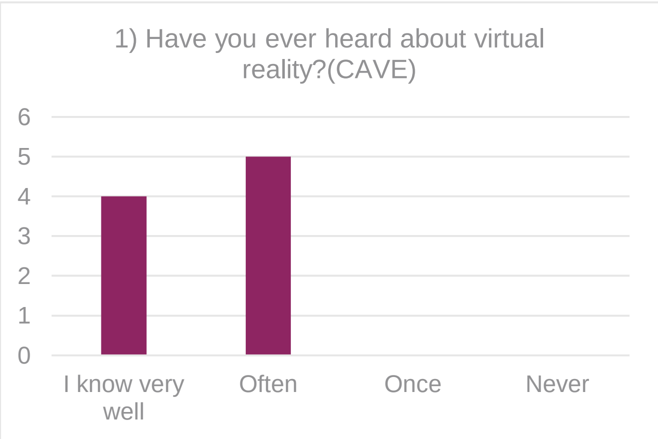
IV) Data analysis

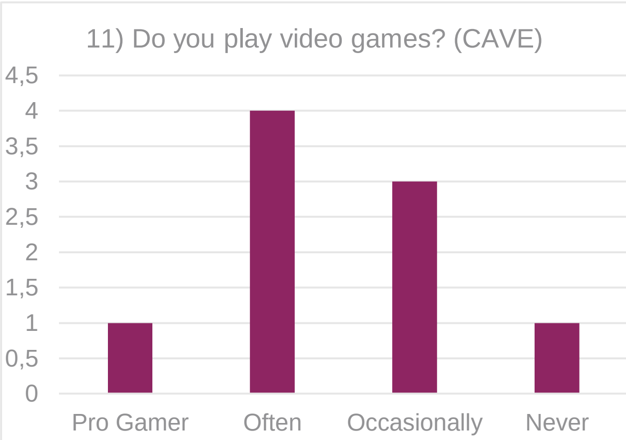
Analysis of the result of our experiment is important to test the purpose of my hypothesis. First we will analyse each type of data (TLX, feedback…) and then, we will combine all these data.

A) Virtual reality personal history survey

I have decided to show the result of this form in three parts. The first part is the result for the CAVE 2 users only, the second part for the Vive users only and the last part is the result of both.
CAVE2:

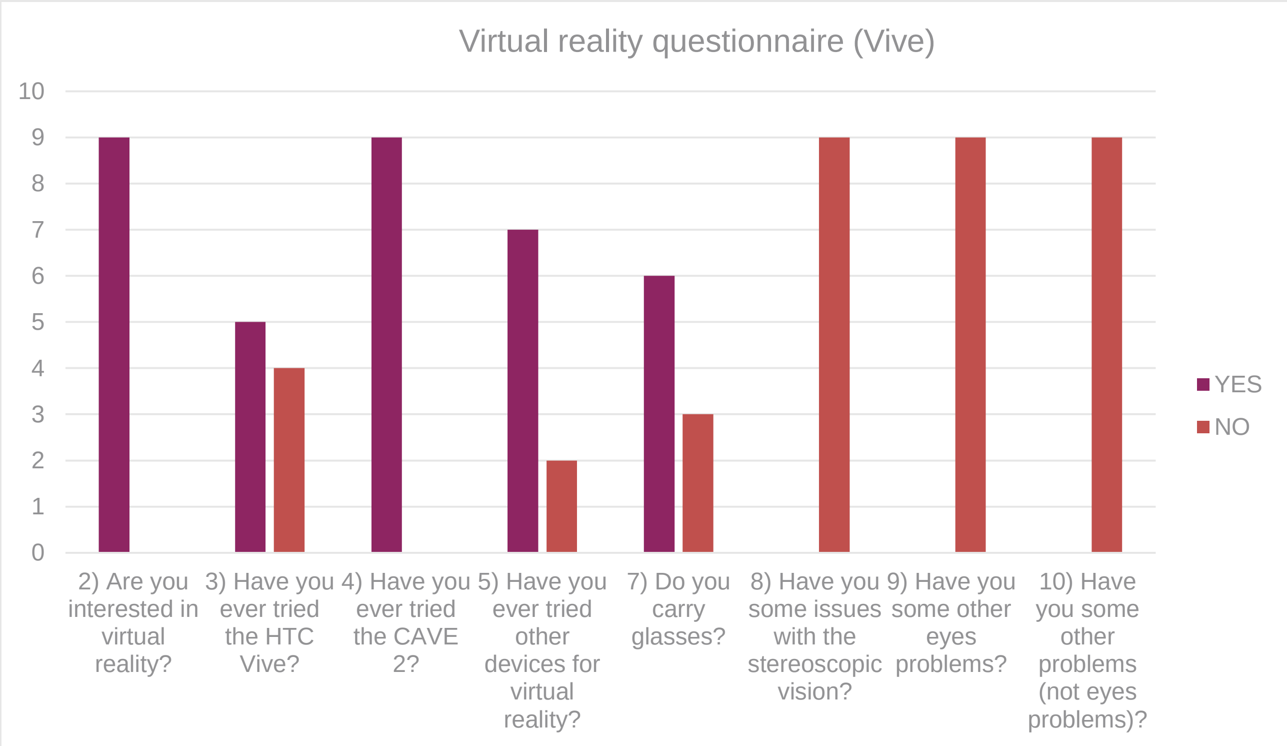


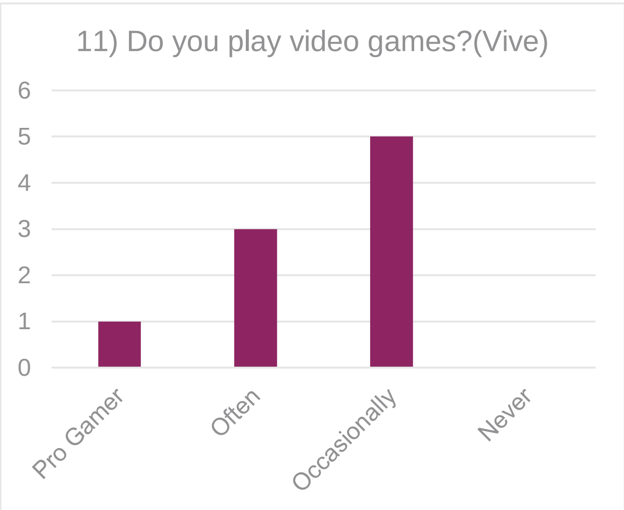


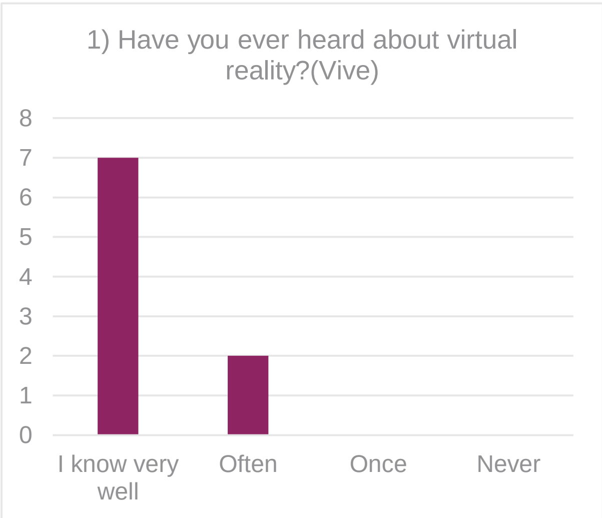


We can see that most of the CAVE users has already tried the CAVE 2. So they are already aware of the device. It was faster for them and easier to take control of the application. But normally the demo is there to erase this disadvantage among users. They are all interested in virtual reality. Their attitude towards the experiment was good. Most of the users has no specific problems. However, almost half of users wears eyeglasses. For CAVE 2, this is not a problem because users kept their eyeglasses during the experiment. Although, most of the users has already played video games almost half of users are not regular players. This factor could explain the inequality of the results among the users for the CAVE 2. Regular players of video games may be more efficient and may obtain a better completion rate and have different task load for the TLX. But for our project this is not really a problem. We just want to examine if the collaborative task between these two devices is better than separate.

Vive:

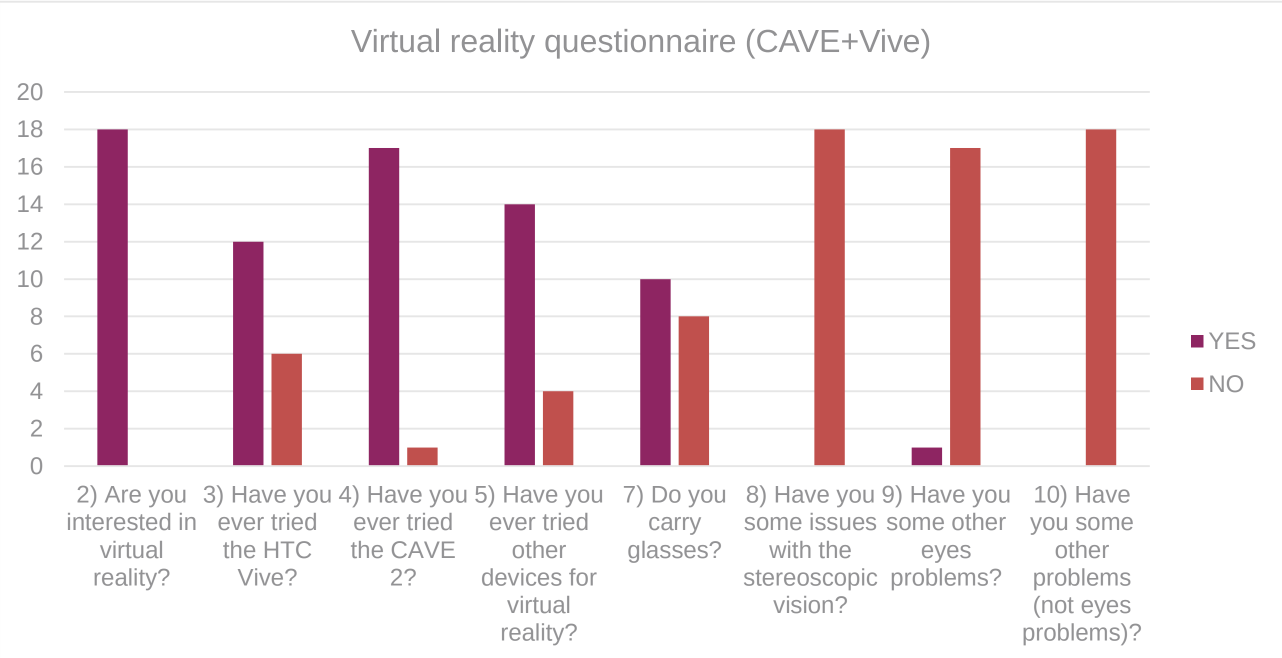


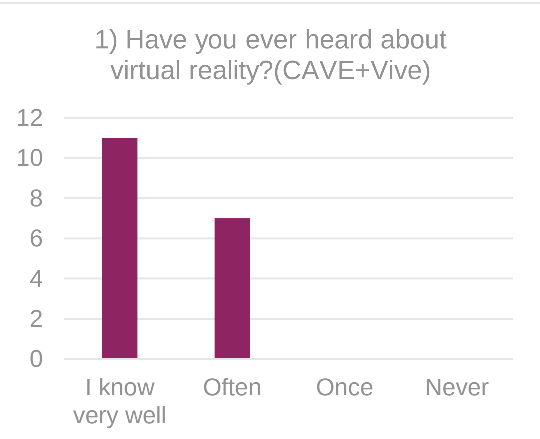


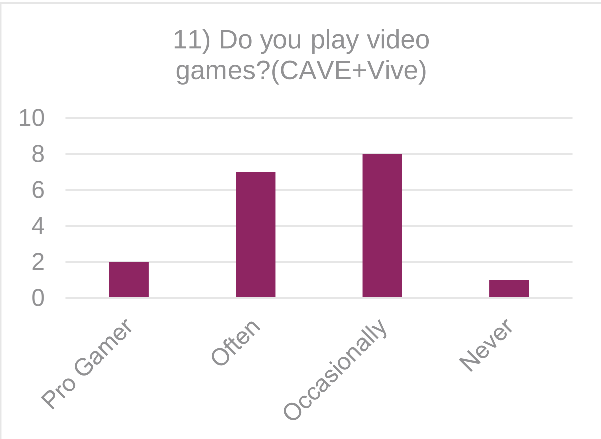


We can see that only half of users have already tried the Vive. Nonetheless, this is not a problem because we have a demo which allows the users to be familiar with devices. Interestingly, if everybody has already played video games, the result is almost the same number of differences between regular and occasional players. This is not a problem because we do not intend to evaluate their individual differences between each other rather against themselves. We intend to examine, if they are more efficient alone or if paired with someone who use a different device (either the CAVE 2 or the Vive). Impressions toward virtual reality is the same. Almost half of our users wears eyeglasses. However, in this particular task it can be a problem. So, we asked these users to remove their glasses before they put the HMD on their head. In doing so, it can be disadvantageous to the users and it could affect the quality of their experience.
However, in this case the user in the CAVE2 who kept his glasses will be able to help the user without glasses with the Vive in terms of distinguishing colours.

Vive +CAVE2:







We can see that all users are familiar with virtual reality, in general. It is so because these users are linked in this laboratory which is a virtual reality laboratory.

This is a good factor that can help with the demo to minimize the skills gaps among users.

The combination of both confirmed what we have observed. Half of the users wore eyeglasses and half of the users are regular video players. This type of differences among users could influence the result. Hence, it would be interesting to observe what is the influence of this result during the collaborative task. We can ascertain that users would prefer collaborative task not based on the functionality of their devices. Rather it is because other users are better than the others. Hence, we have proposed all these forms to try to eliminate these cases which are not relevant to our experiment.

B) NASA-TLX (Task Load Index)

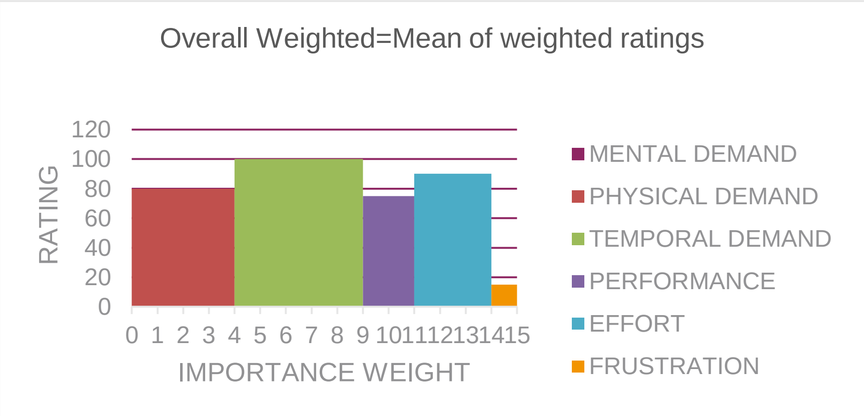
In the case of the NASA-TLX, we cannot combine Vive and CAVE 2. We need to analyze this case separately. For each device we consider these two scenarios: Single (where user works alone) and Collaborative (where users work together). For each scenario, we consider for "Each user" and "Average". "Each user" is only there to illustrate the way we obtain the second histogram called "Average." We have to establish the histogram for each player for each task for each situation according to the TLX instructions. We have made a total of 36 histograms for 18 users, 18 histograms for each device, 2 histograms per user. However, in order to facilitate our analysis, we have made a histogram which illustrates an "Average" of these result. We still need to determine each type of task. Therefore, we have a total of 4 histograms for the four types of task.

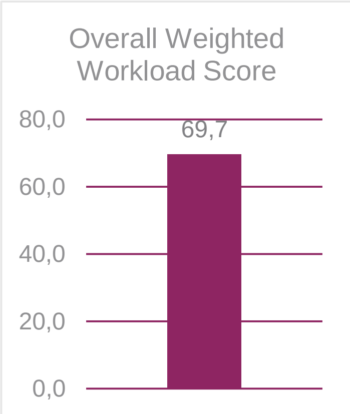
In conclusion, we average nine histograms for "Each other" to obtain "Average." To illustrate, I chose to show only one histogram (randomly selected) in each scenario and to include all nine in the annex at the end of this report. We will analyze each "Average" histogram for all these cases.

<u>Vive:</u>

Single:

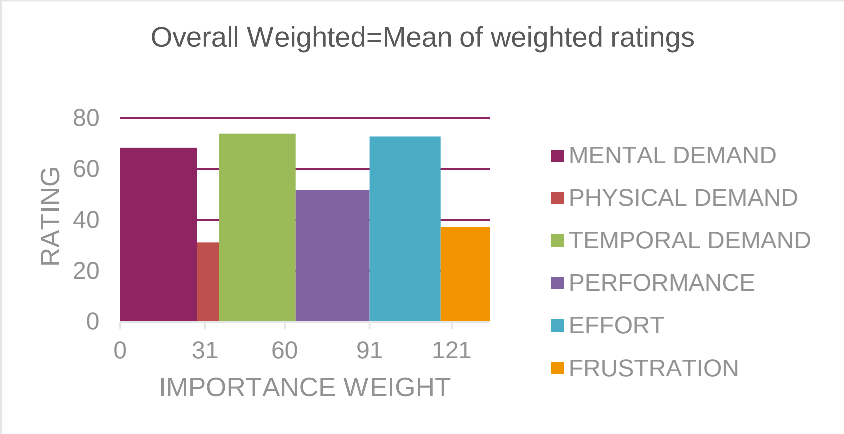
<u>Each user:</u>

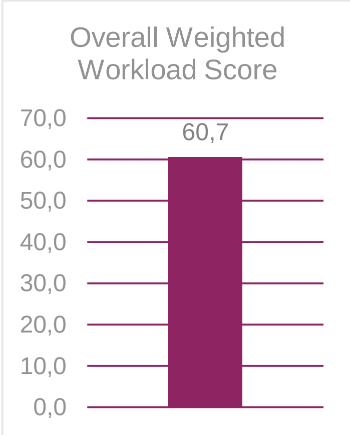




This histogram is valid for only one user using the Vive when he works alone.

Average:

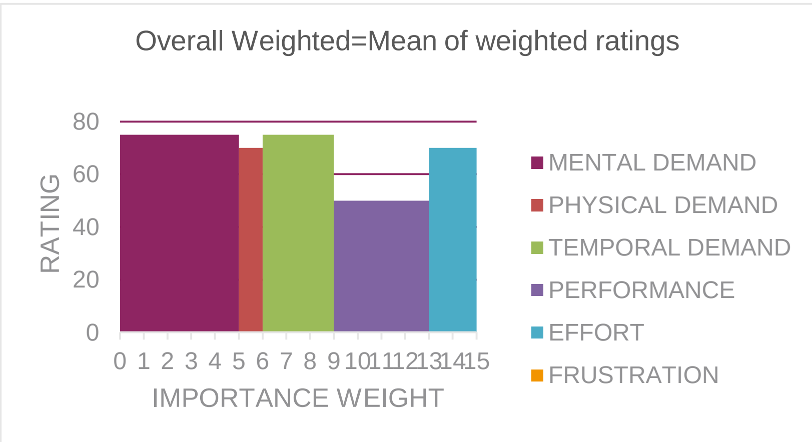


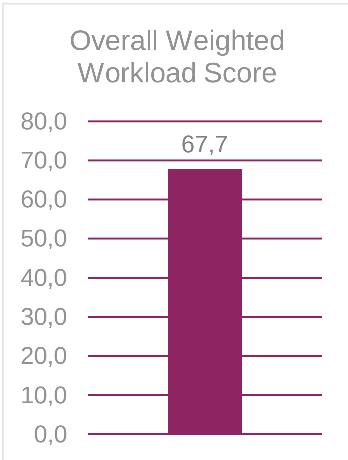


It is evident that the most important factors in the workload are Mental demand (≈80%), Temporal demand (≈80%) and Effort (≈70%) with an equal importance (or almost the same weight). The task demanded a high level of thinking within a pressured time frame and a huge effort from the user to complete this task.
According to users, the task was not easy and the time was too short. Most of them encountered difficulties to complete this task in time.

Collaborative:

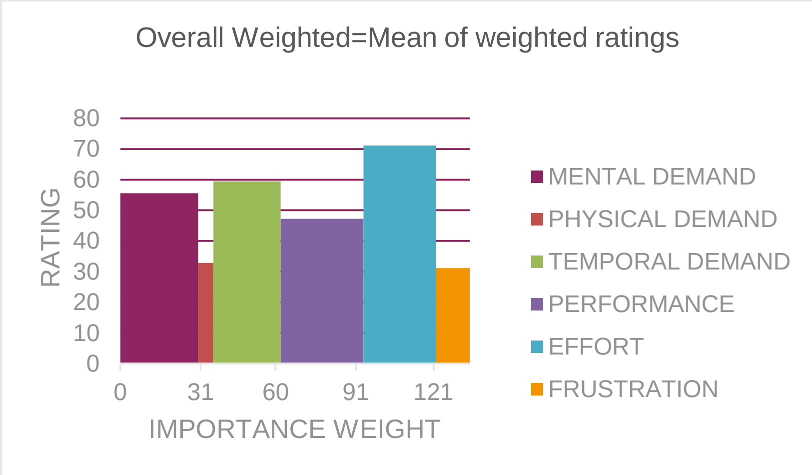
Each user

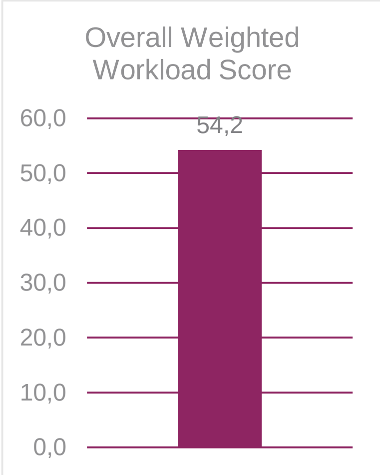




This histogram is valid for only one user using the Vive when he works with someone else in CAVE 2.

Average:





It is evident that the most important factors in the workload are Effort (≈70%) with its high rating and the performance with its high weight (its importance (abscissa)). The task demanded a lot of thinking. However, performance appears to be an important element for the user. Most users paid more attention to the final result and thought that their results were not superb but not bad nor average. Users also think that task was difficult and complicated.

Review:

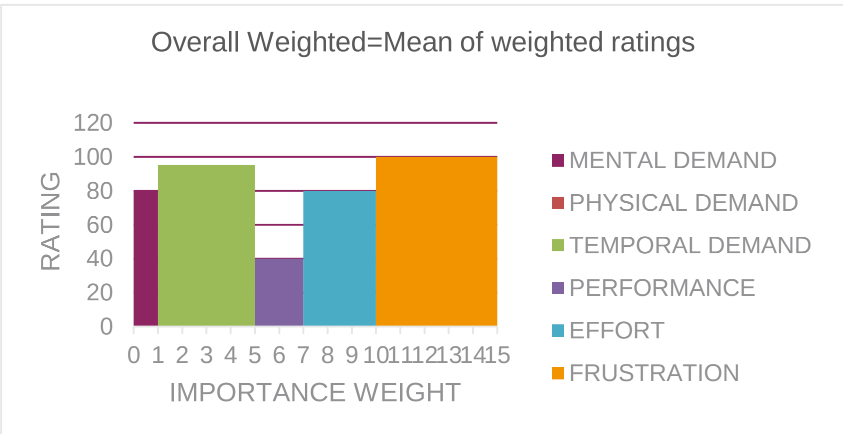
We can notice that users thought that both tasks are hard to complete and demanded more mental use. However, in the collaborative task, time and effort are not predominant factors anymore and that Performance became more important. We can conclude that tasks on both scenarios appear to be of the same level of difficulty as for the Vive users. In the collaborative task, users felt less time pressure and needed to make less effort. These users were more focused to their work. Consequently, in the collaborative work scenario the workload score is slightly higher than the workload score of the Single task. The Collaborative task demanded less workload than the Single task.

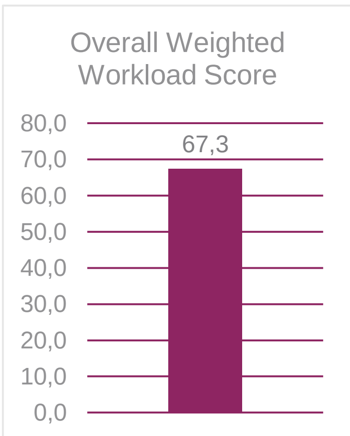
Thus, we can conclude that the collaborative task is easier than the Single task for Vive users.

CAVE:

Single:

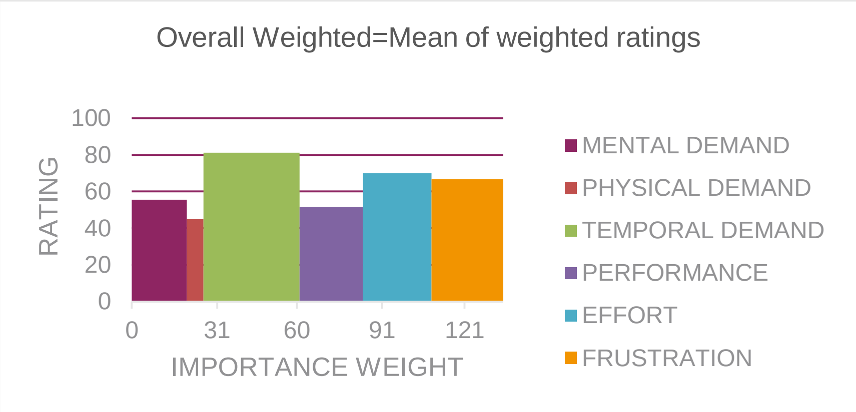
Each user:

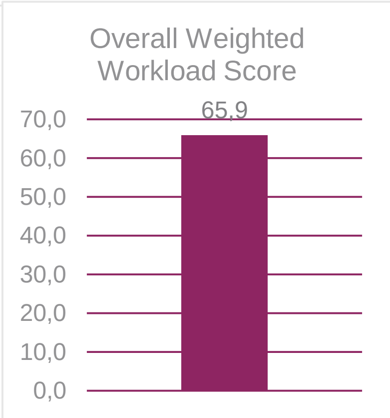




This histogram is valid for only one user using the CAVE when he works alone.

<u>Average:</u>

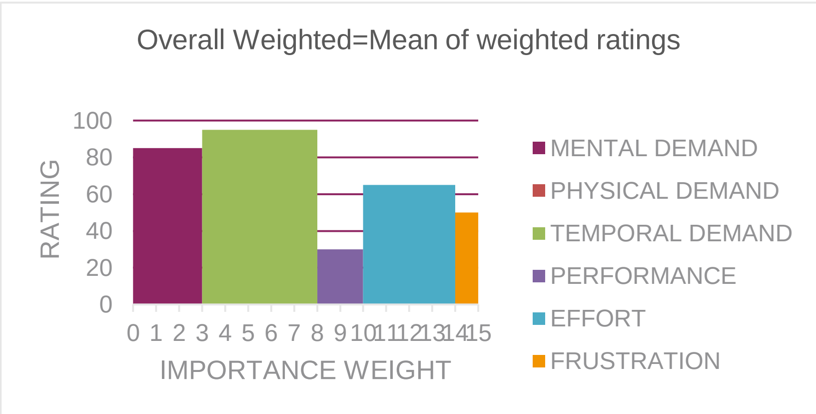


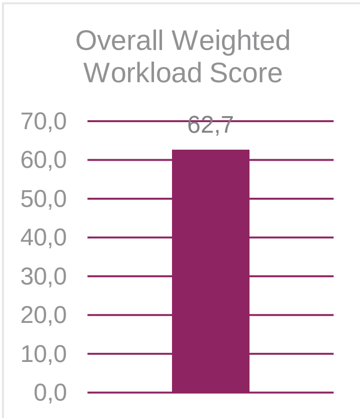


We can notice that the most important factor in the workload is the Temporal demand with higher rating (≈80%) and higher weight. We can also consider the other factor, the Mental demand (≈70%). For these users, working under time pressure was a real problem and the task was not easy. These users thought the time was too short to complete this difficult task.

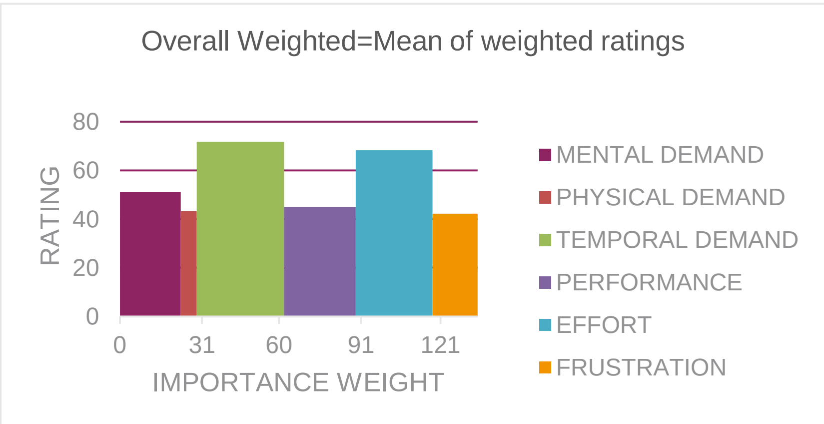
Collaborative:

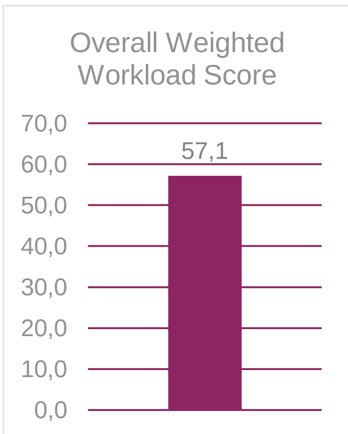
<u>Each user:</u>





<u>Average:</u>





We notice that the most important factors in the workload are the Temporal demand (≈70%) and the Effort (≈70%). Weight is rated more important for the Temporal demand. Therefore, the Temporal demand is more important than the Effort.
Thereupon, for users, being under time constraint was a real problem and the task was not easy. Users thought that the time was too short to complete this hard task.

Review:
We postulate that users think that both tasks are difficult and the time was too short to complete it.

Indeed, there are factors which are predominant in the Temporal demand and the Effort demand. However, the rating of the Temporal demand in Collaborative task is 10% less important than the Single task. We can conclude that the task on both scenarios appear to be of the same difficult level for the CAVE users. But the CAVE users in the Collaborative task felt a little bit less time pressure than users in the Single task. On top of that, in the collaborative work the workload score is slightly higher than the workload score of the Single task. Therefore, the Collaborative task demanded less workload than the Single task.
Collaborative task appears to be easier than the Single task for the CAVE user. However, the difference is not very significant for the CAVE users.

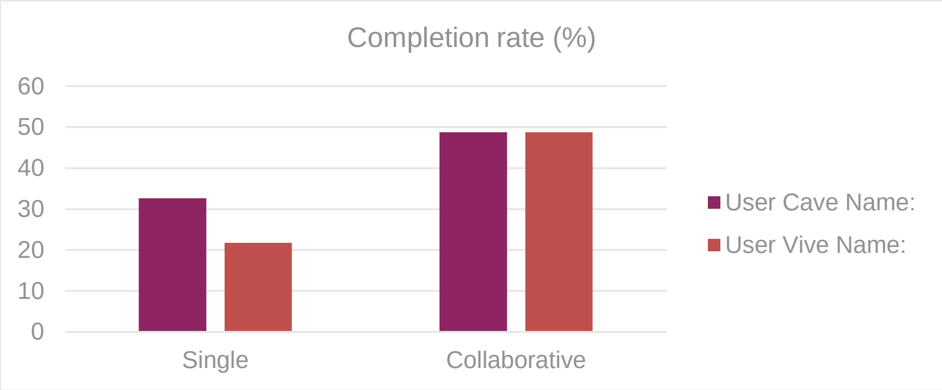
Conclusion:

According to the evaluation of both tasks, collaborative task appears to be easier than the Single task despite the fact that they the same level of difficulty on both tasks. Consequently, the combination of the CAVE and the Vive improves the performance of the users. In the case of the Vive, the difference is really important. There is a huge gain between the collaborative and the single. The Vive user improves his performance due to the assistance of the CAVE user. This gain is less significant for the CAVE user. Henceforth, we need to complete our analysis using the other survey to validate this first result.

C) Completion Rate

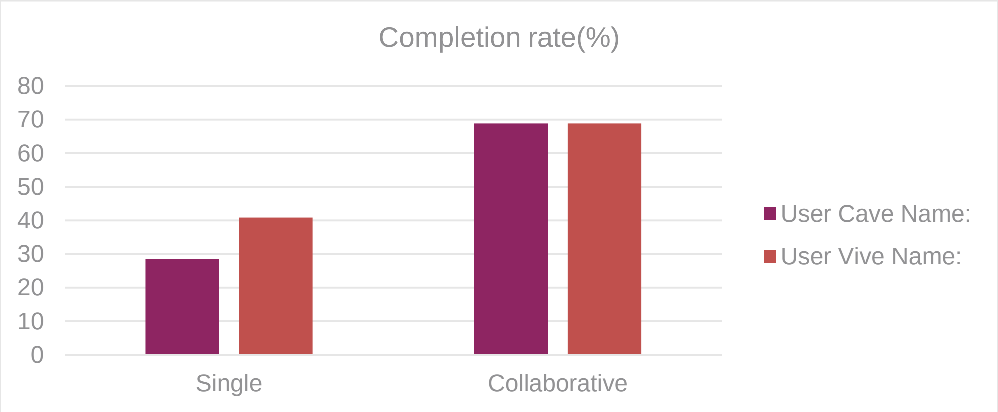
I have made a histogram called “Each user” which illustrates the completion rate of all cases for the experiment (couple of users). I made a total of 9 histograms. We made a histogram to represent an average of all these histograms for analysis. I can only include one histogram “Each user” to illustrate. We can find all these 9 histograms in the Annex.

Each user:



This one was only available for experiment (one couple of users).

Average:



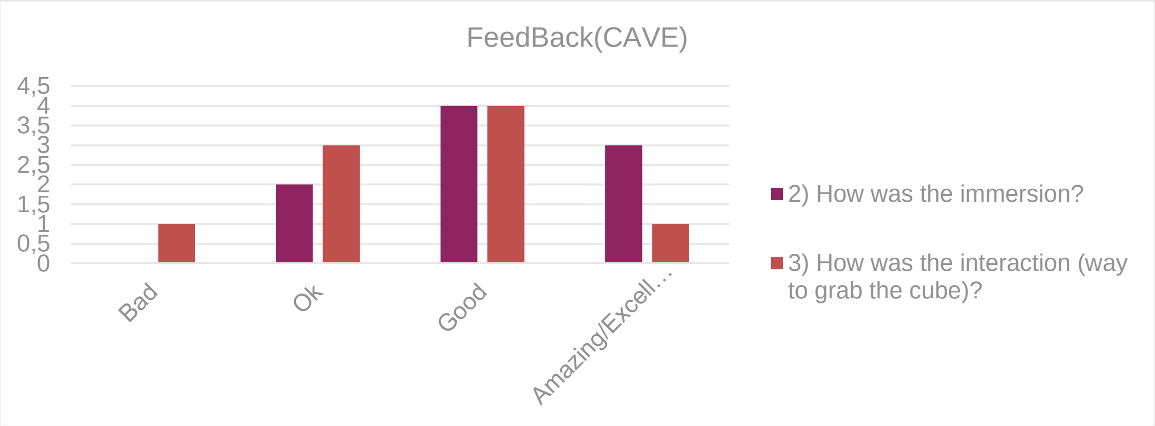
We can notice that Vive users are in average more efficient (≈40%) than the CAVE users (≈30%). We also observed that both users: Vive and CAVE made a better result in a Collaborative scenario than in Single with 70% in average.

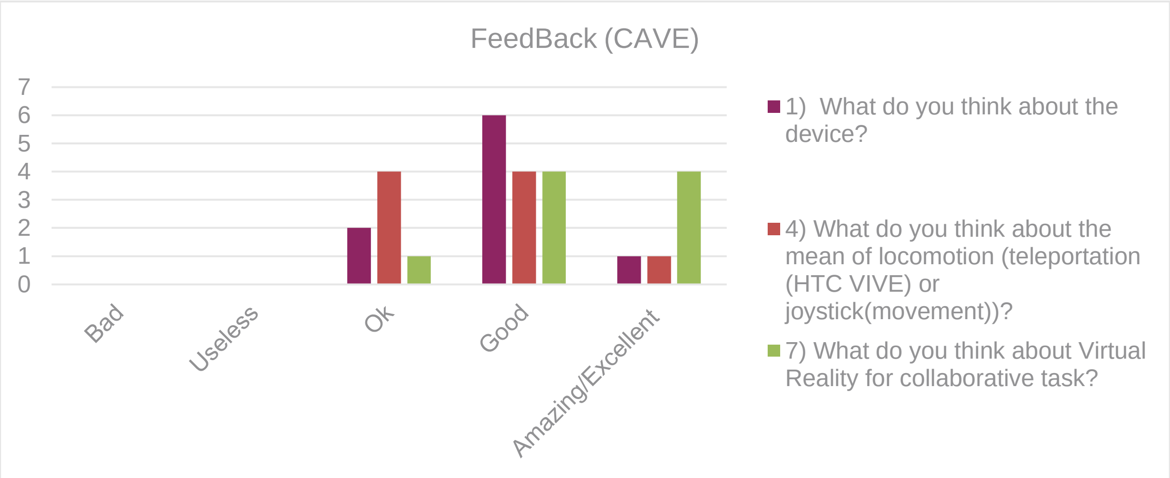
Therefore, we can conclude that users are more efficient when they work together with the Vive and the CAVE contrary to working alone. This difference is more significant for the CAVE users with 40 % less. Even if the gap is less important with 30% less, it matters. This chart alone is not sufficient to conclude that Vive is a device more efficient than the CAVE. However, the relevant gap of the performance between the Collaborative task and the single task is an argument favourable for our hypothesis which stated that the combination of the CAVE and the Vive improves the performances of the users.

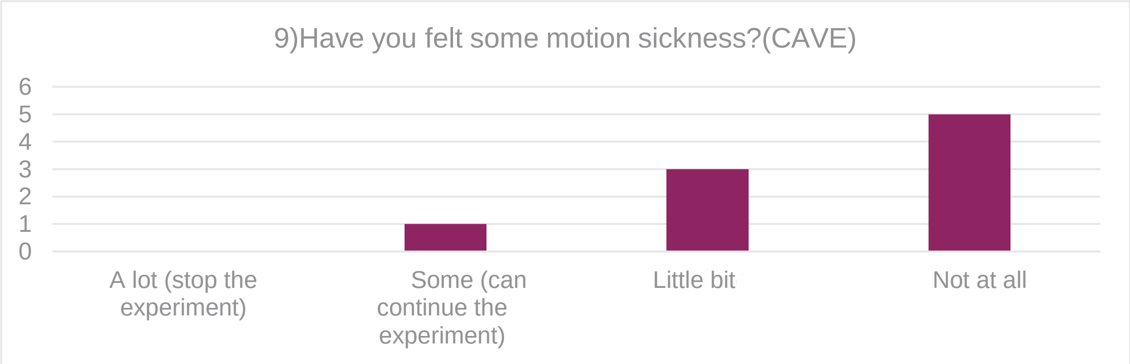
D) Feedback

I have decided to show the result of this form in three parts which is similar to the previous form "Virtual reality personal history survey." The first part is the result for the CAVE 2 users only, the second part is for the Vive users only and the last part is for both.

CAVE2:

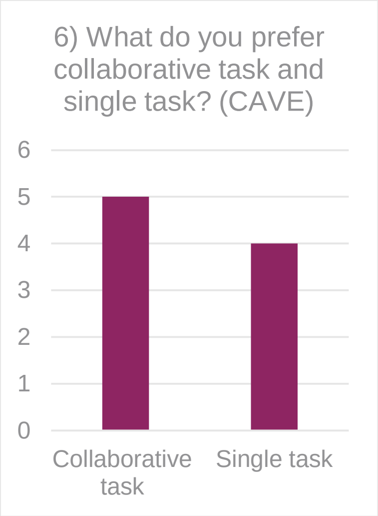


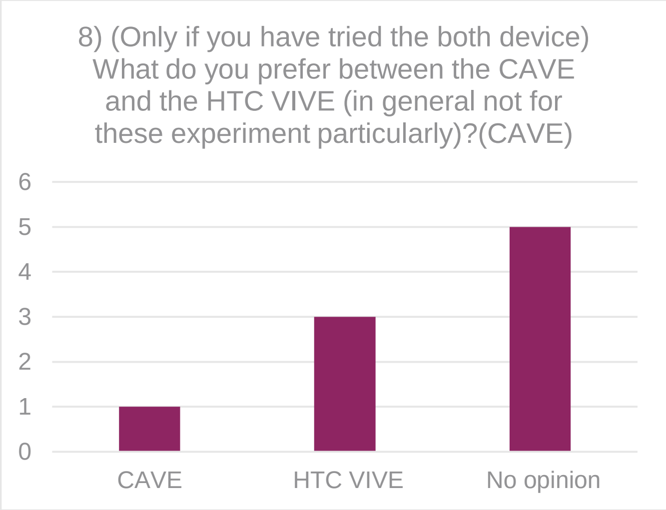




We can notice that the majority of the users think that immersion in the CAVE is superb or excellent. The majority of users think that the interaction and the means of locomotion are practical and good. The majority of the users think the CAVE is good and also the Virtual Reality for collaborative is good. The majority of the users experience only a slight of motion sickness or not at all.

Therefore, we can conclude that CAVE users have positive experience in the CAVE. There are no important factors which alter the quality of the experiment and consequently the results.

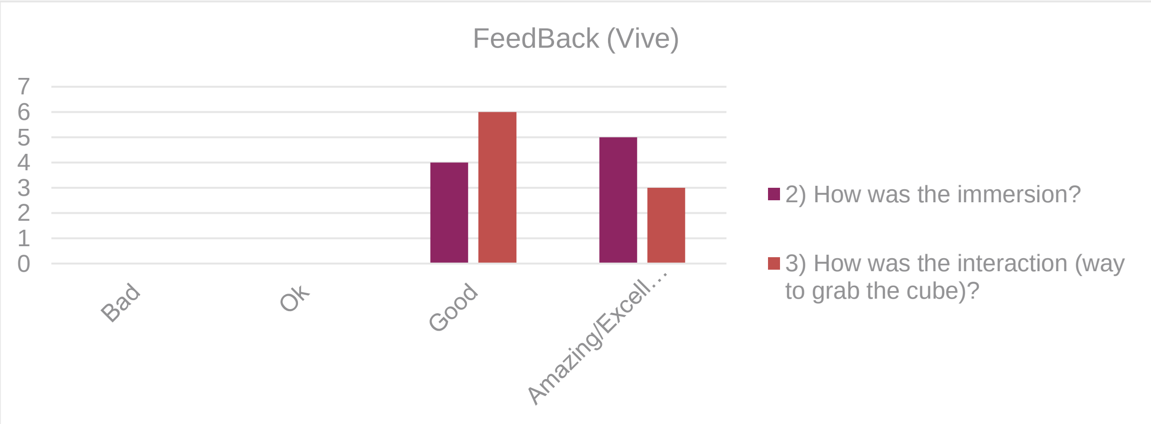


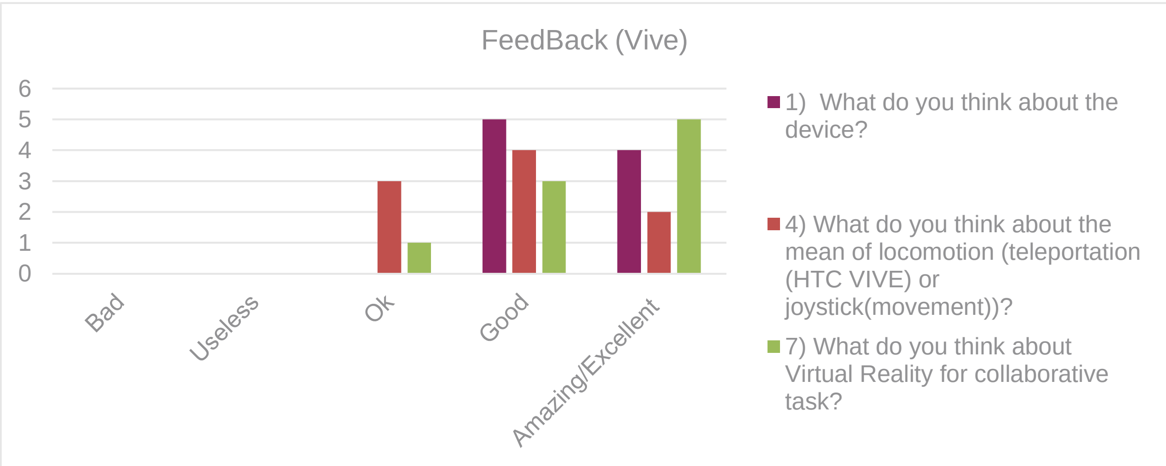


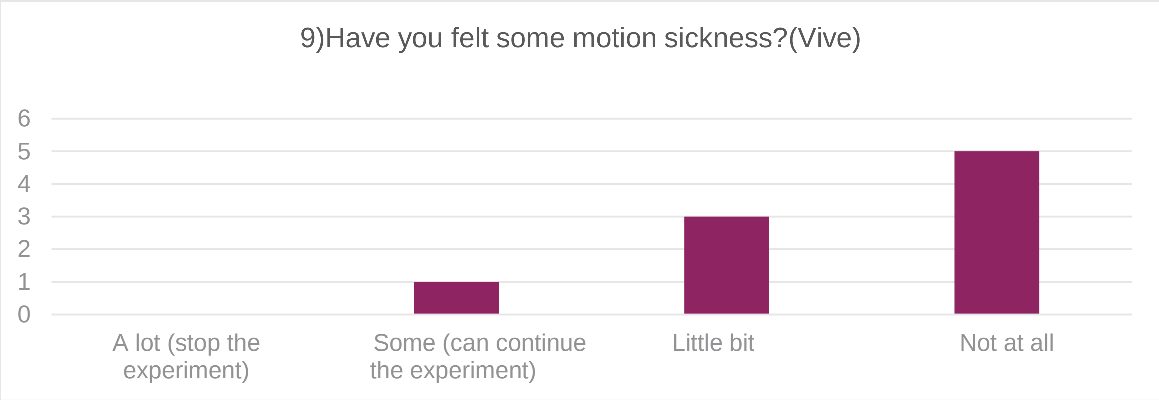
We can notice that only half of the users of the CAVE have an opinion. This result is not significant to conclude anything.

However, we observed that just a little over half of the CAVE users prefer the collaborative task. From the comment written in the forms (you can see the comment in the Annex) the reasons for these are multiple, and thus, it is difficult to draw any conclusion from these comments.

Vive:

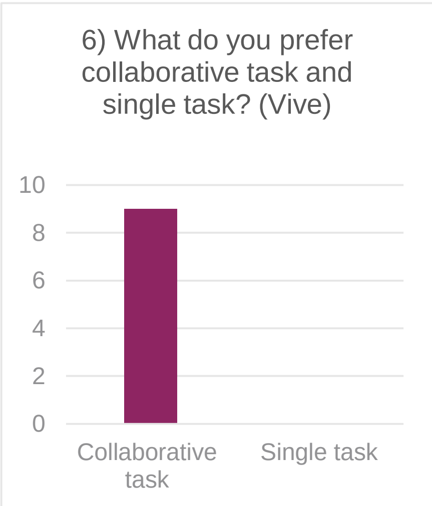


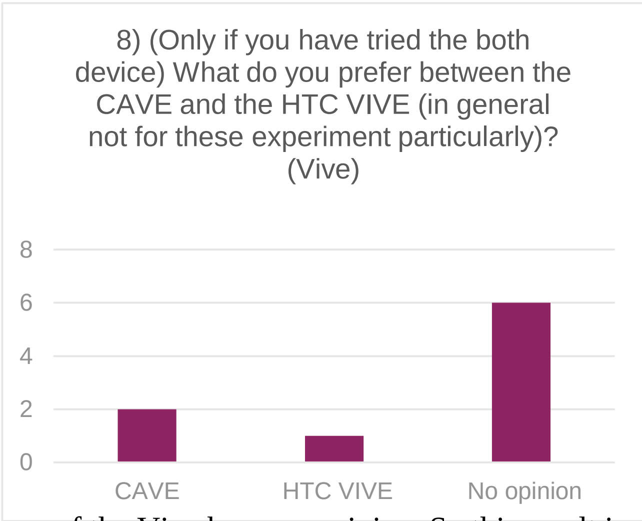




We can notice that the majority of the Vive users think the immersion in the Vive is good or excellent. The majority think the interaction and the means of locomotion are fine. The majority of the users think the Vive is good and also the Virtual Reality for collaborative is good. The majority of the users felt a slight motion sickness or not at all.

Therefore, we can conclude that Vive users achieved a great experience using the Vive. There are no important factors which alter the quality of the experiment and consequently the results.

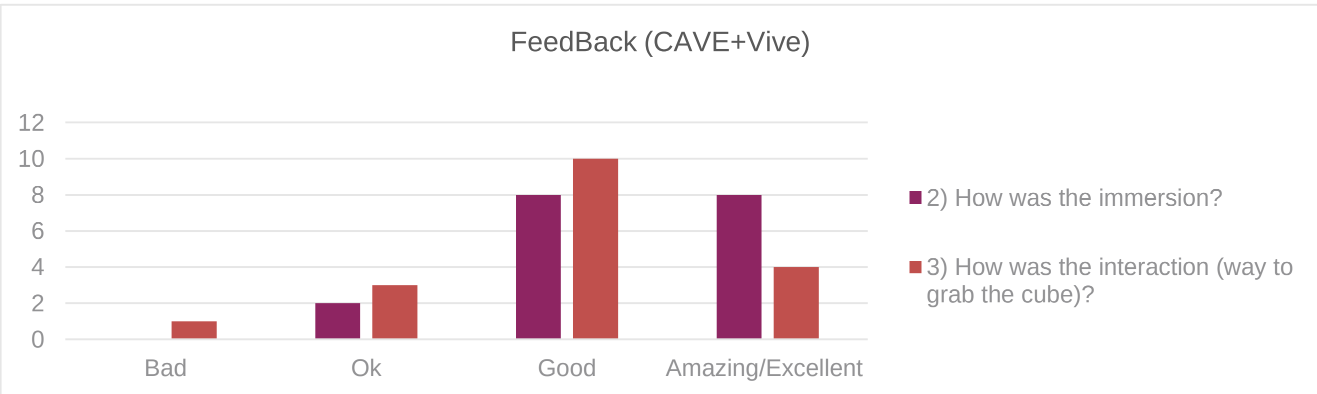


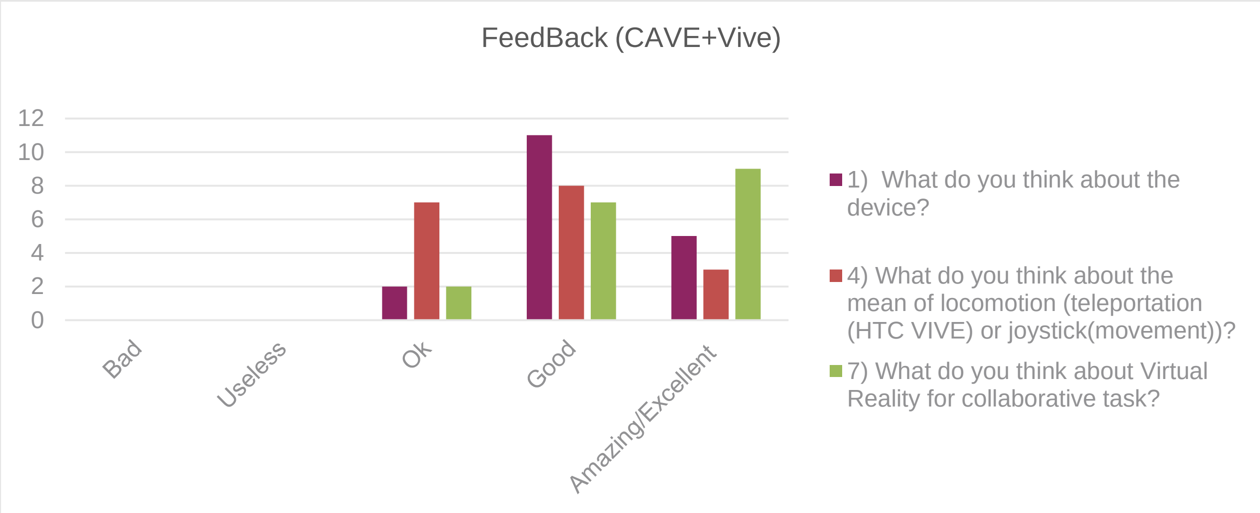


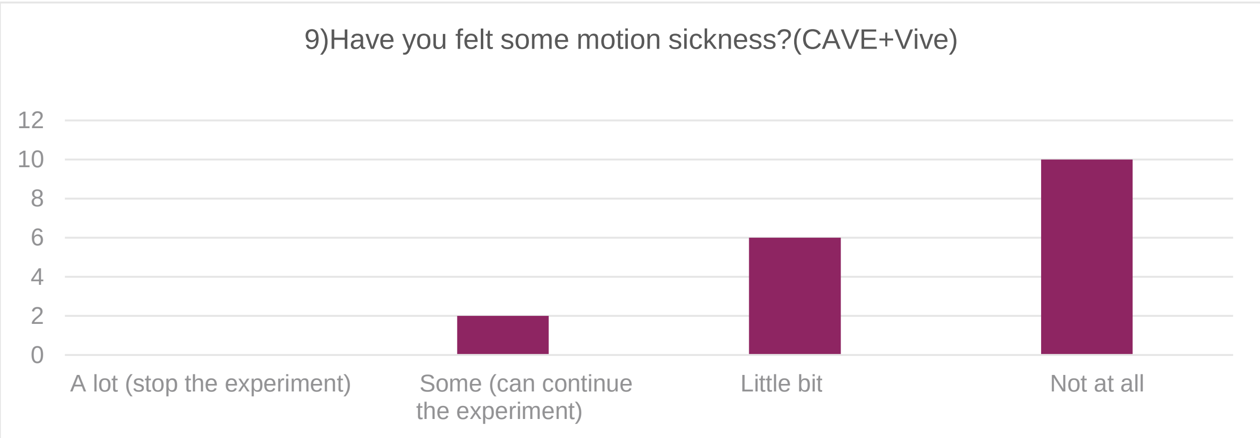
We can notice that the majority of the users of the Vive have no opinion. So this result is not significant to conclude anything.

However, we can notice that all CAVE users prefer the Collaborative task contrary to the Single task.

CAVE2+Vive:

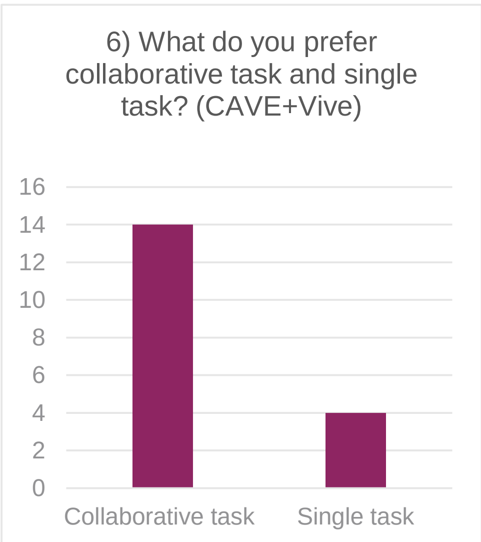


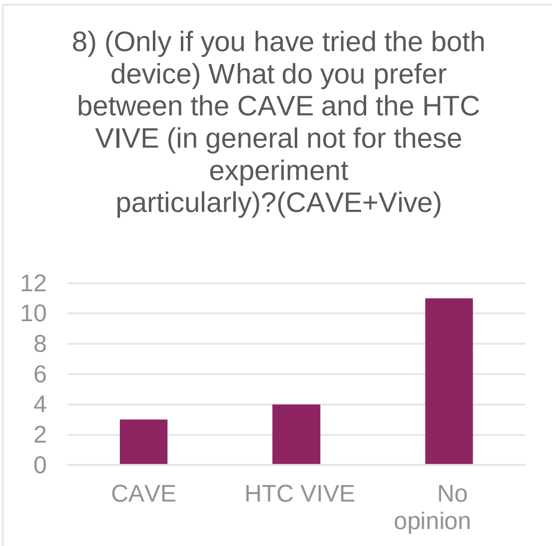




When we combined the two, we find the same results. So we can notice that the majority of all users (Vive and CAVE) think that the immersion of their devices is good or excellent. The majority thinks the interaction and the mean of locomotion are fine. The majority of the users think their device is good and also the Virtual Reality for collaborative is good. The majority of the users felt only a little bit of motion sickness or not at all.

Therefore, we can conclude that all users (Vive and CAVE) achieved a great experience.





Still, there are majority of no opinion. Thus, we cannot conclude anything.
When we combine the results we can notice that there is an increase on the trend who are in favour of the collaborative task. In fact, majority of the users (CAVE and Vive favor the Collaborative task than the Single task. The result gives sufficient relevance to conclude that the Collaborative task is preferred than the Single task.

E) Review of the results

It can be recalled that our hypothesis and problematic are as follows:

Hypothesis:
Collaboration improves the user's performance due to the combination of the HTC Vive and the CAVE.

Problematic:
Does a collaboration between a CAVE system and an HMD improves task performance?

We have previously concluded:
According to the TLX:
_The Collaborative task demanded less workload than the Single task for the Vive and the CAVE users.
_The level of both tasks appears to be the same level of difficulty for the Vive and the CAVE users.
_ The Collaborative task appears to be less stressful and easier for the Vive users (independent of the level of difficulty) as opposed to the Single task.
_ Though the Collaborative task seems to be easier and less stressful, the result has no significance to the CAVE users.
According to the completion rate:
_ The Vive and the CAVE users are more efficient during the Collaborative task than during the Single task.

According to the Feedback:
_ All conditions are met to achieve a good experience for the Vive and the CAVE.
_ All Vive users believe that the Collaborative task is better than the Single task.
_ Only just a little over half of the CAVE users thought that the Collaborative work is better than the Single work.

When we analysed in detail the results, though it appears that the result of the CAVE users has no significance in the TLX and in the Feedback section (question about preference between Collaborative and Single task), these results are in favour of the Collaborative task.
In fact, unlike VIVE users who prefer the Collaborative task, it shows that almost half of the CAVE users prefer the Single task. This preference can explain why there is no significant result for the TLX for the CAVE users. We can posit that these users prefer to work independently

rather than in concert with another individual. Their behaviour may not be related with the experiment and our devices. When we ask them why they prefer the Single task this is their answers:

« Less pressure to get it right »
“I’d rather accomplish the whole task on my own, I felt more rushed doing it with someone else”
“I can call it my own work”
“ I can decide what building to build first”

The comments of these users to justify their choices tend to confirm our hypothesis (that their behaviour has no connection with the experiment and our devices). However, it would have been more interesting to test this with more users to confirm our hypothesis.
Even if these results are not significant, they are in favour of the Collaborative task. According to our results, users globally are more efficient, less stressful, and require less effort to execute a task of the same level of difficulty when they work in concert with Vive and CAVE as opposed to work independently with CAVE or Vive only. Users prefer the Collaborative task contrary to the Single task.

Finally, we can conclude that the collaboration between a CAVE system and an HMD improves task performance.

Conclusion:

My internship at Mechdyne was a great opportunity. Mechdyne is a notable company in Virtual Reality community. During my internship, Mechdyne had provided the tools and means to realize my project. The partnership with EVL was a huge benefit for my intended work. EVL is a famous laboratory where first CAVE 2 was created. All their equipment became accessible for my study especially CAVE 2. Mechdyne supplied the VIVE which completed my tools requirement for my project. CAVE 2 and VIVE are two valuable tools to determine the performance level and efficiency of collaborative task.

My objective is to determine if the combination of both devices will improve task performances and increases efficiency of collaborative task. I have arranged experiments with paired users to work together.

Upon evaluation, general result revealed a significant improvement. Therefore, I conclude that the collaboration between a CAVE system and an HMD significantly improves task performance and increases efficiency of collaborative task.

Consequently, it is also encouraging for more experiments to adjust CAVE results and to add new devices like HoloLens for an Augmented Reality experience. This way, it will bring its own advantages and reducing its weaknesses.

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Summary of appendices

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A) CAVE: 1

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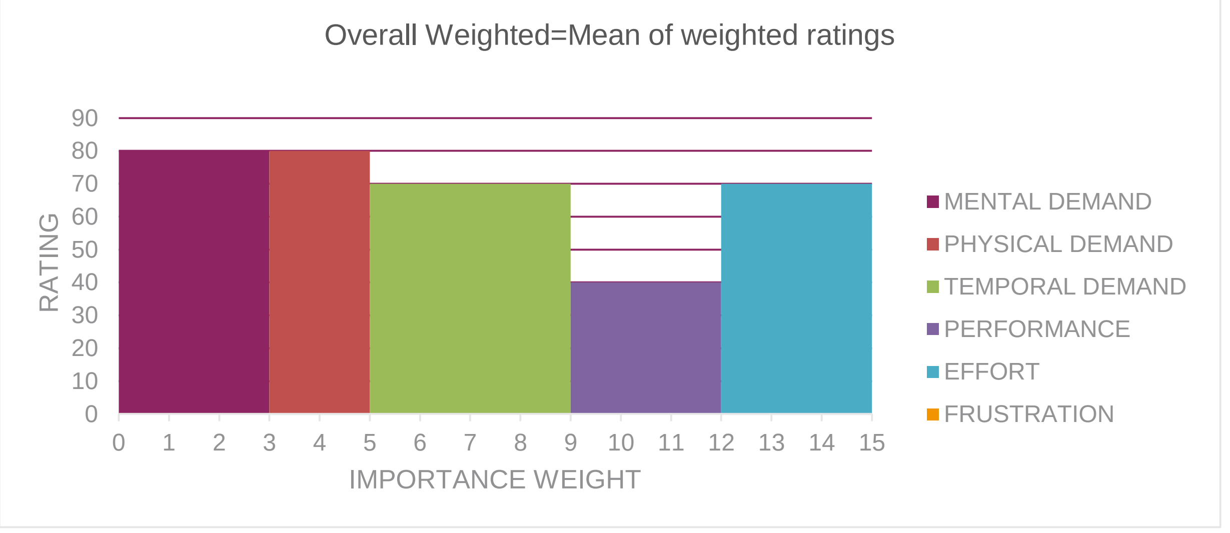
I) Results of each session:

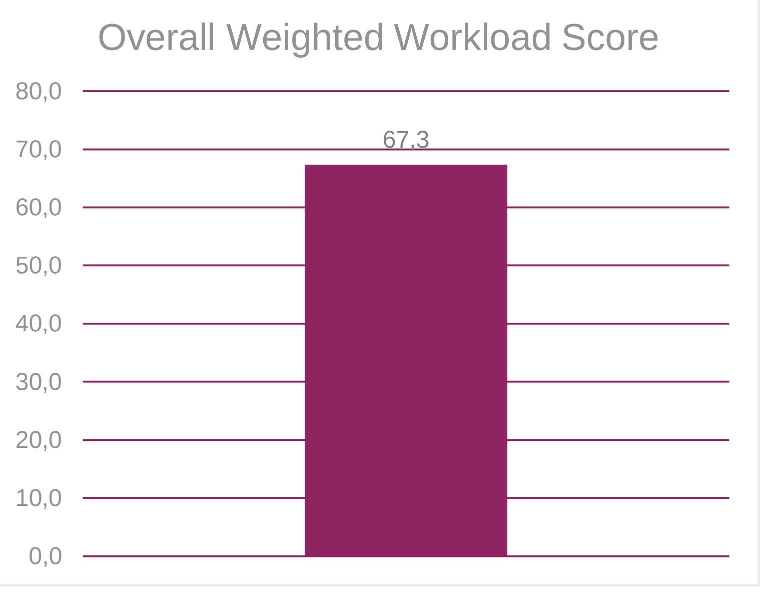
A) CAVE:

<u>Session 1 :</u>

TLX:

Single:





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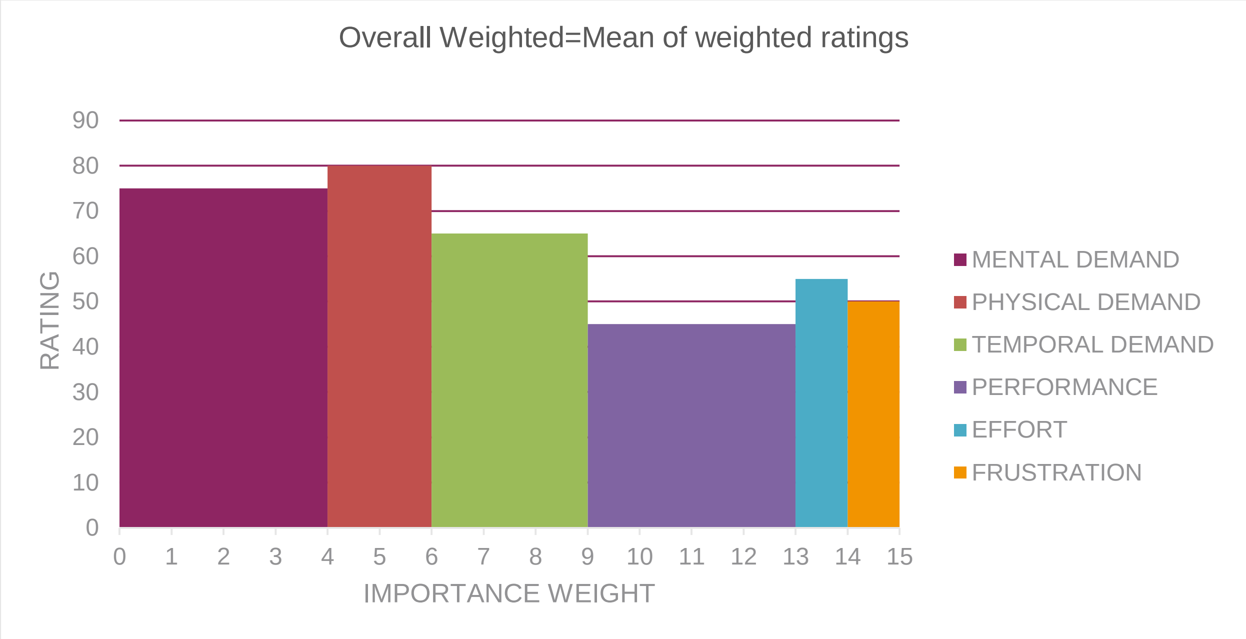

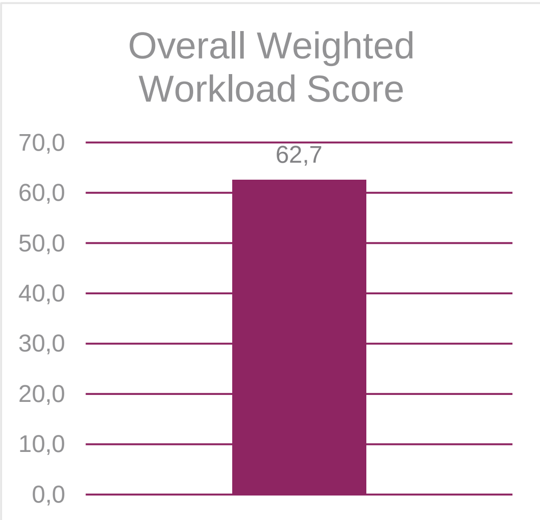

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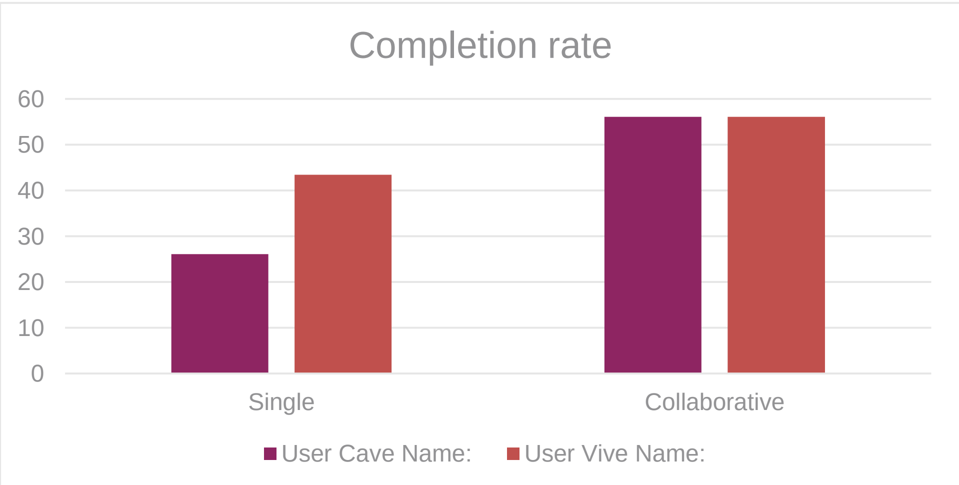

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TLX:

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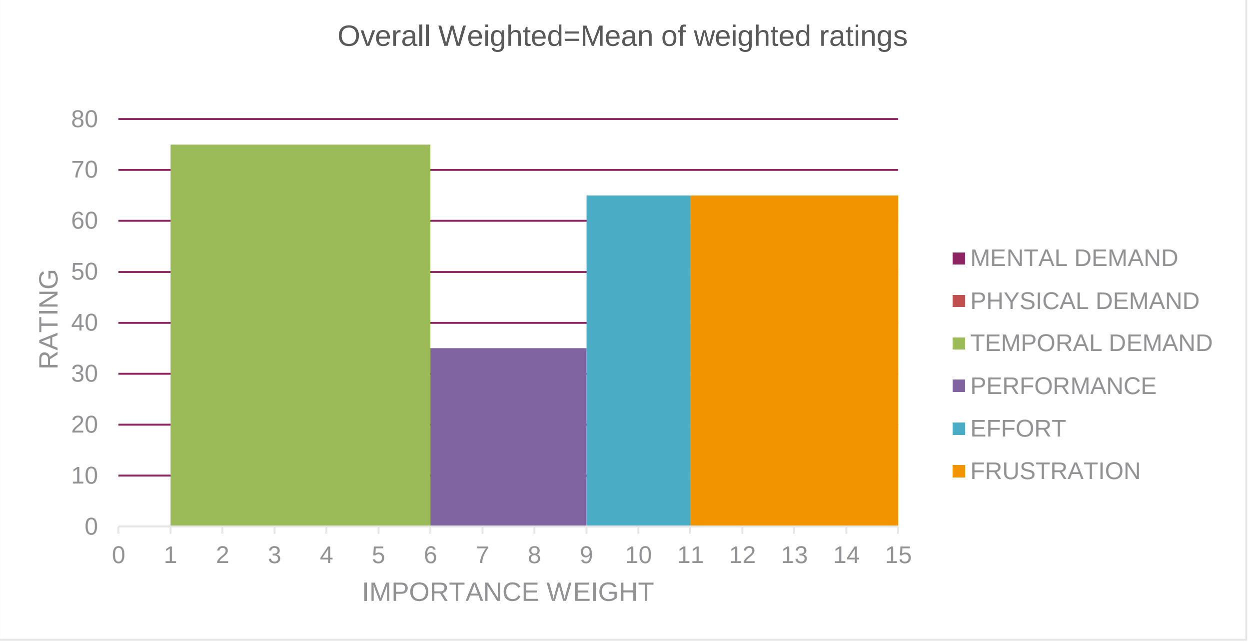

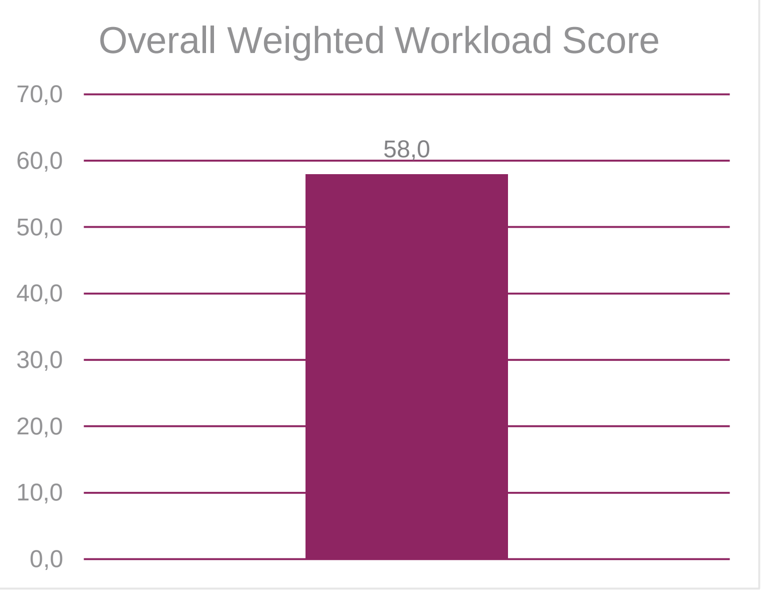

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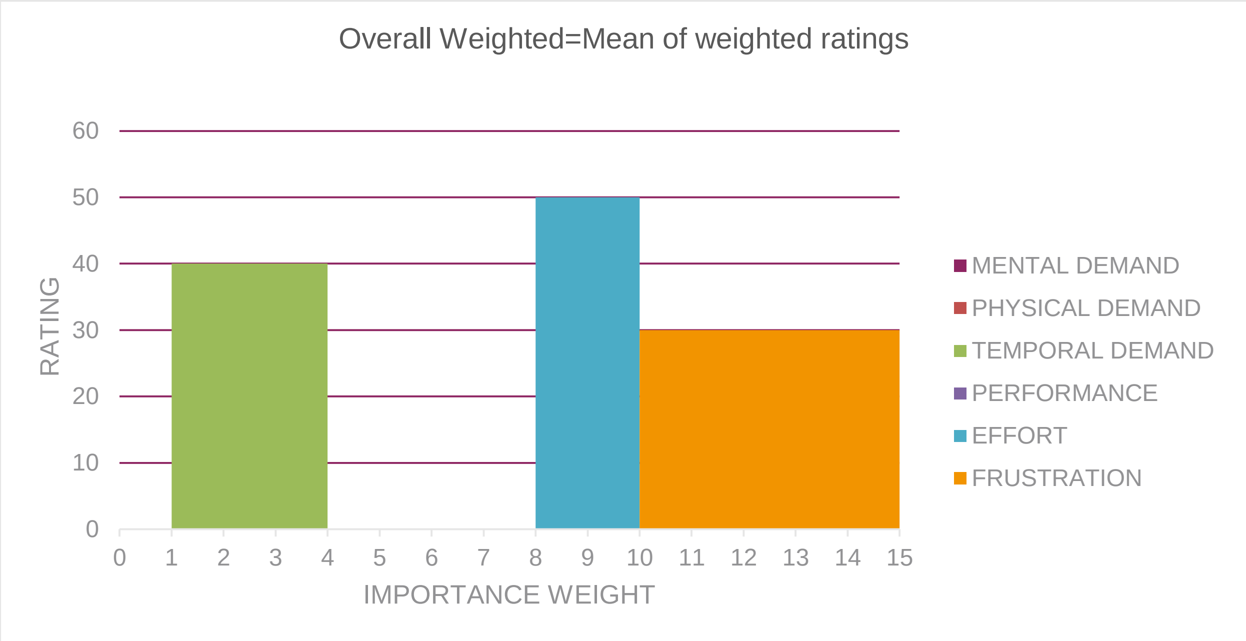

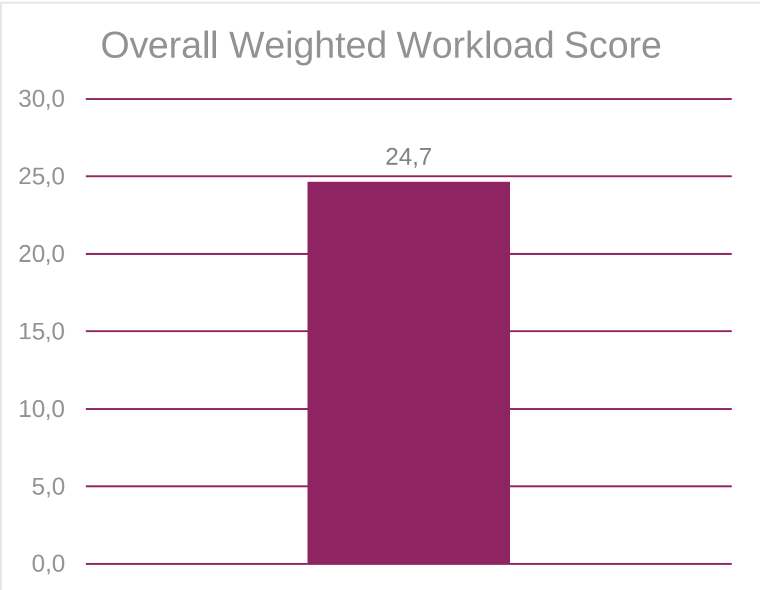

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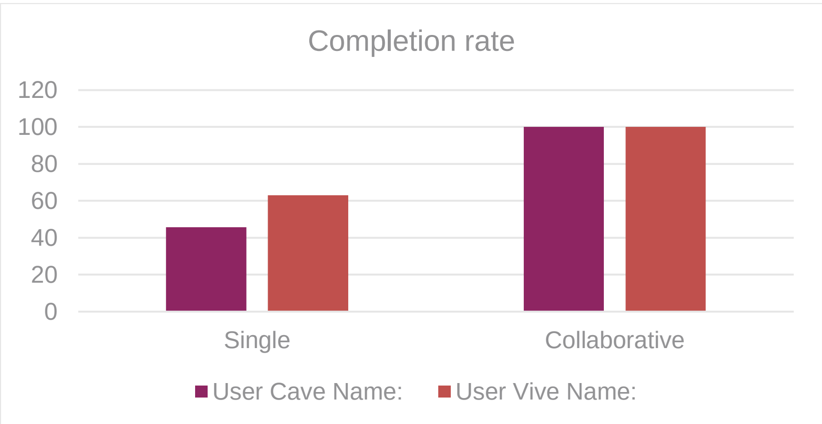

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TLX:

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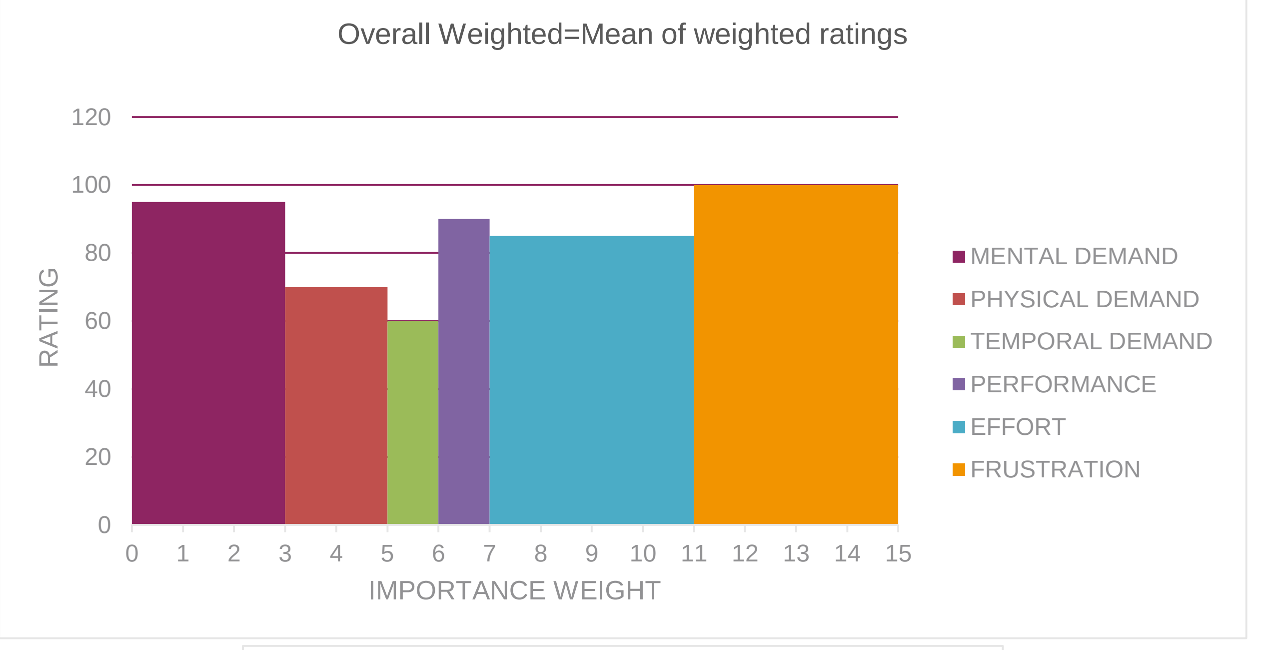

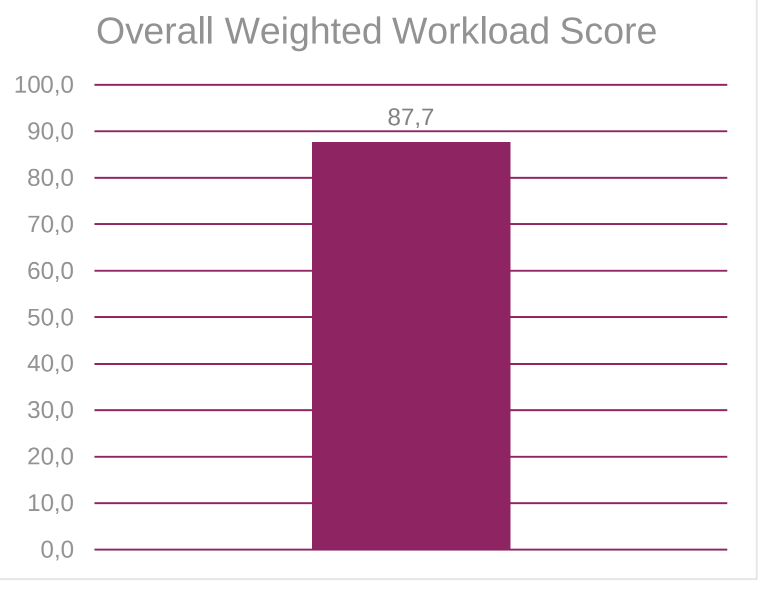

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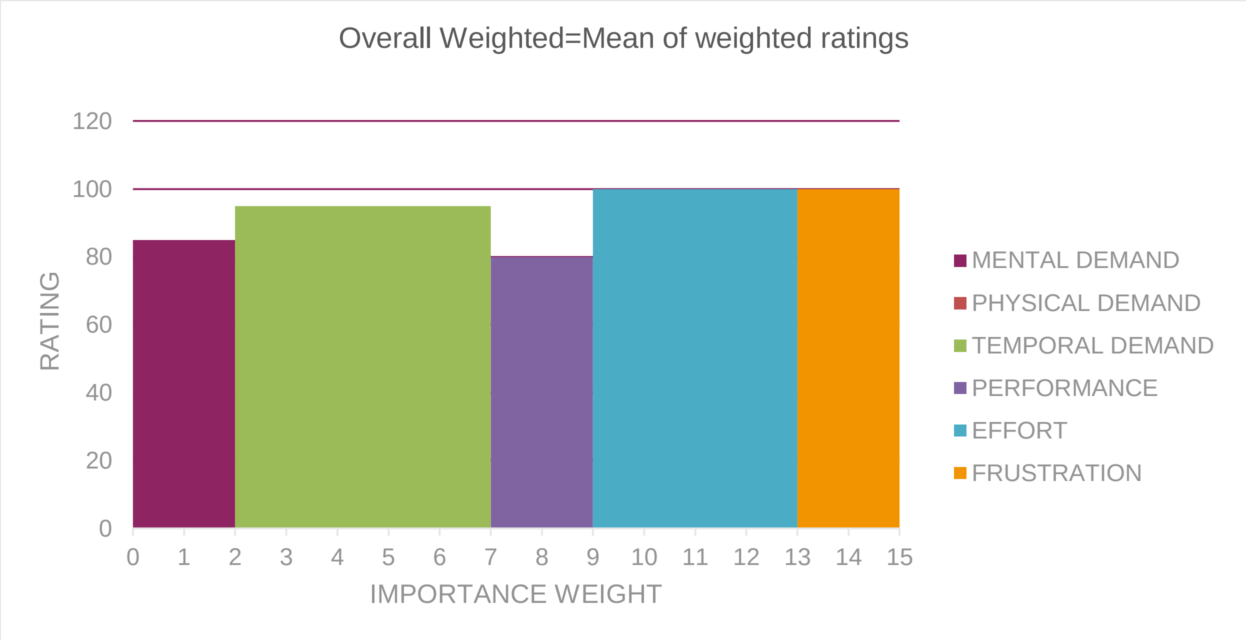

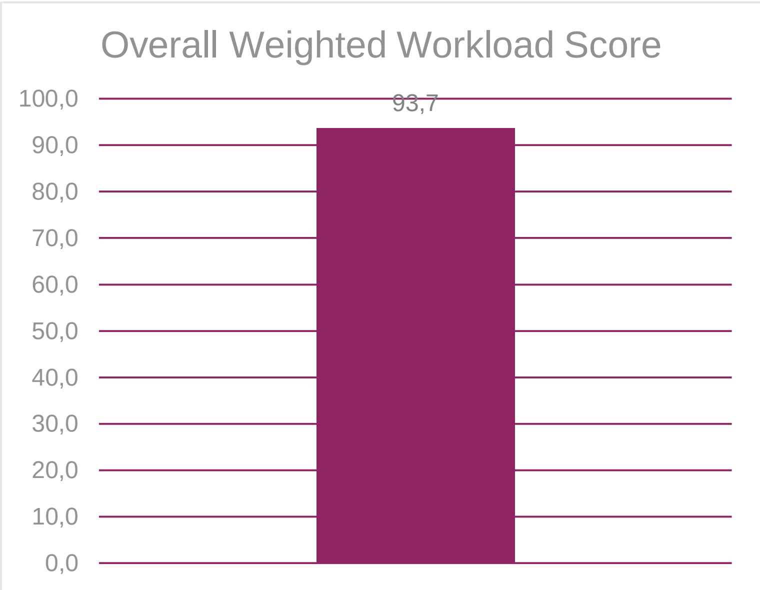

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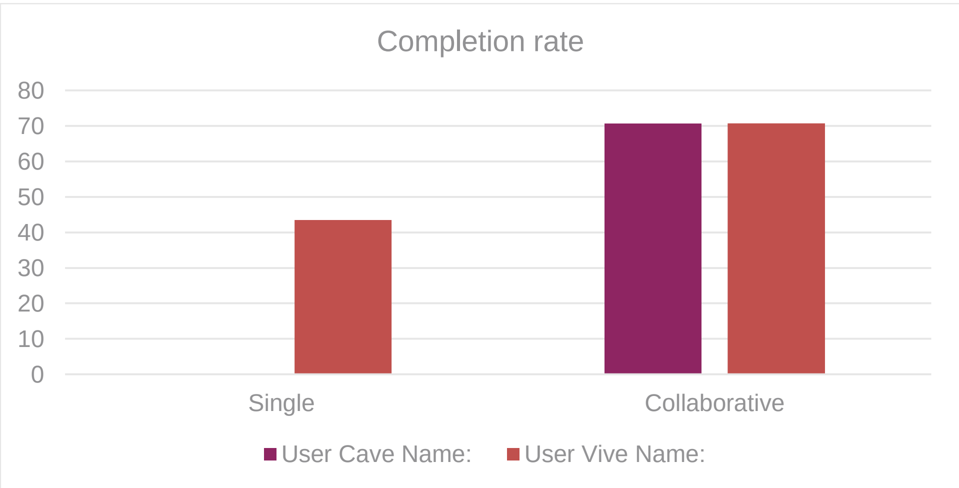

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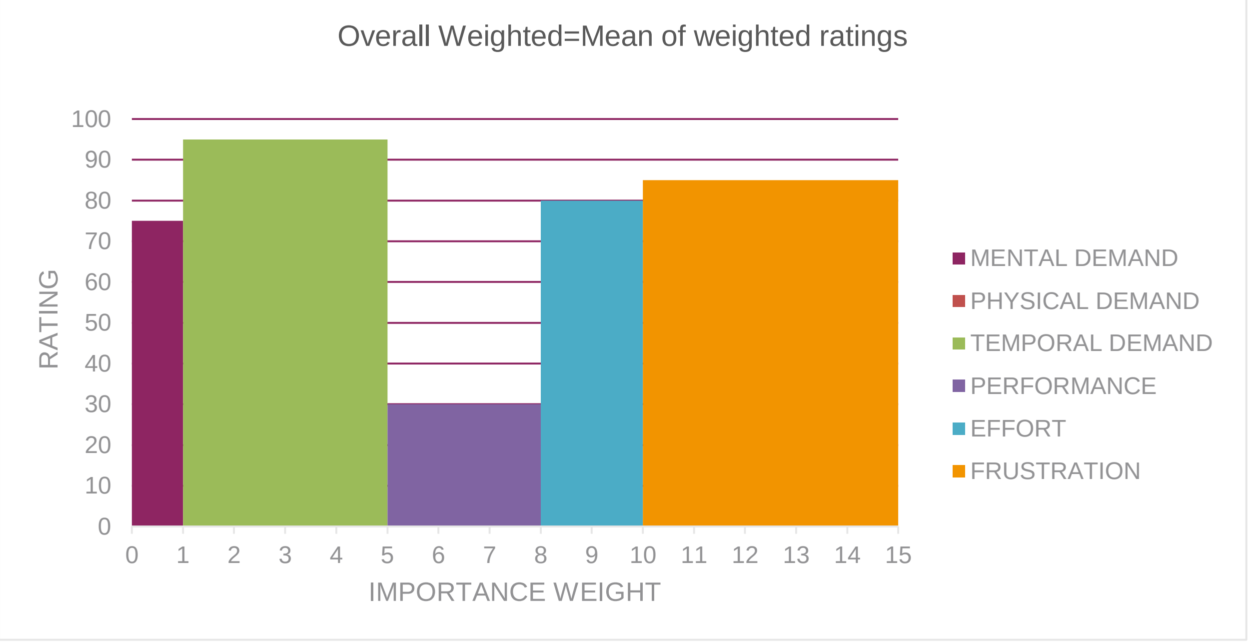

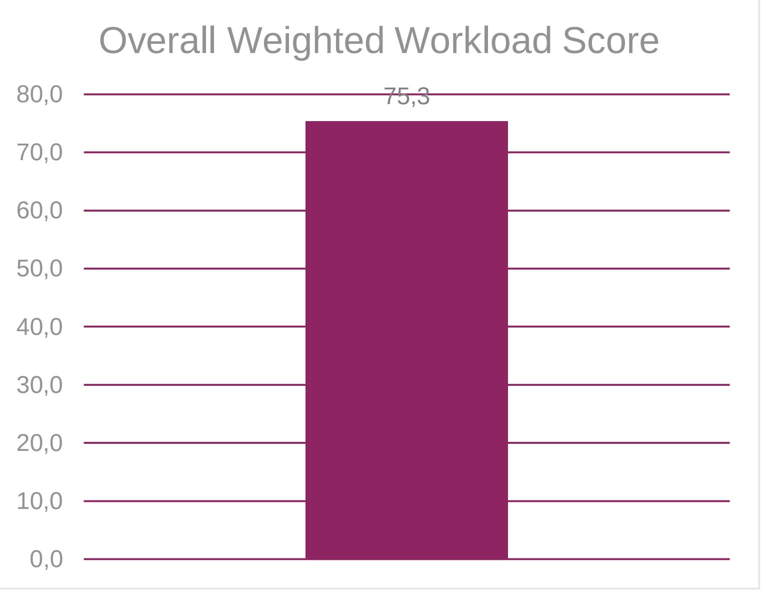

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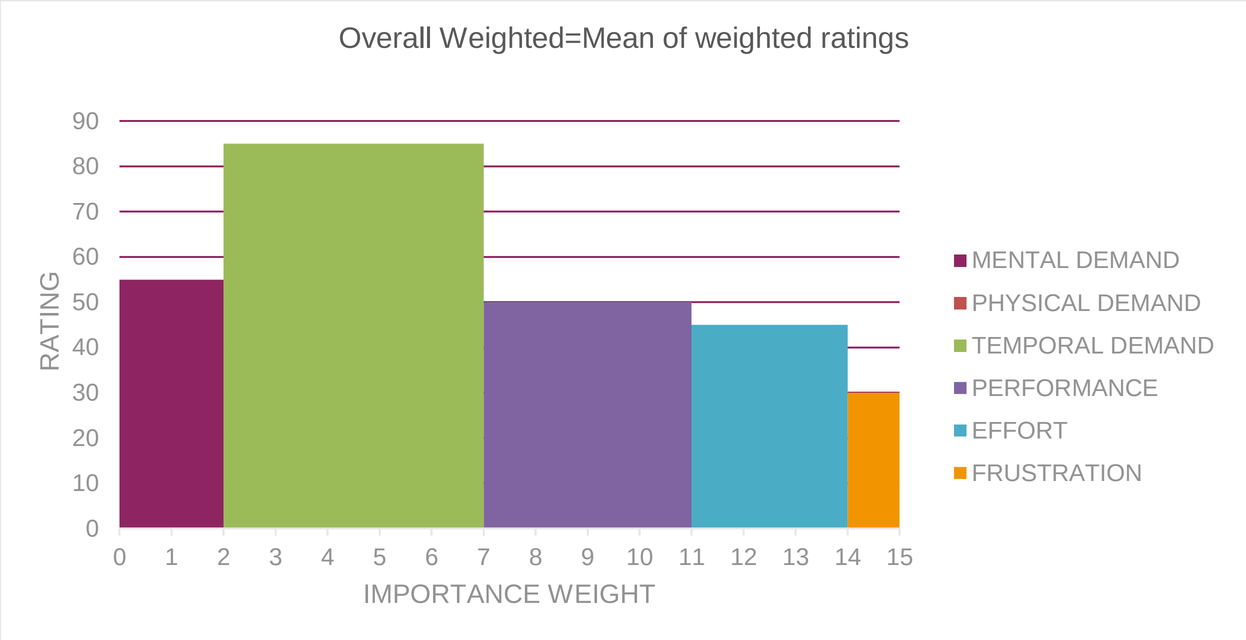

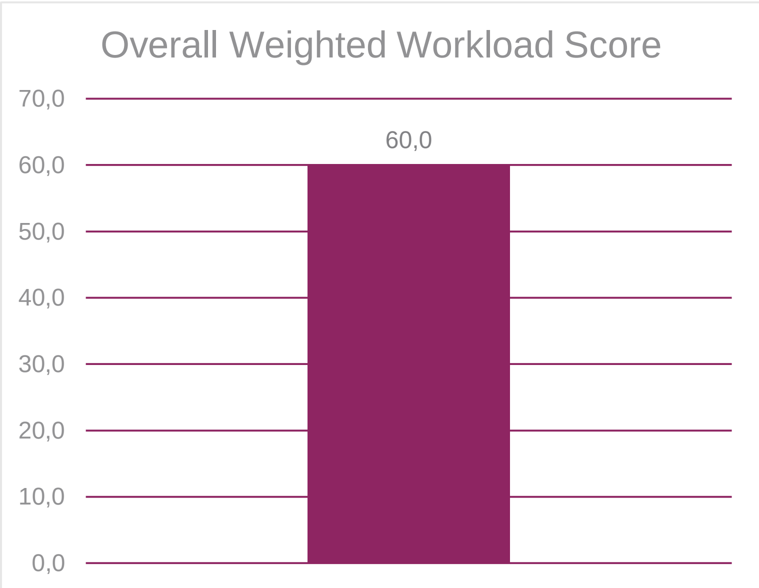

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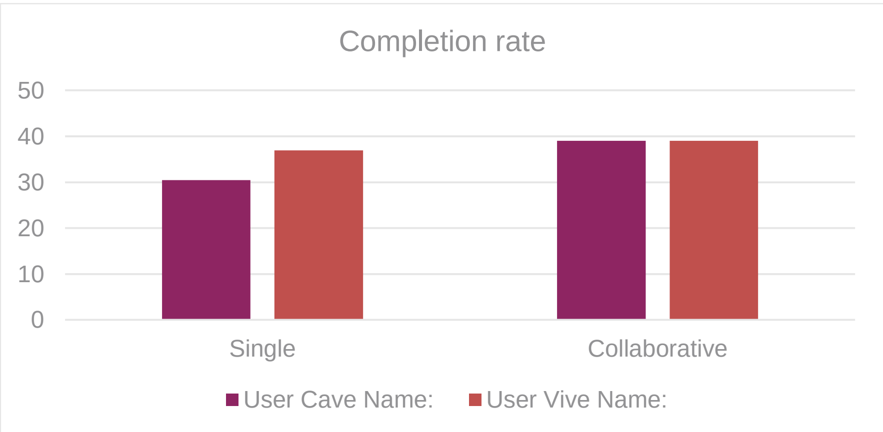

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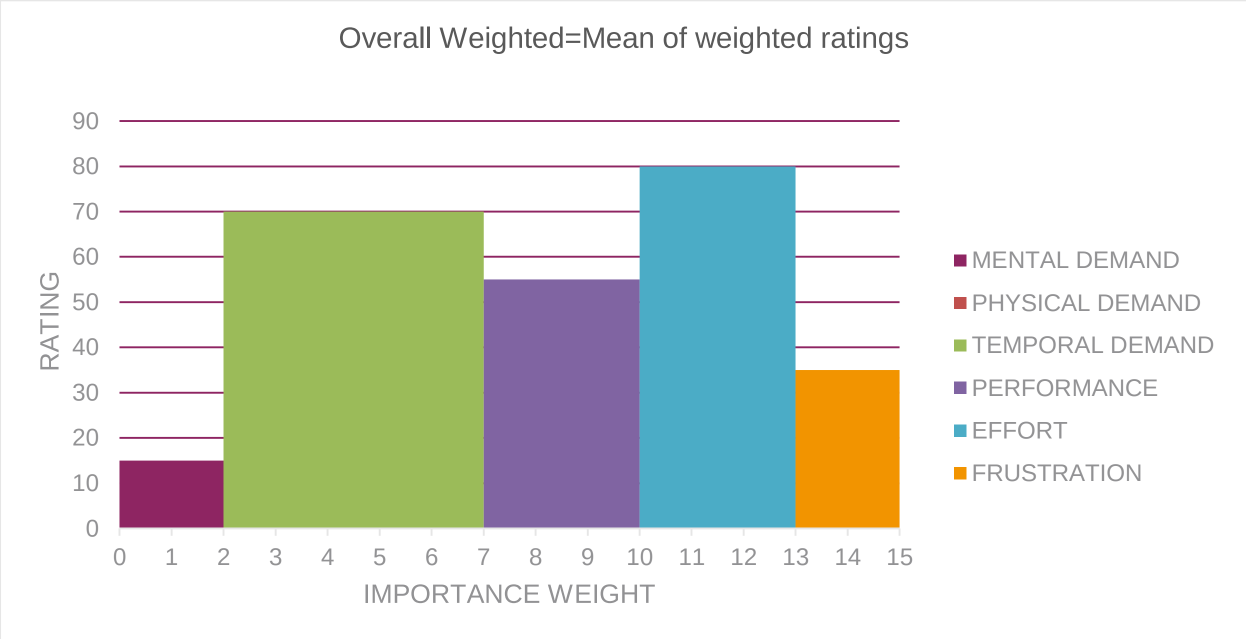

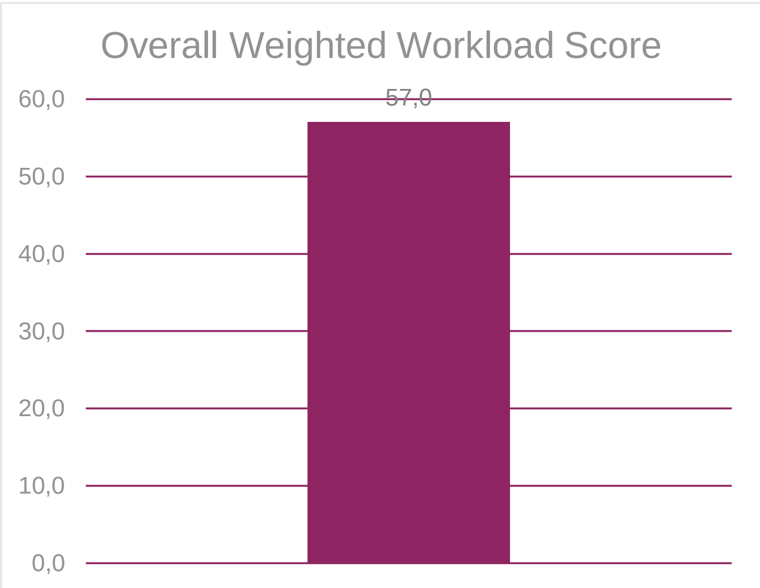

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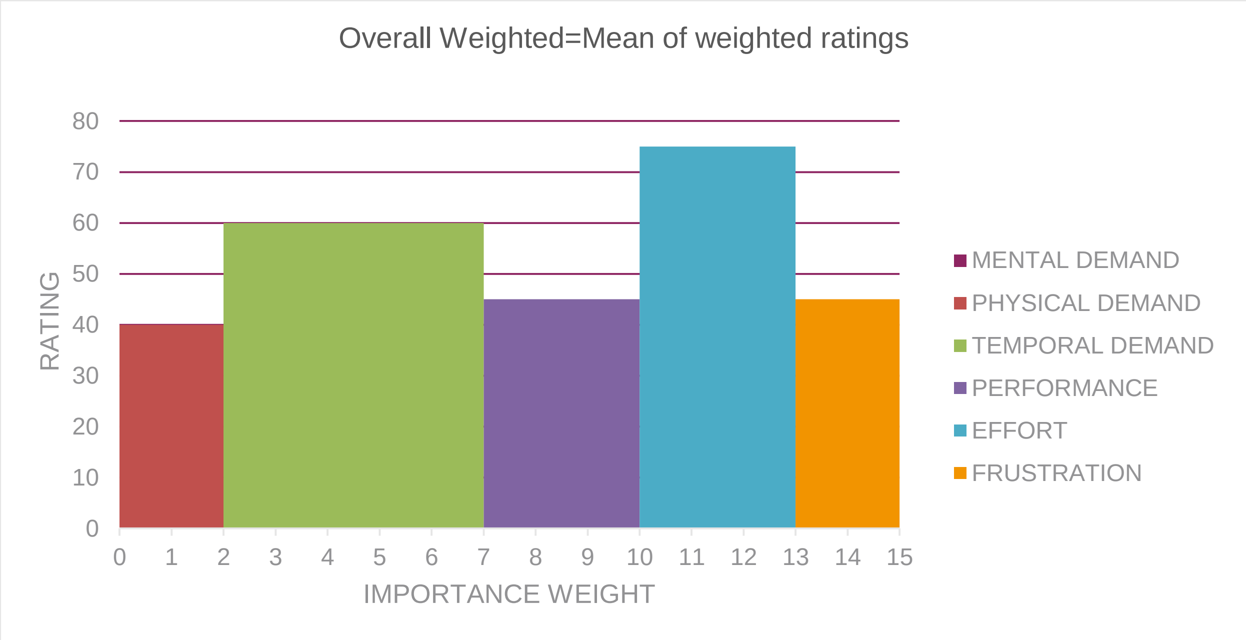

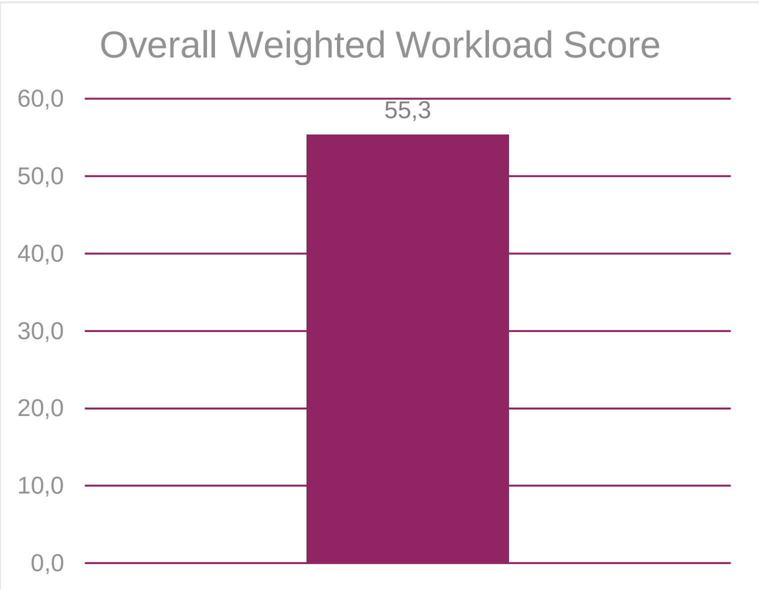

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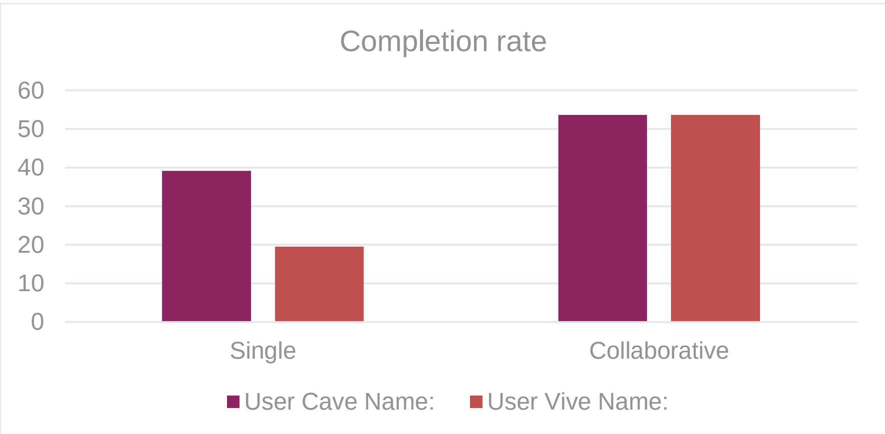

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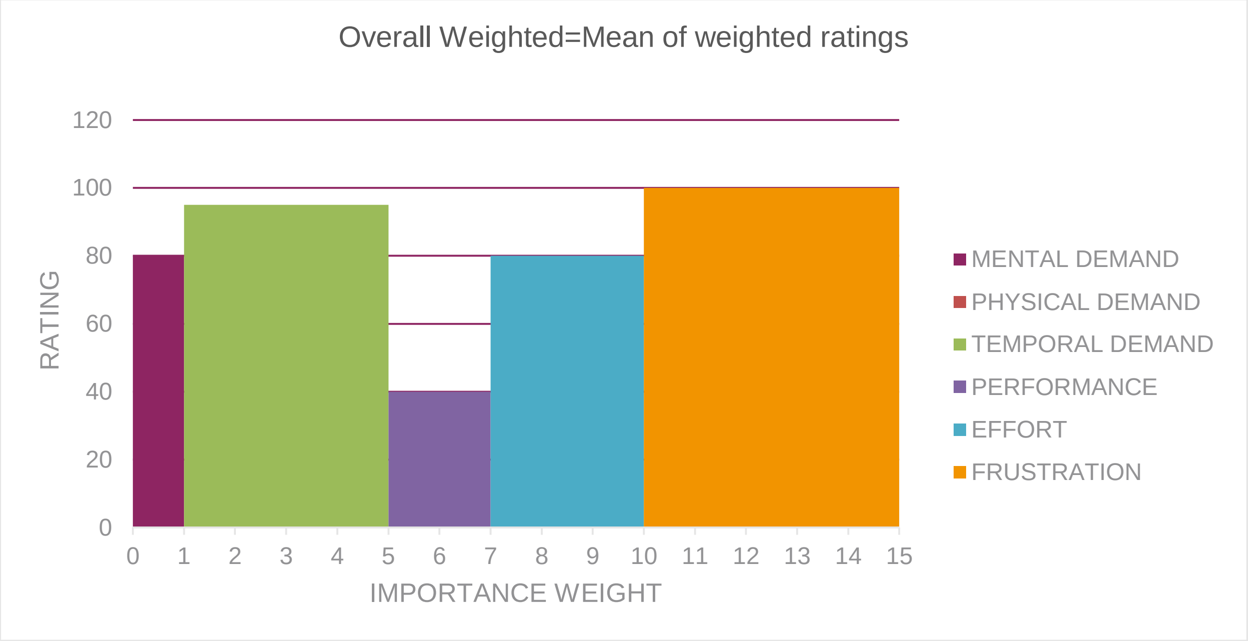
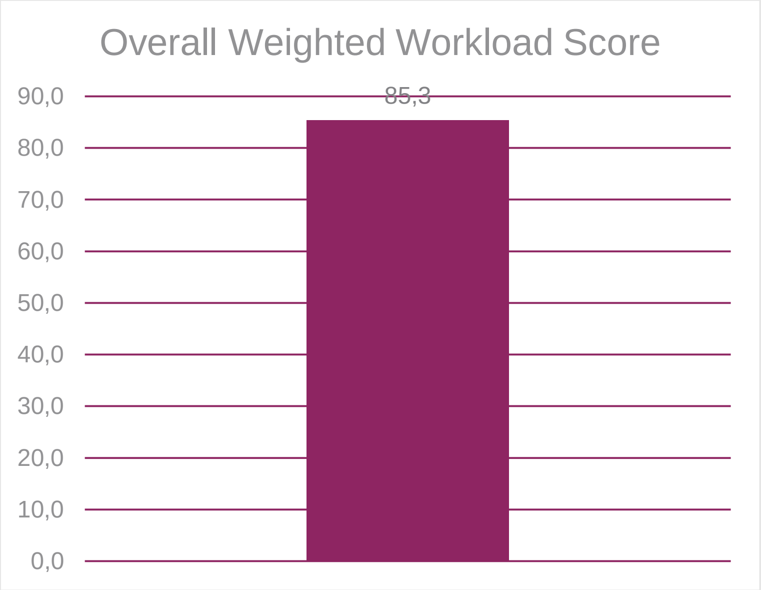
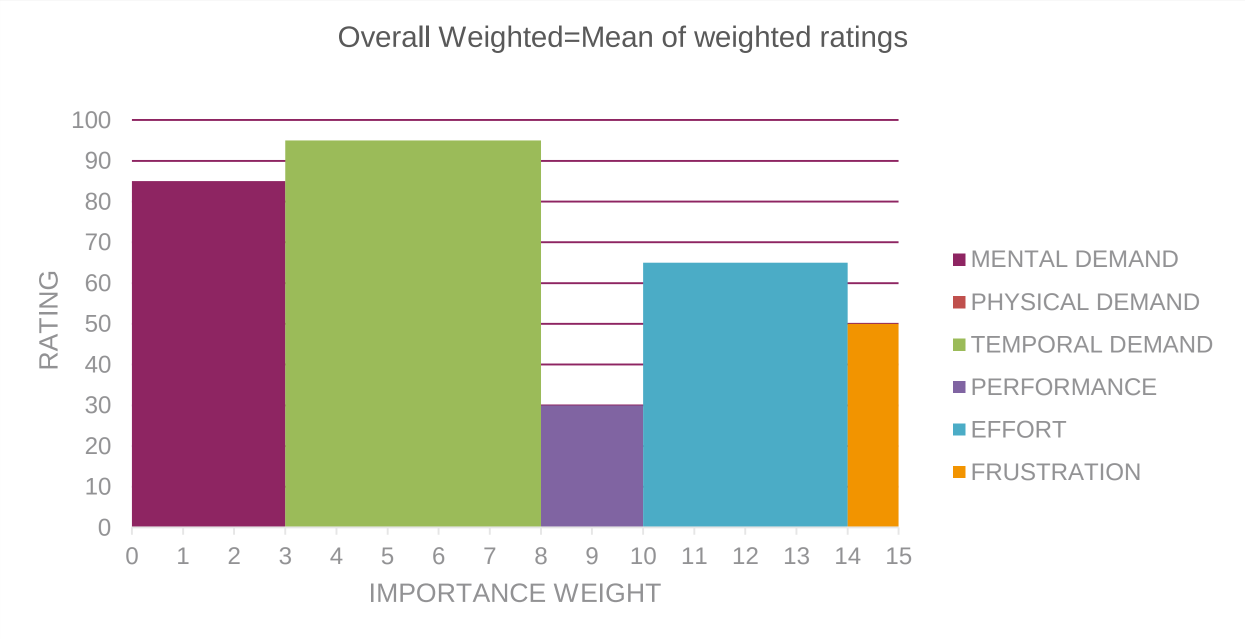
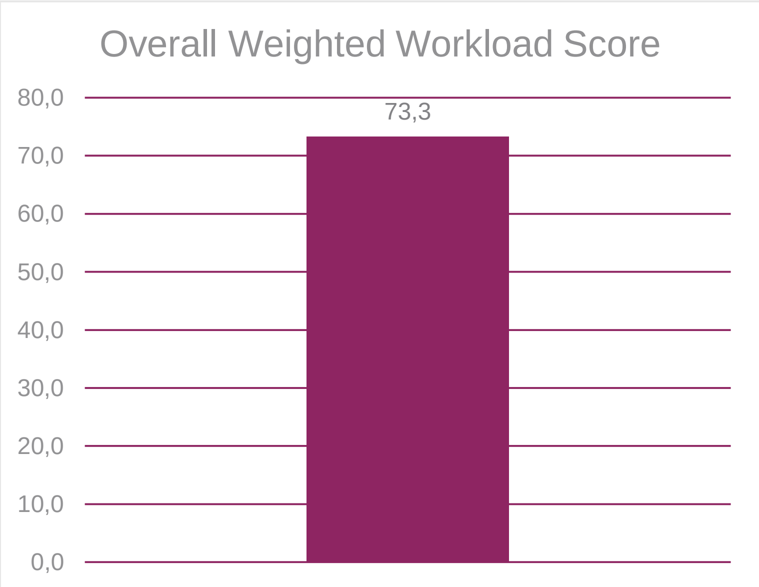




Collaborative:





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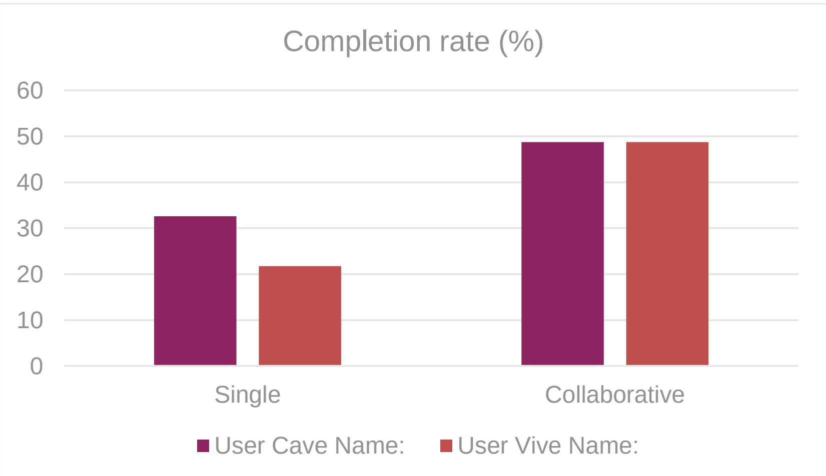

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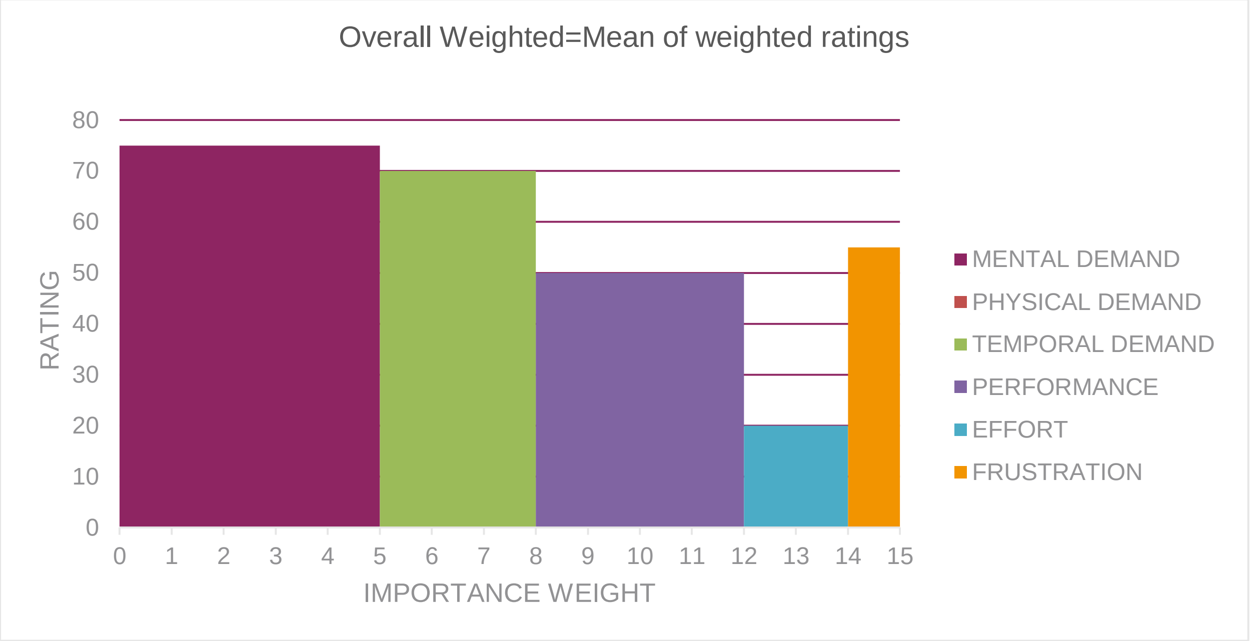

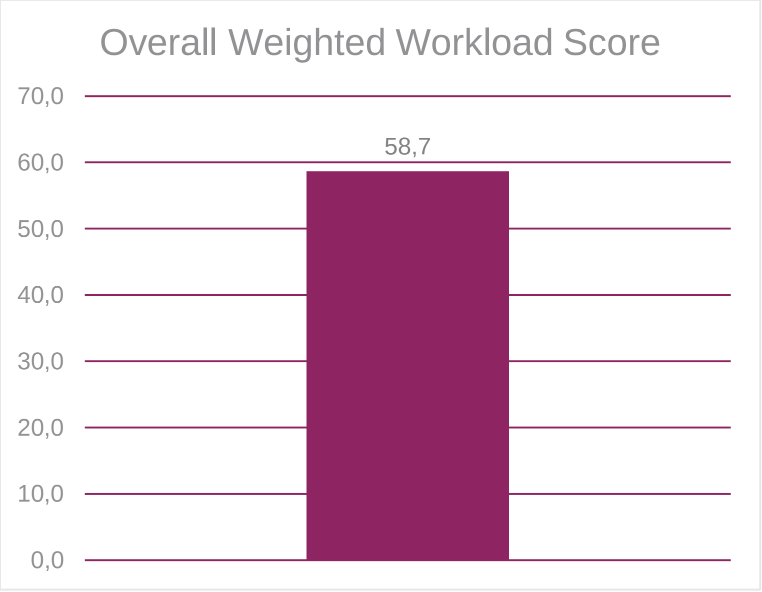

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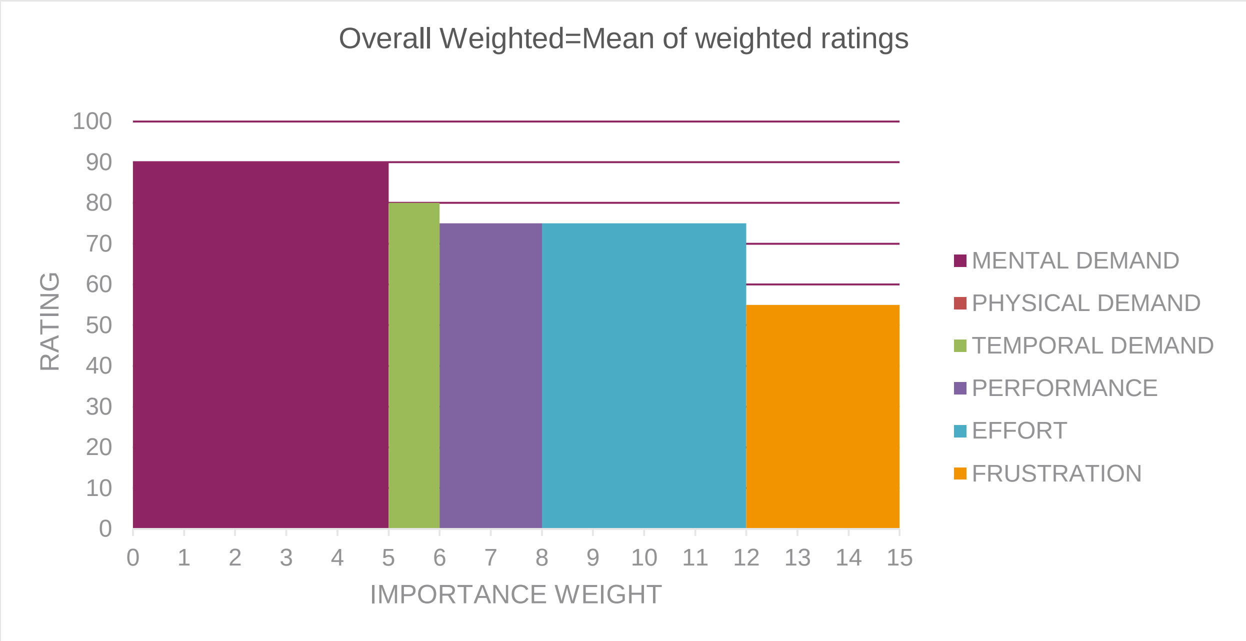

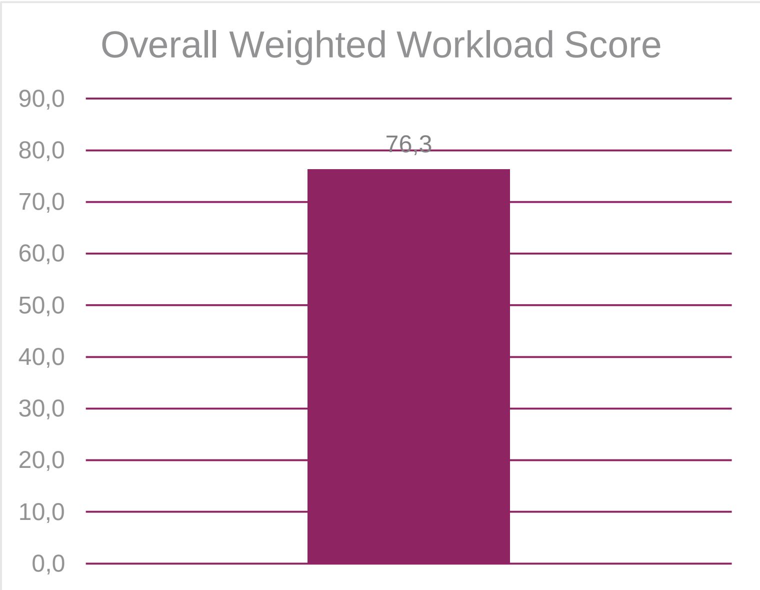

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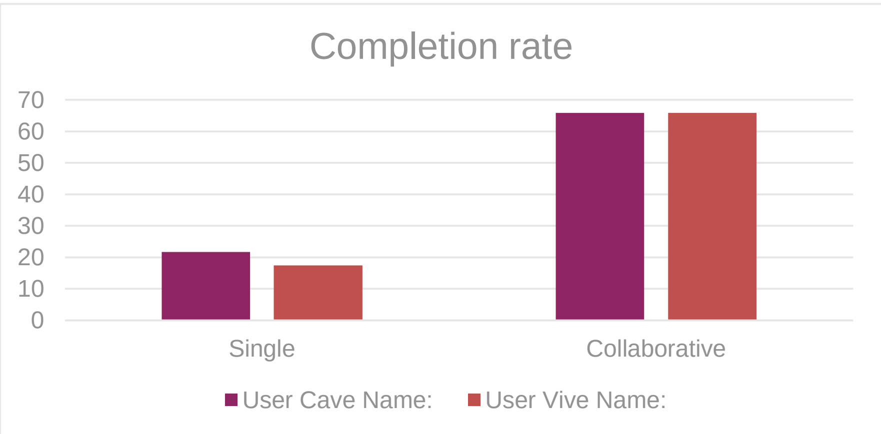

Session 8:

TLX:

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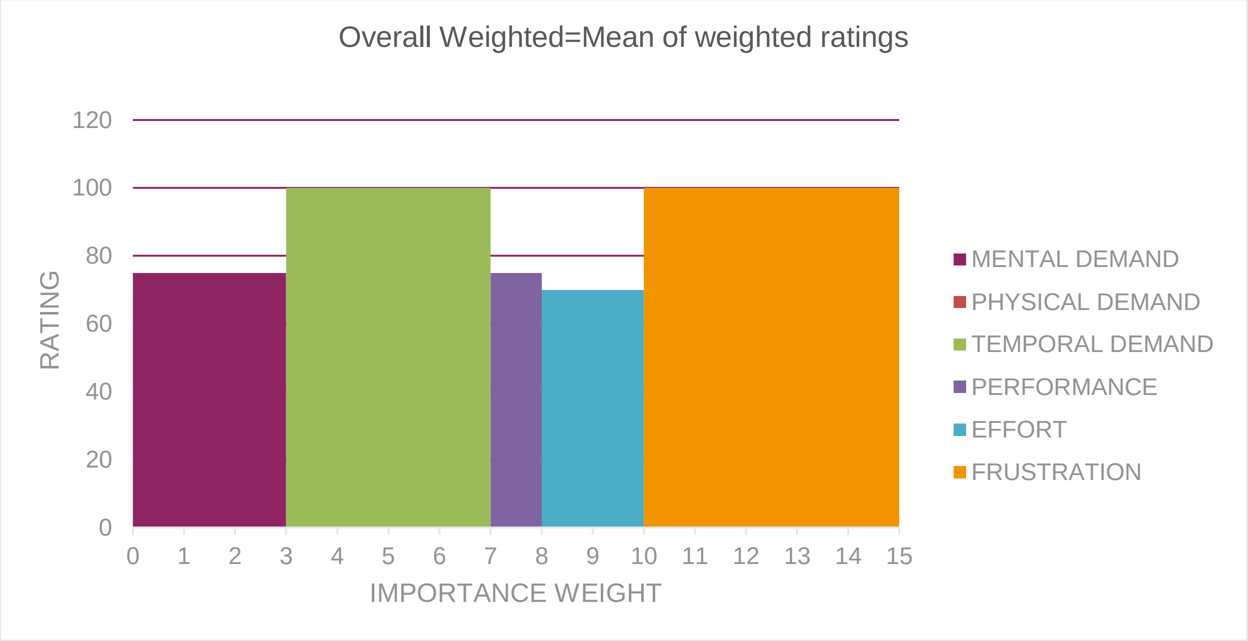

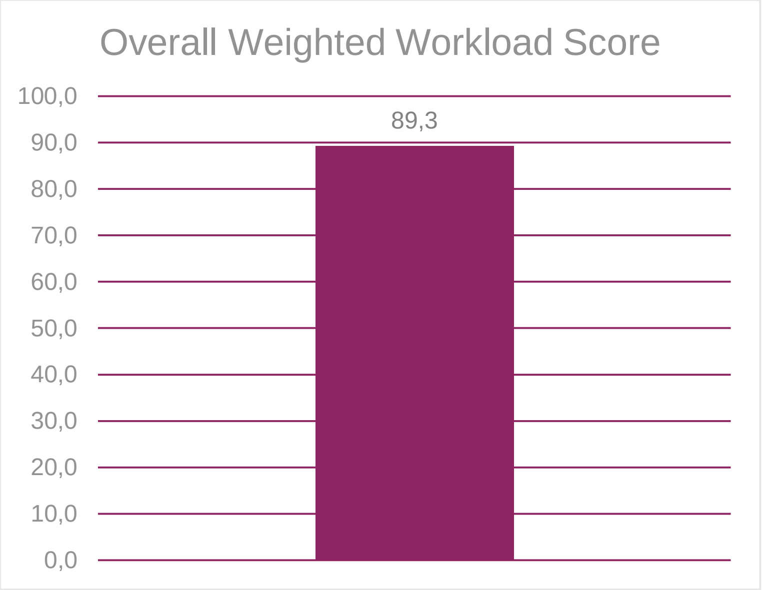

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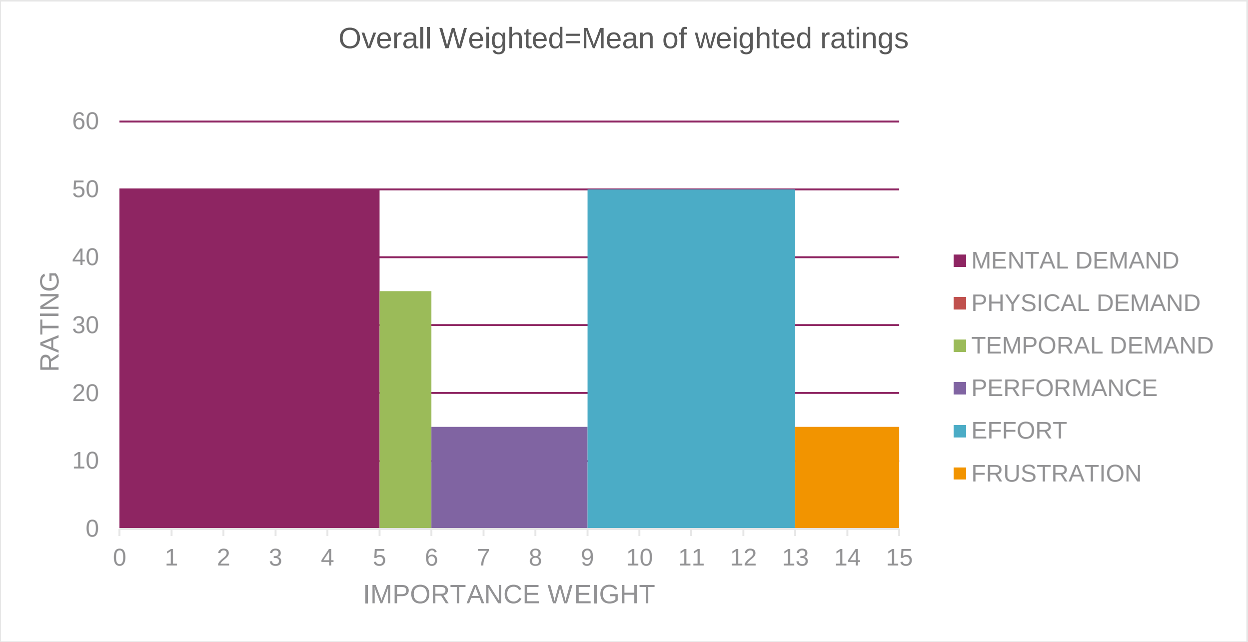

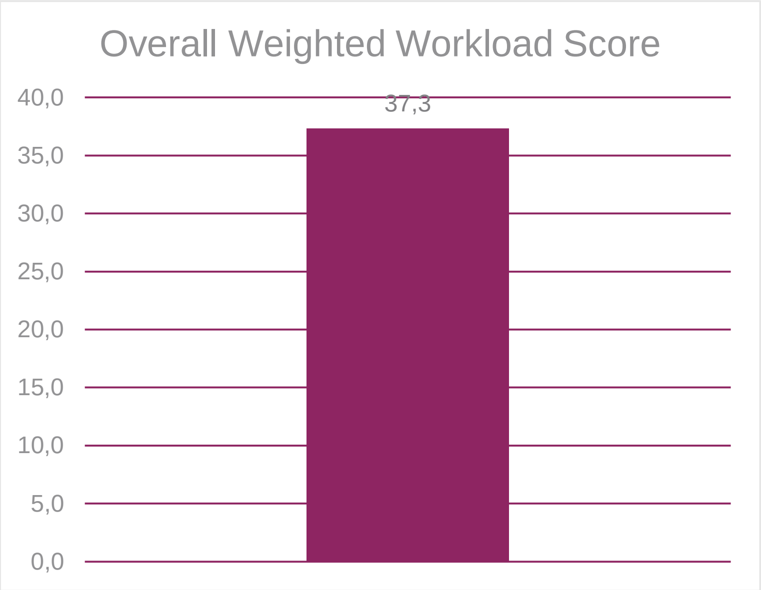

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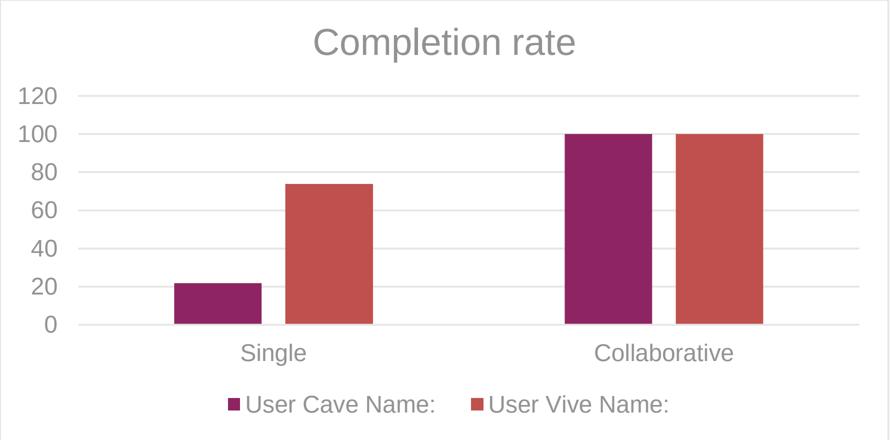

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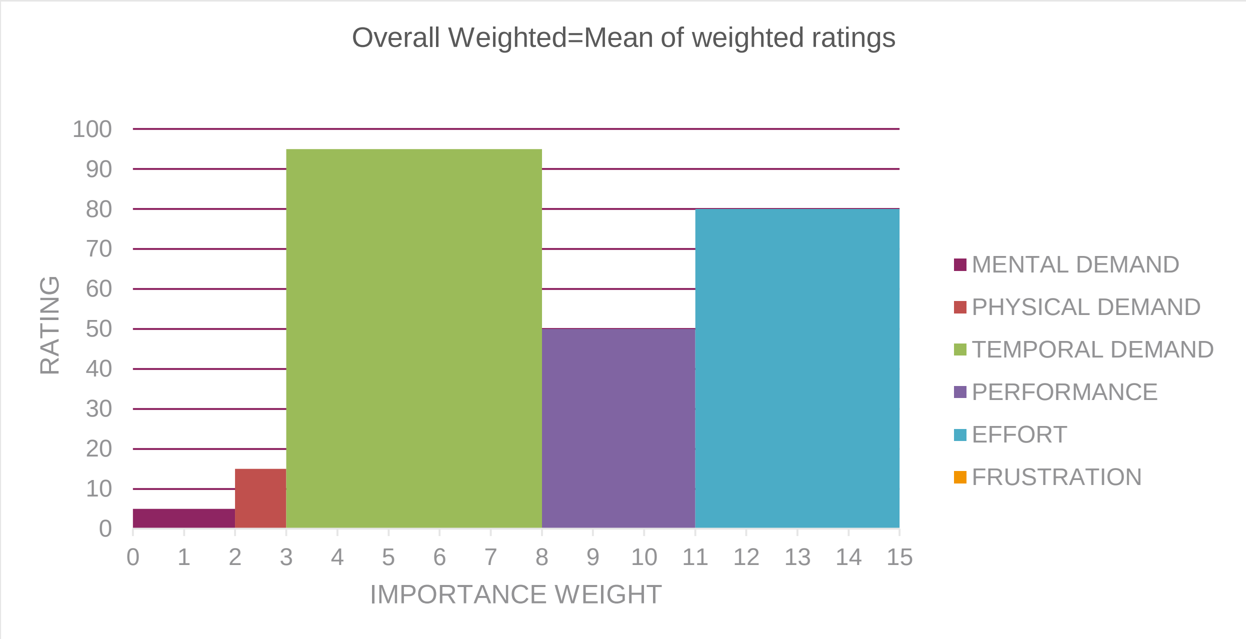

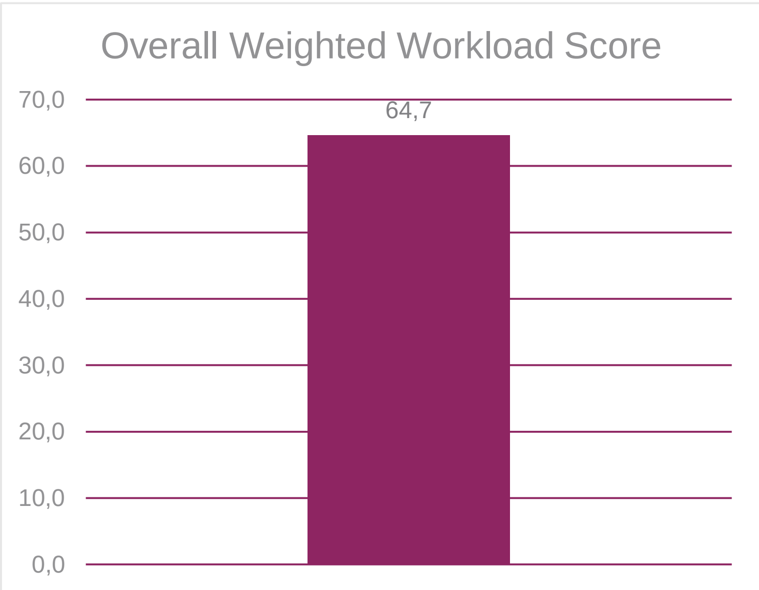

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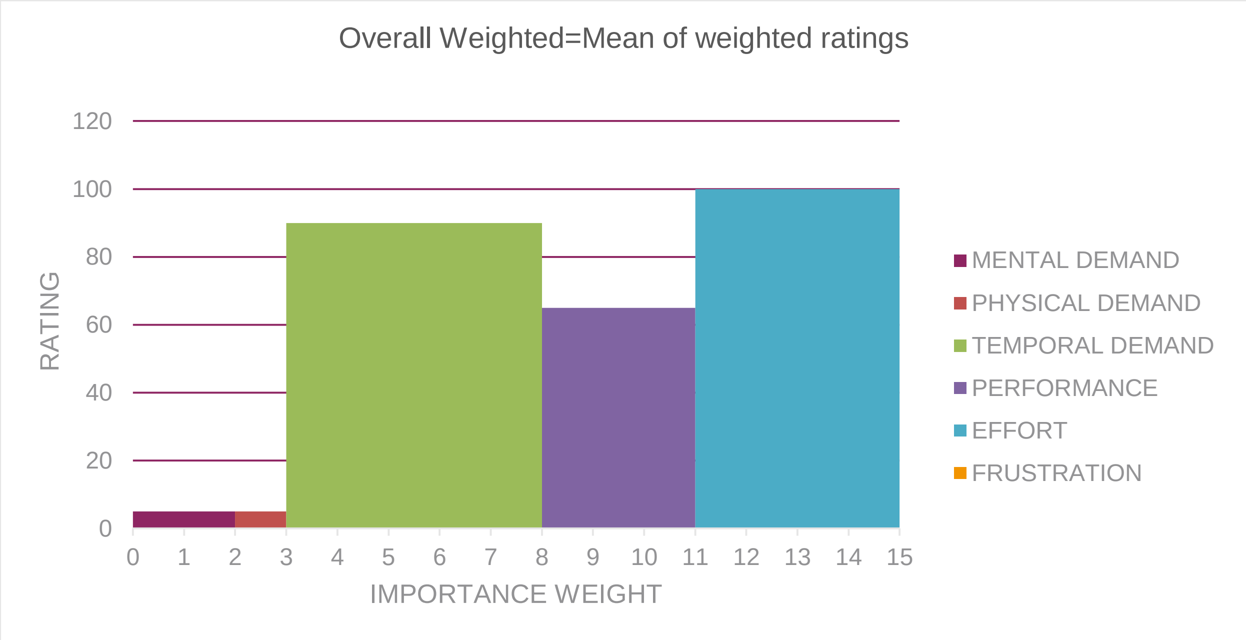

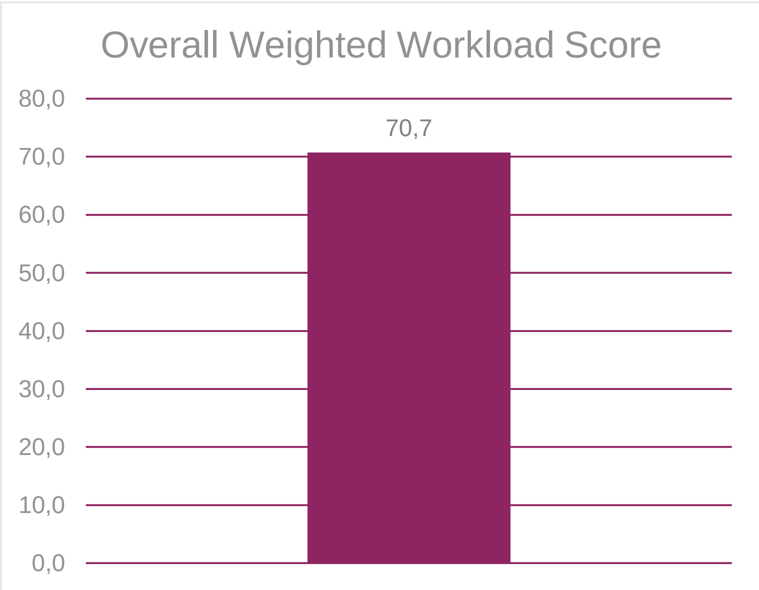

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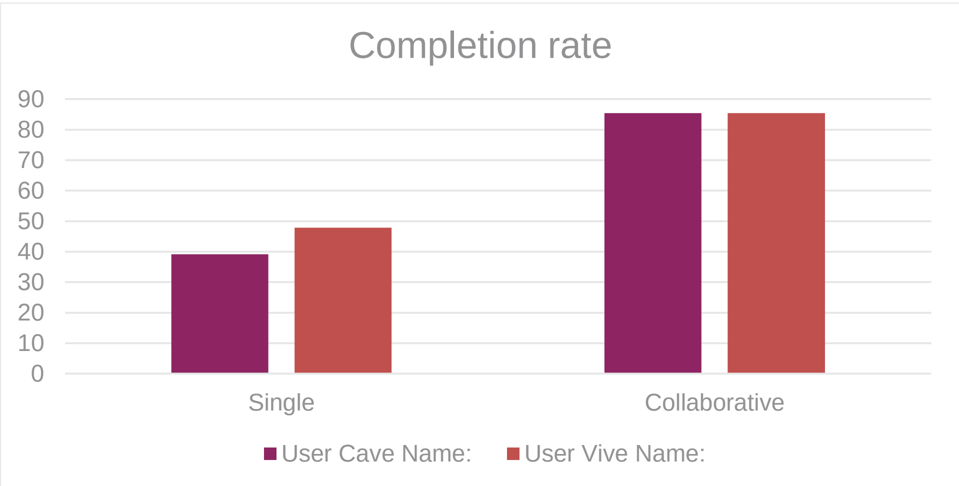

B) Vive:

<u>Session 1 :</u>

TLX:

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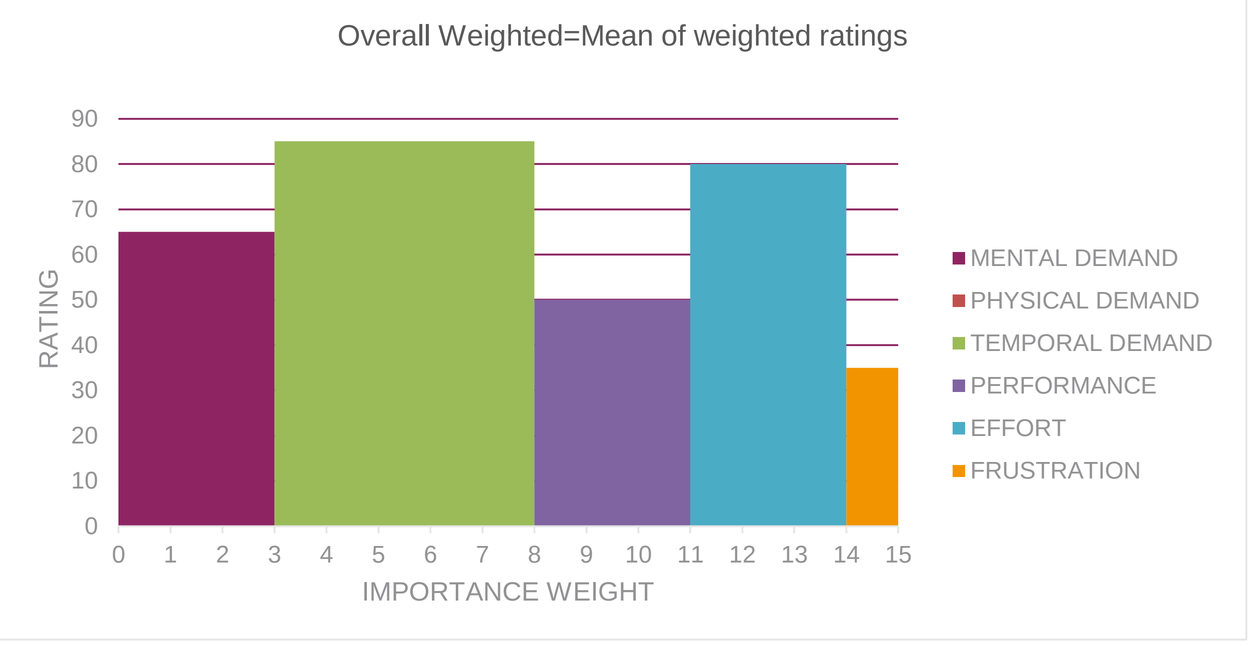

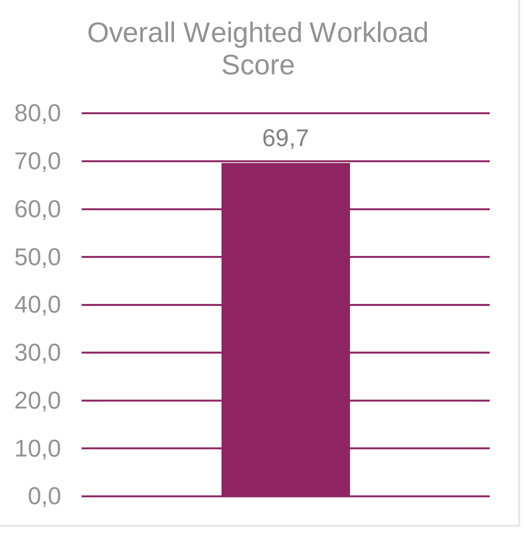

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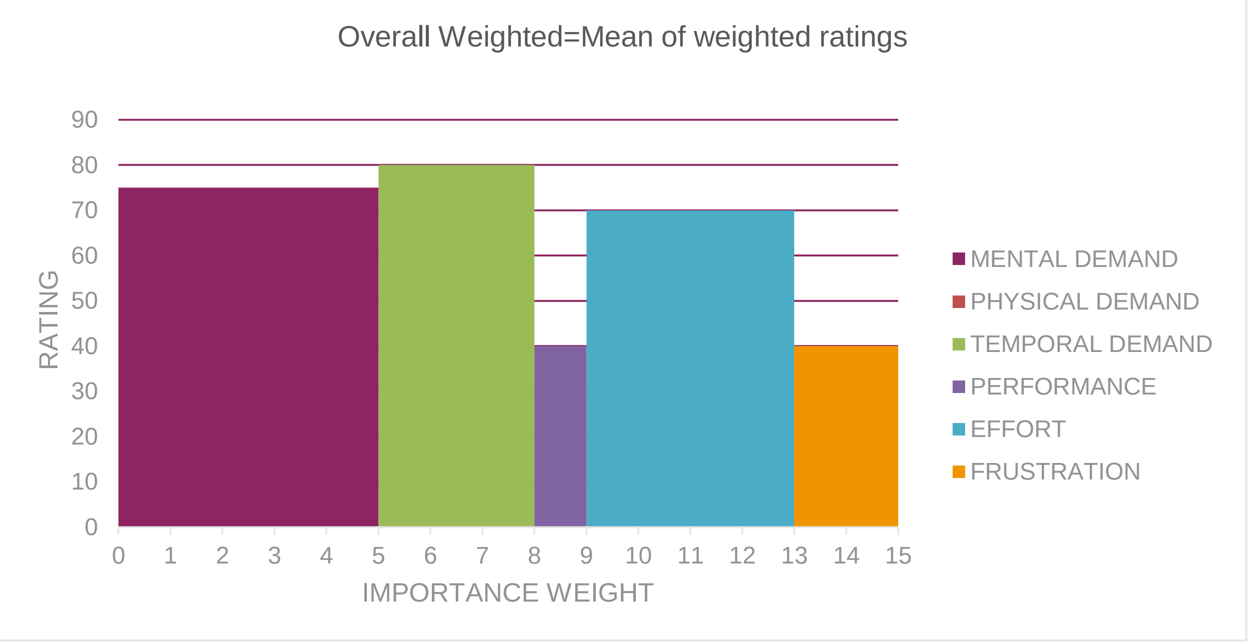

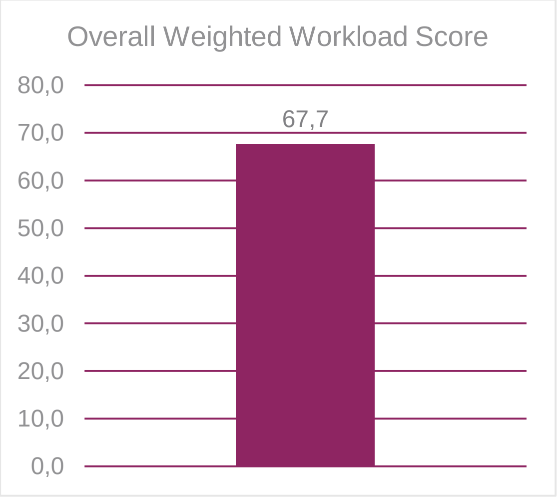

<u>Session 2:</u>

TLX:

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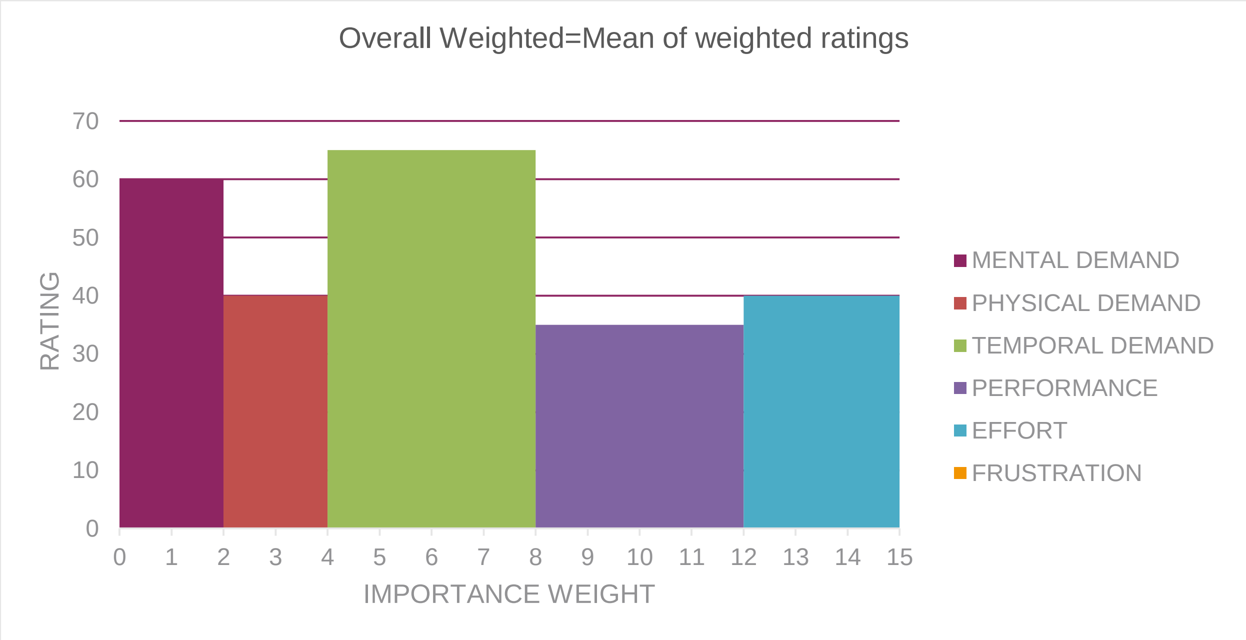

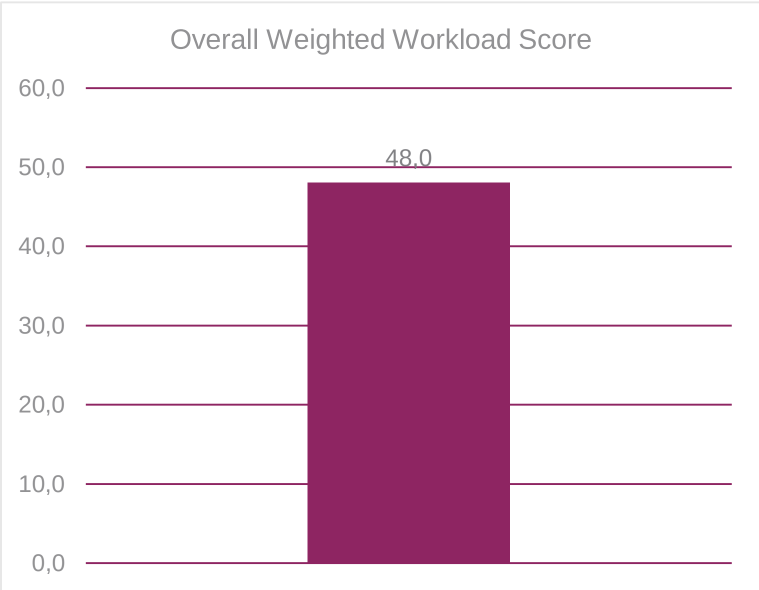

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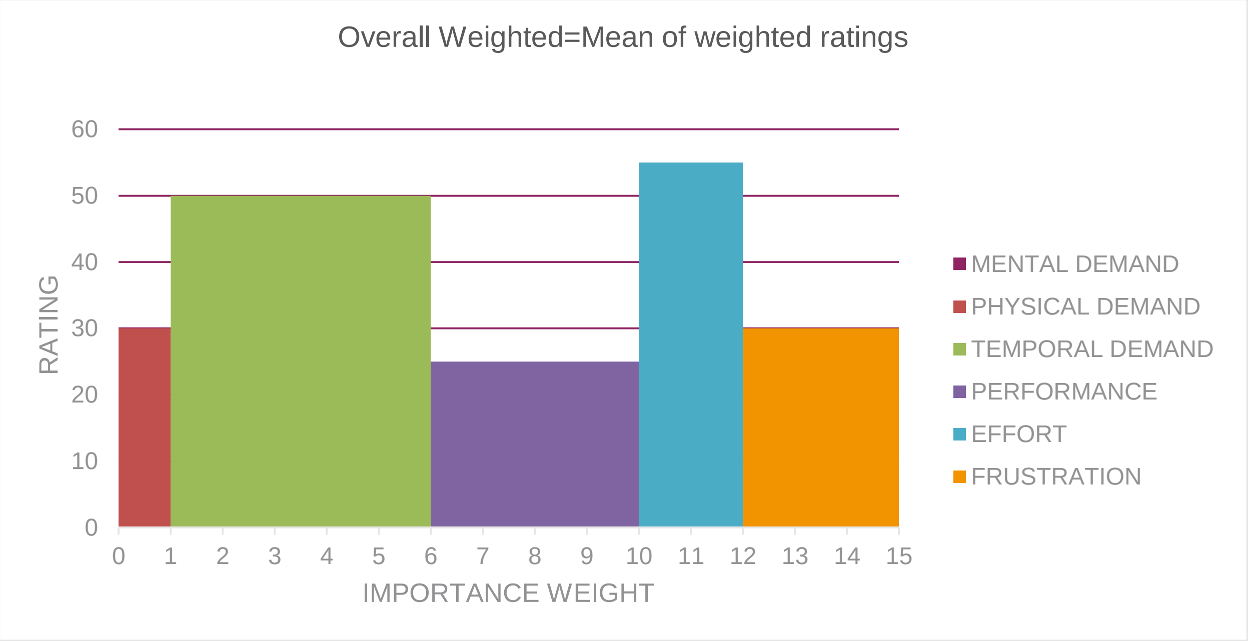

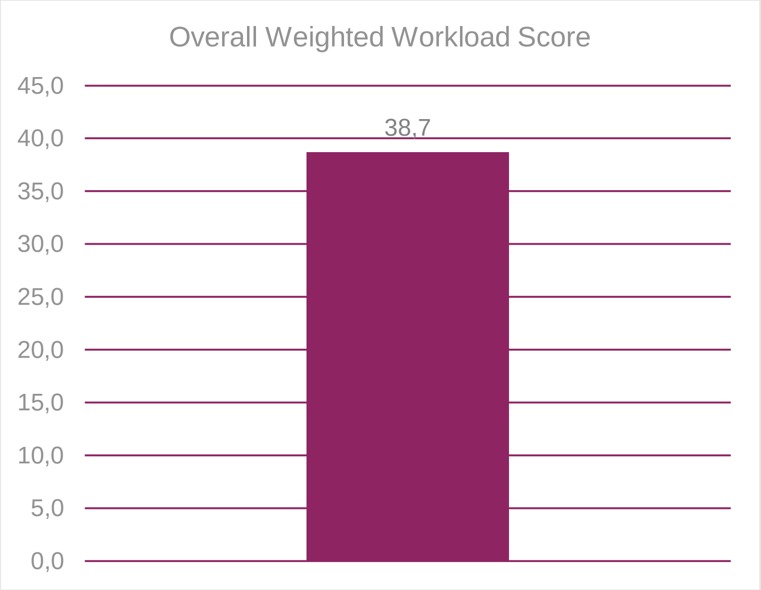

<u>Session 3:</u>

TLX:

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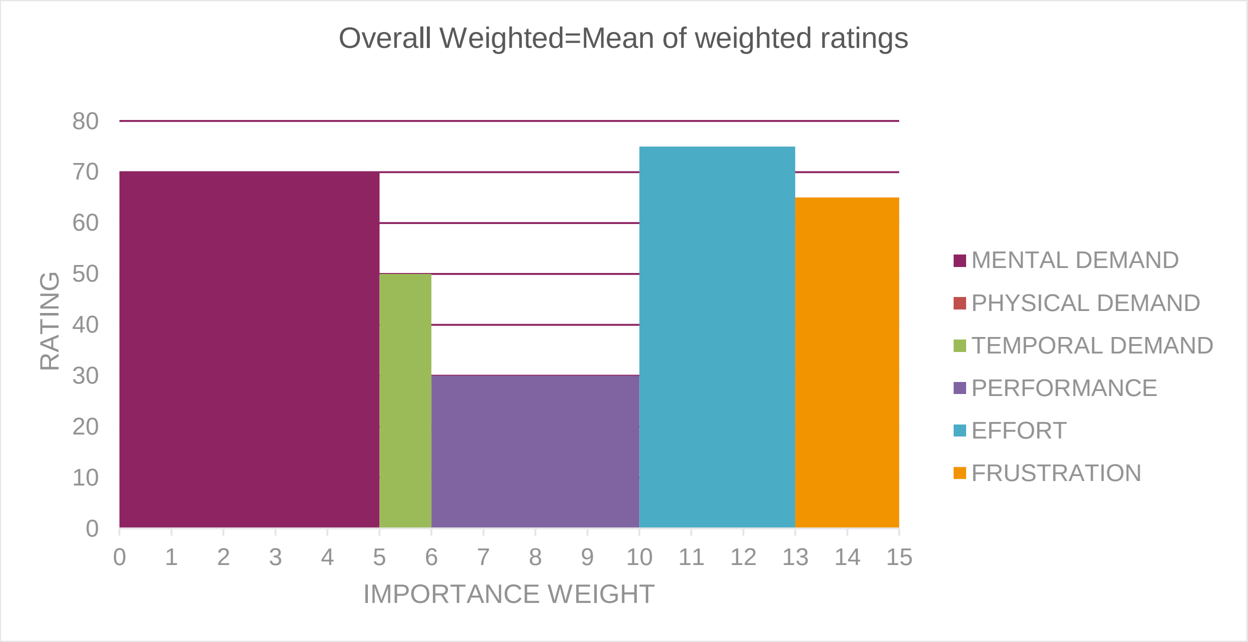

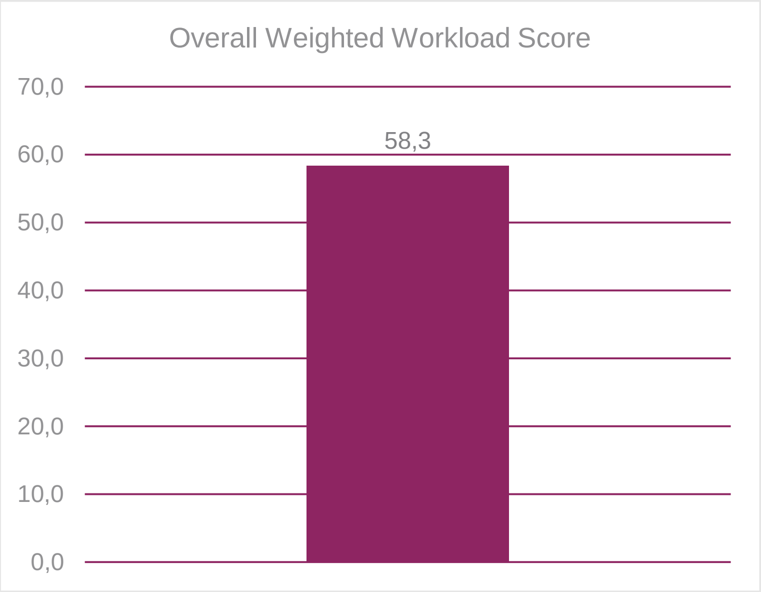

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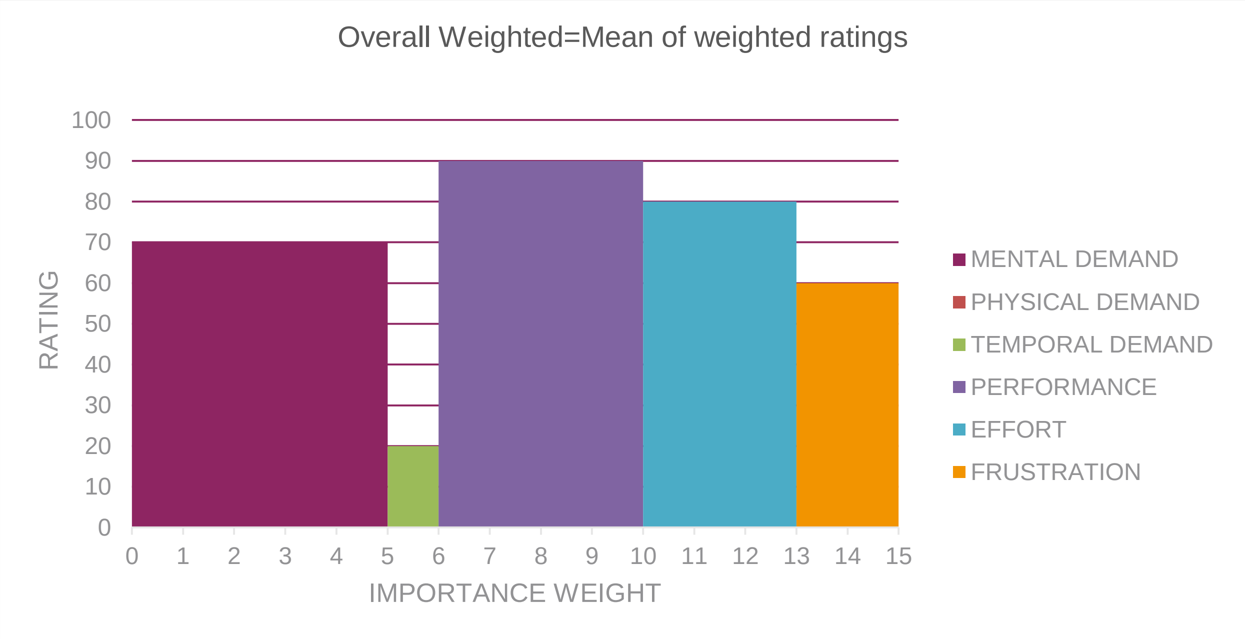
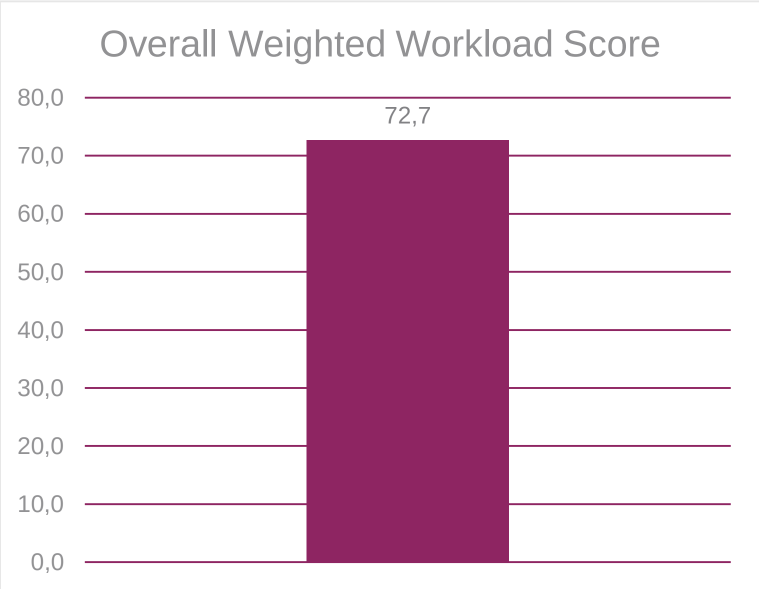
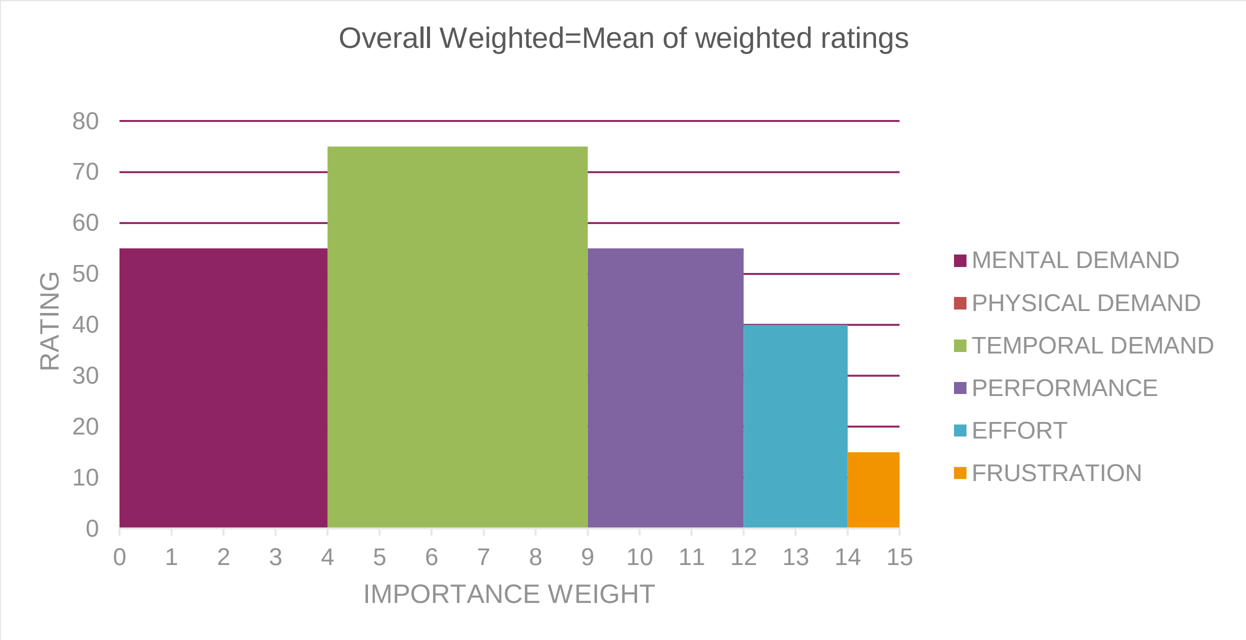


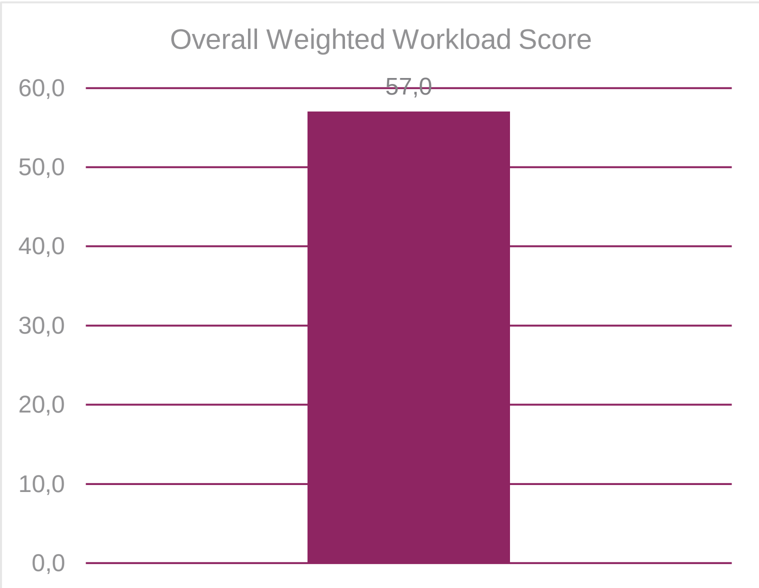


<u>**Session 4:**</u>

TLX:

Single:





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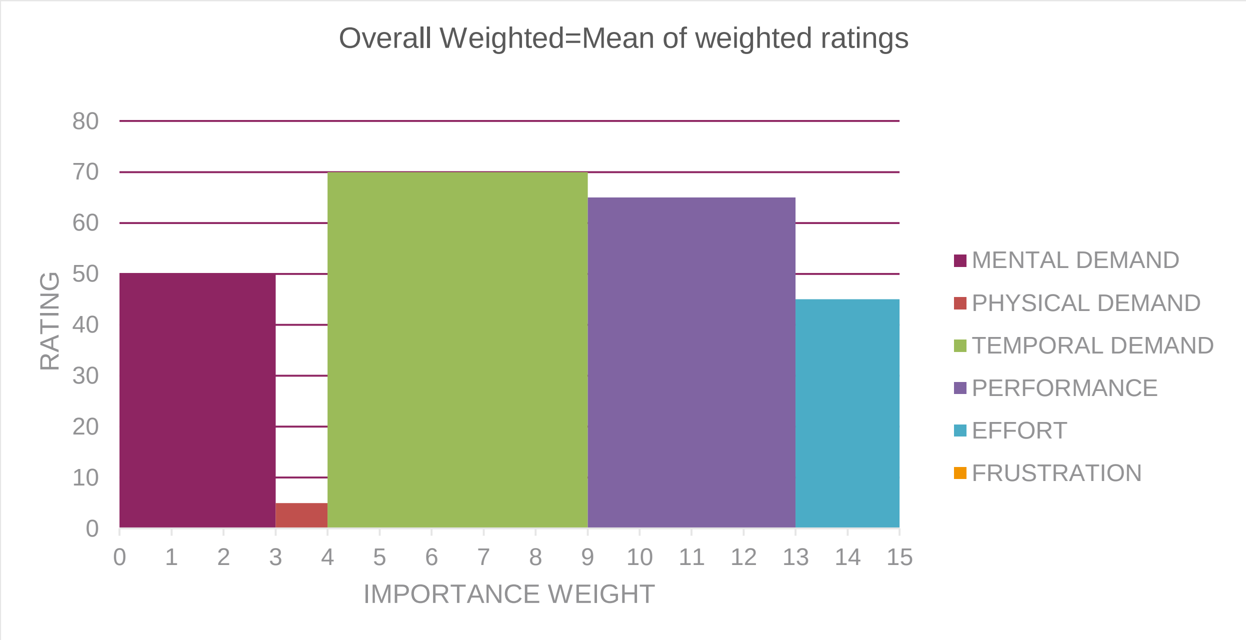
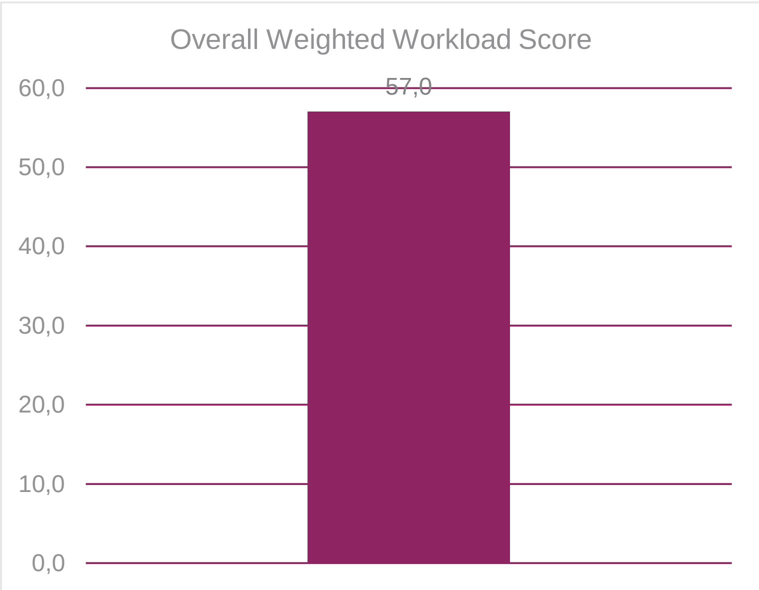
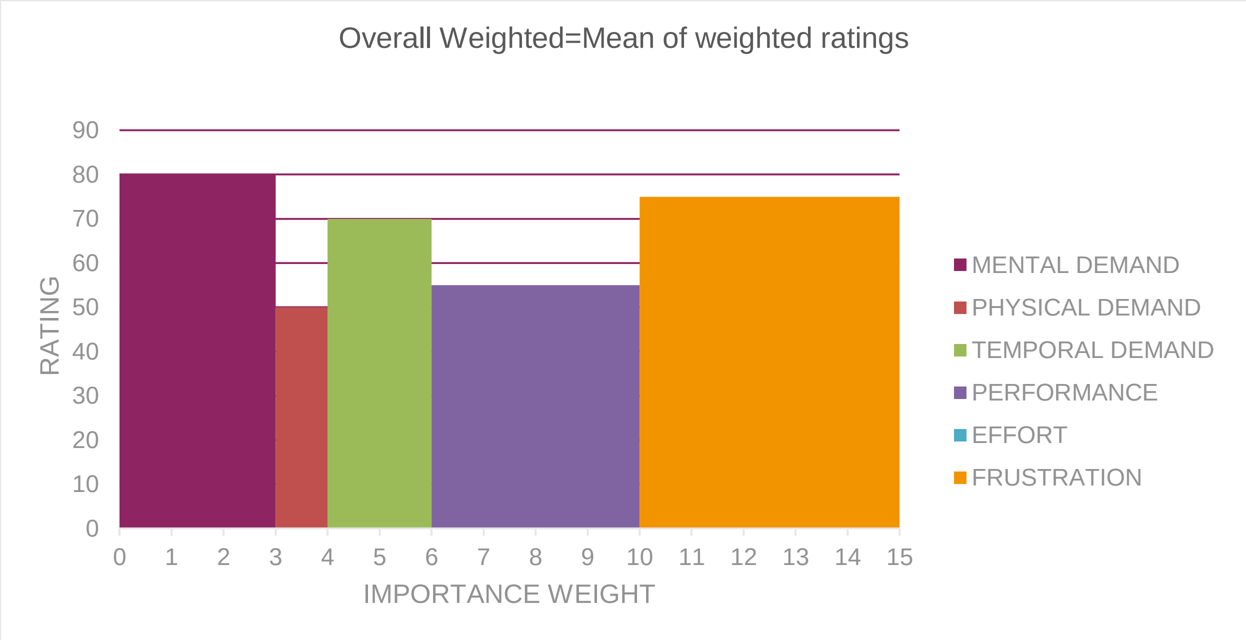


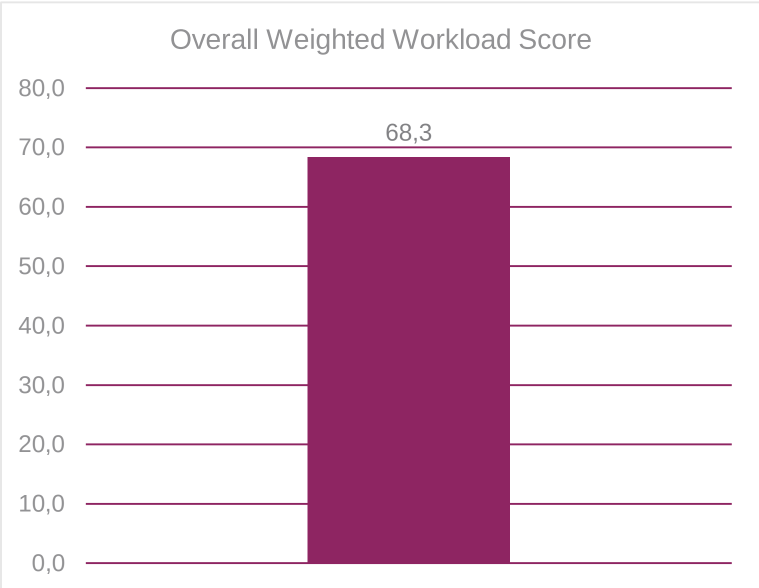


Session 5:

TLX:

Single:





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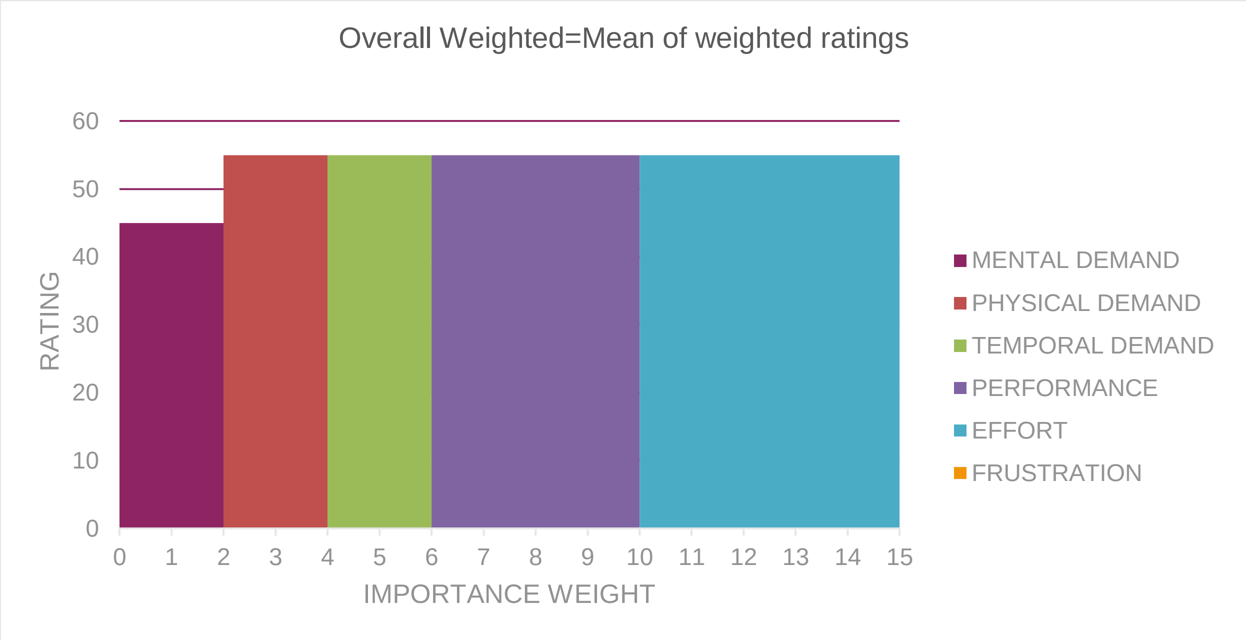

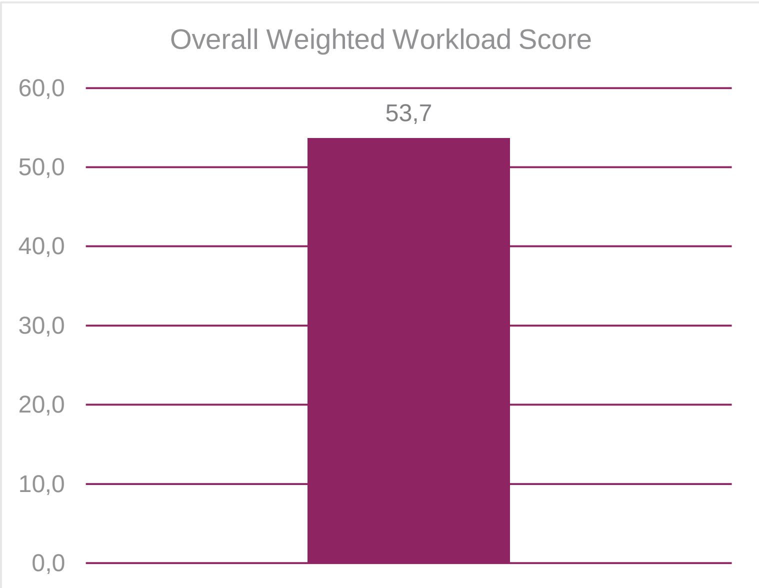

<u>Session 6:</u>

TLX:

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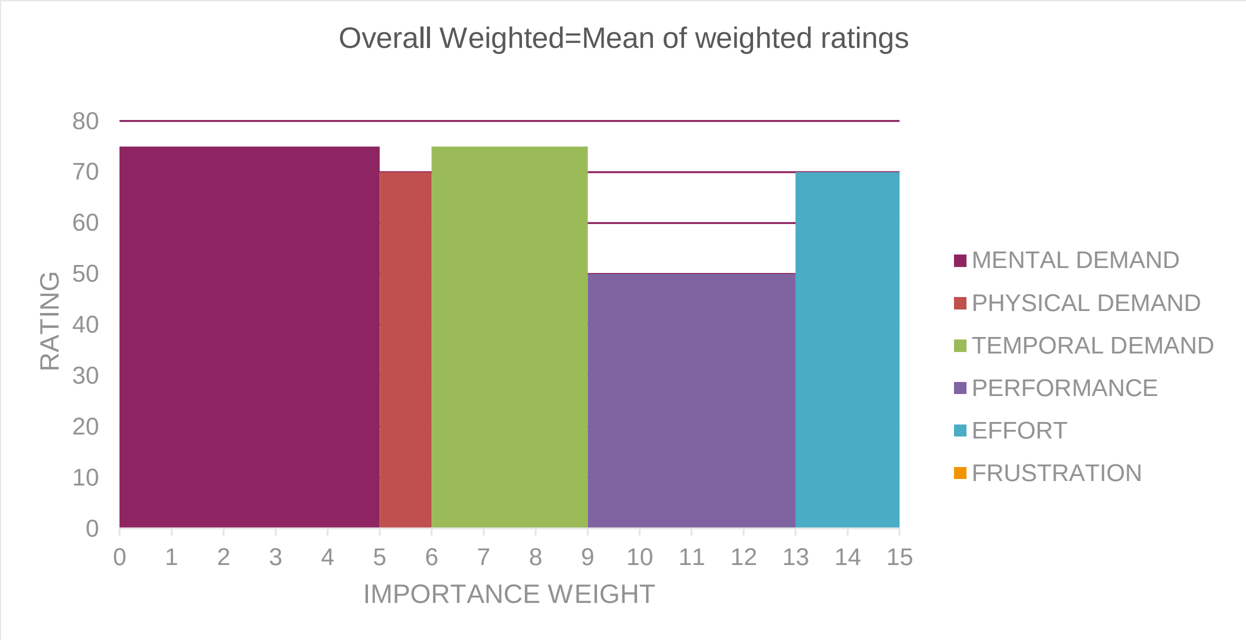

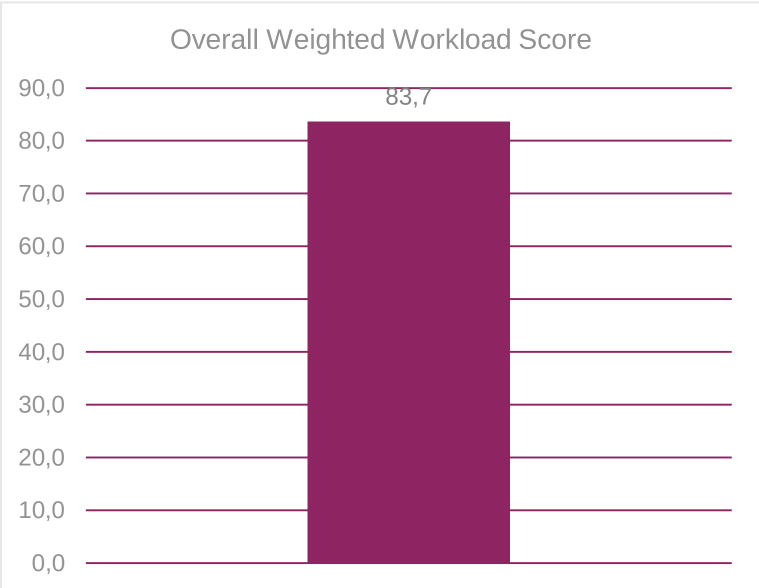

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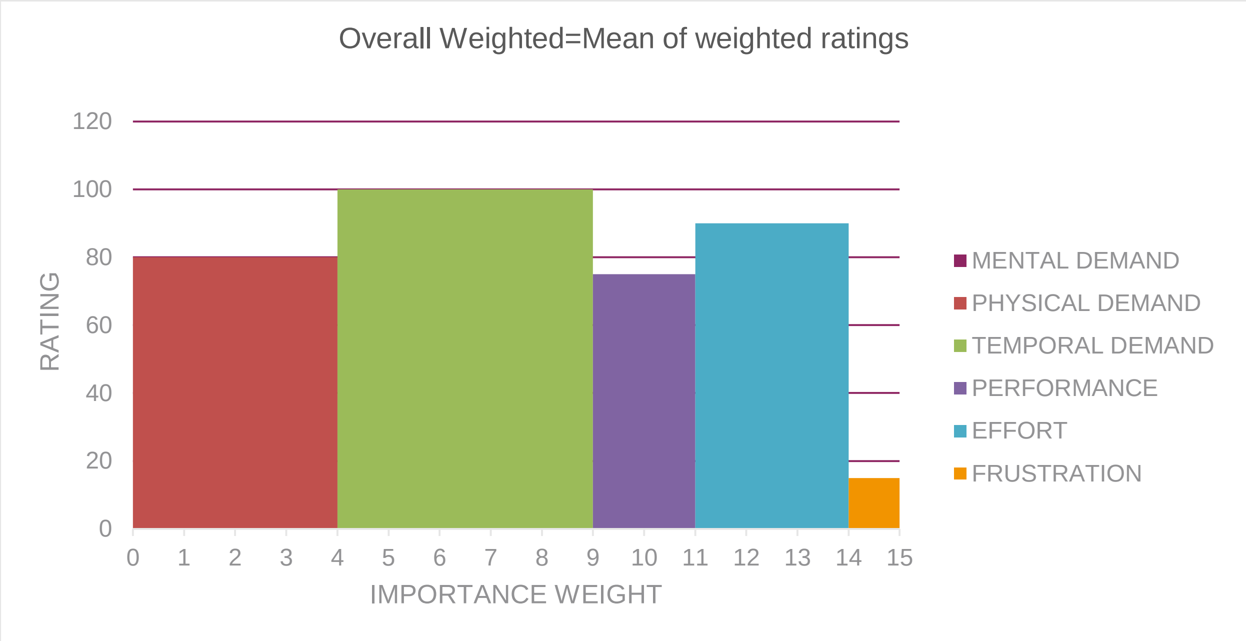

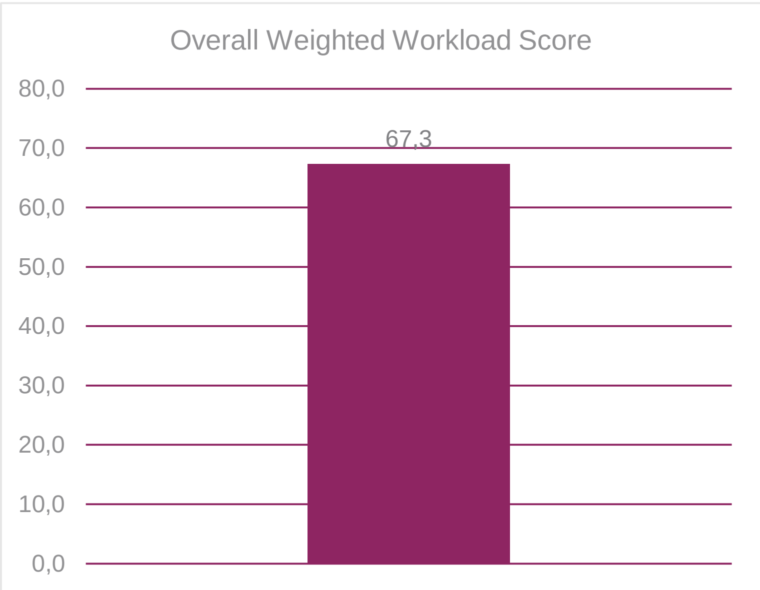

<u>Session 7:</u>

TLX:

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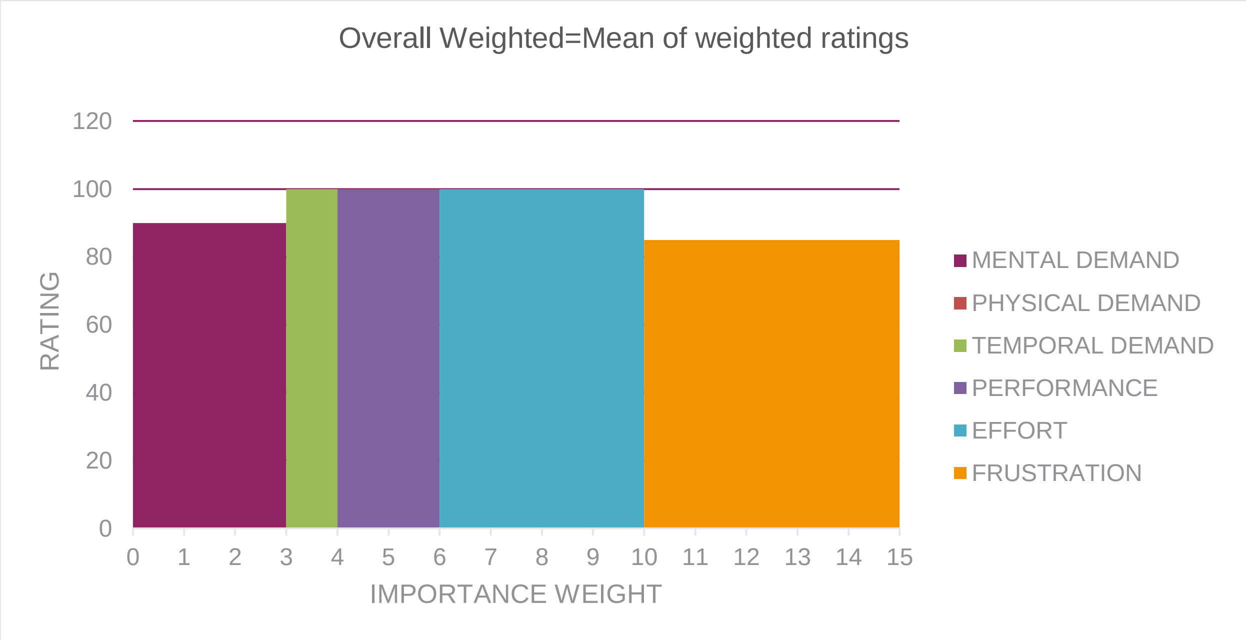

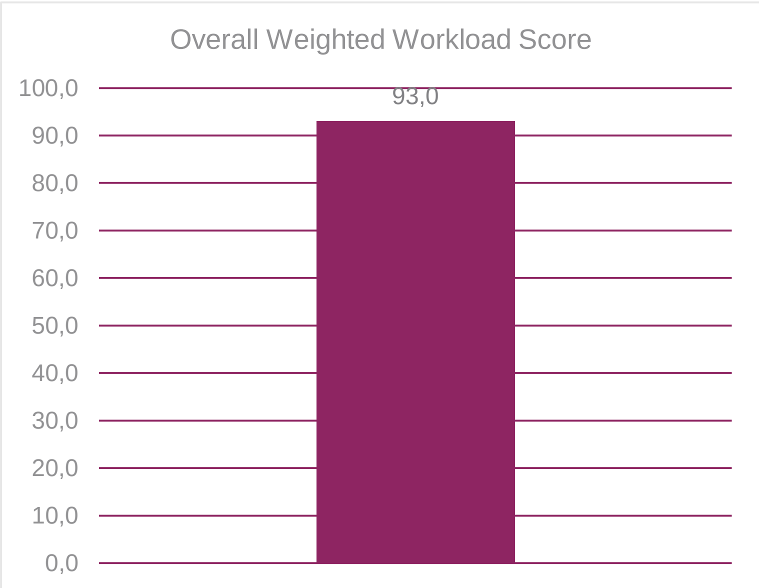

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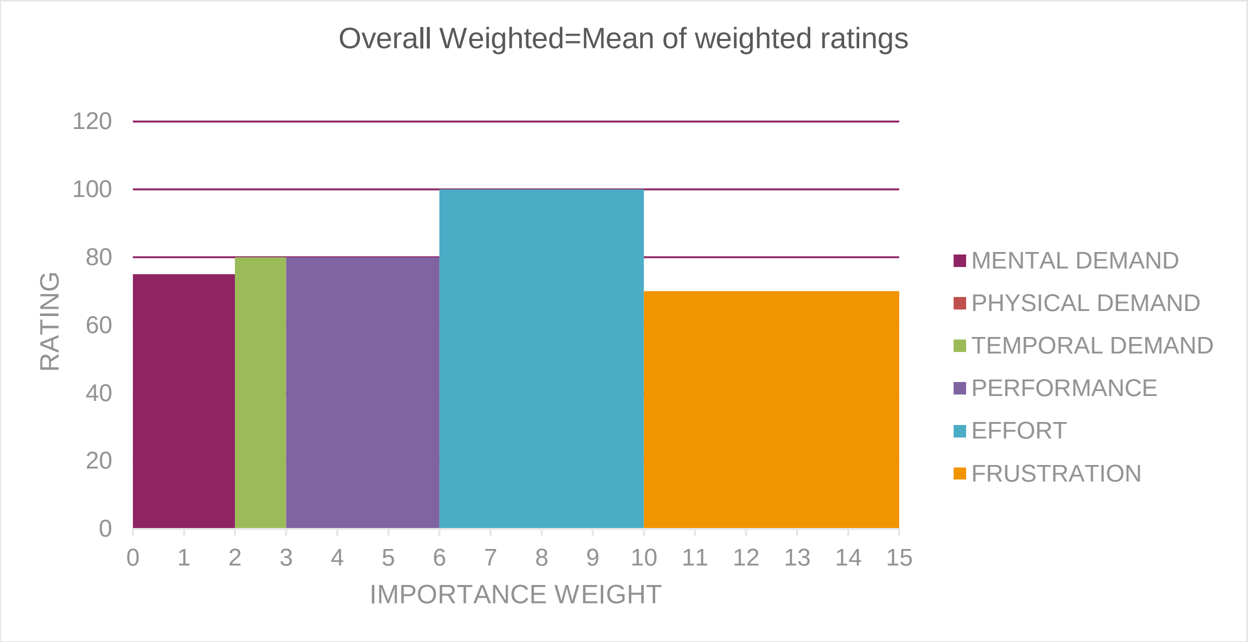

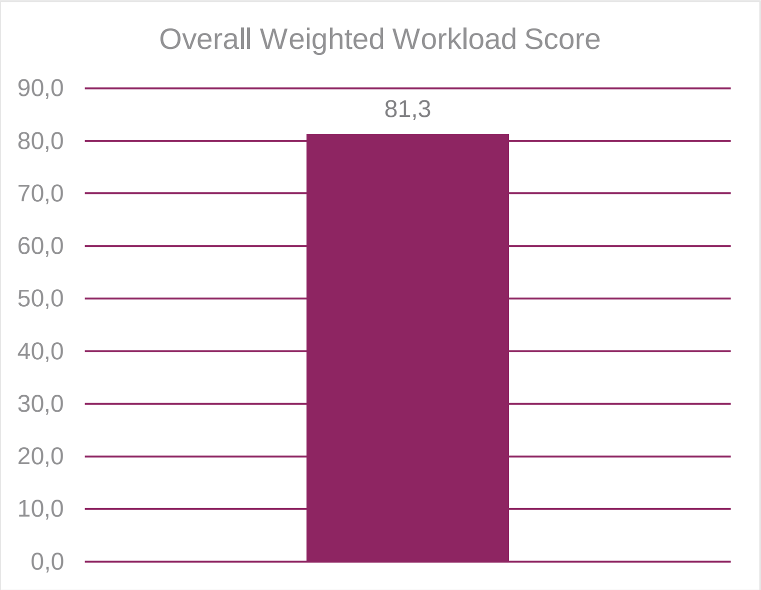

<u>Session 8:</u>

TLX:

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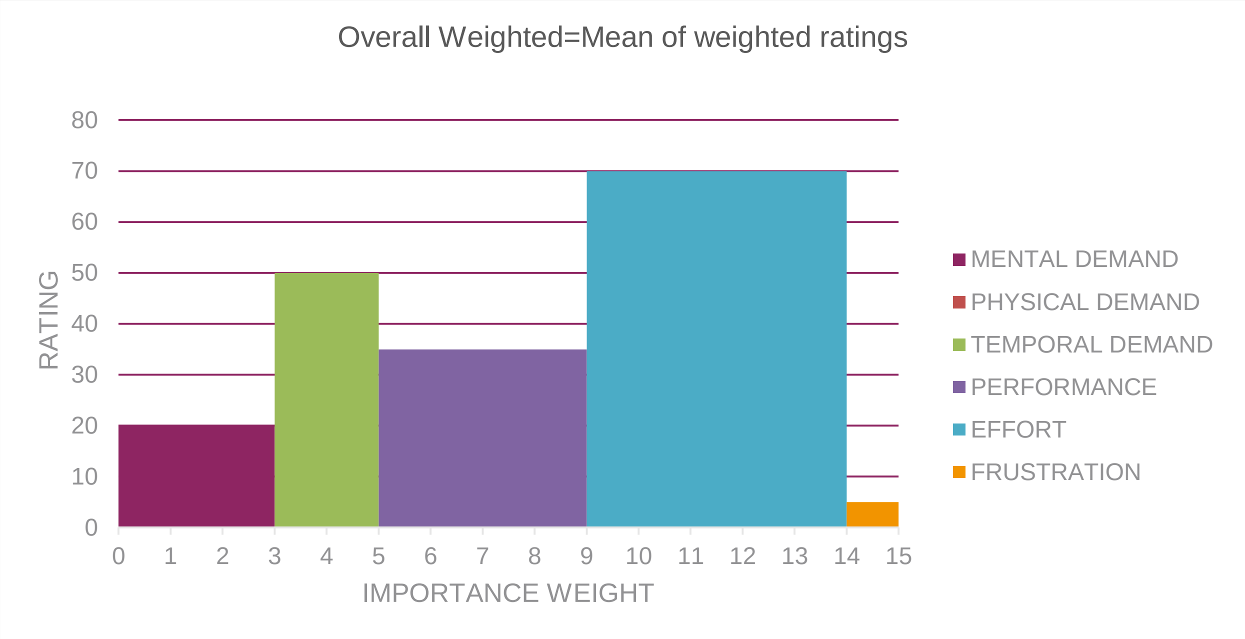

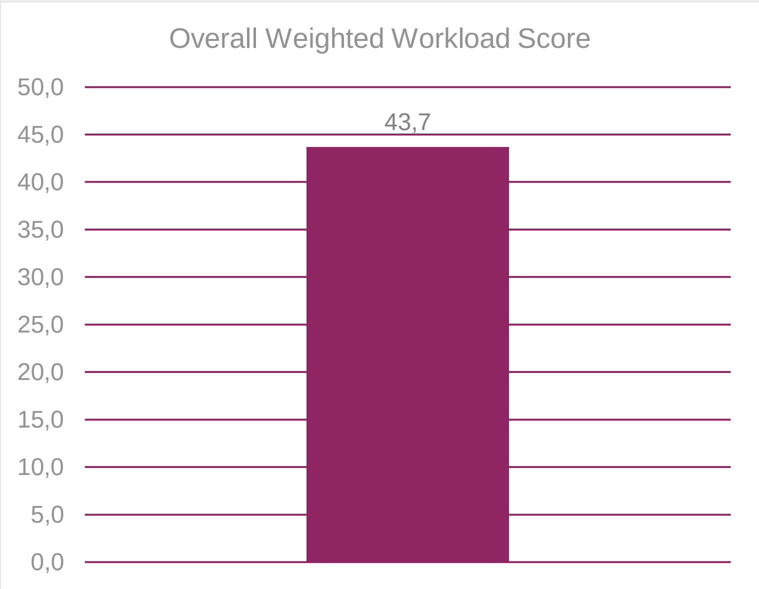

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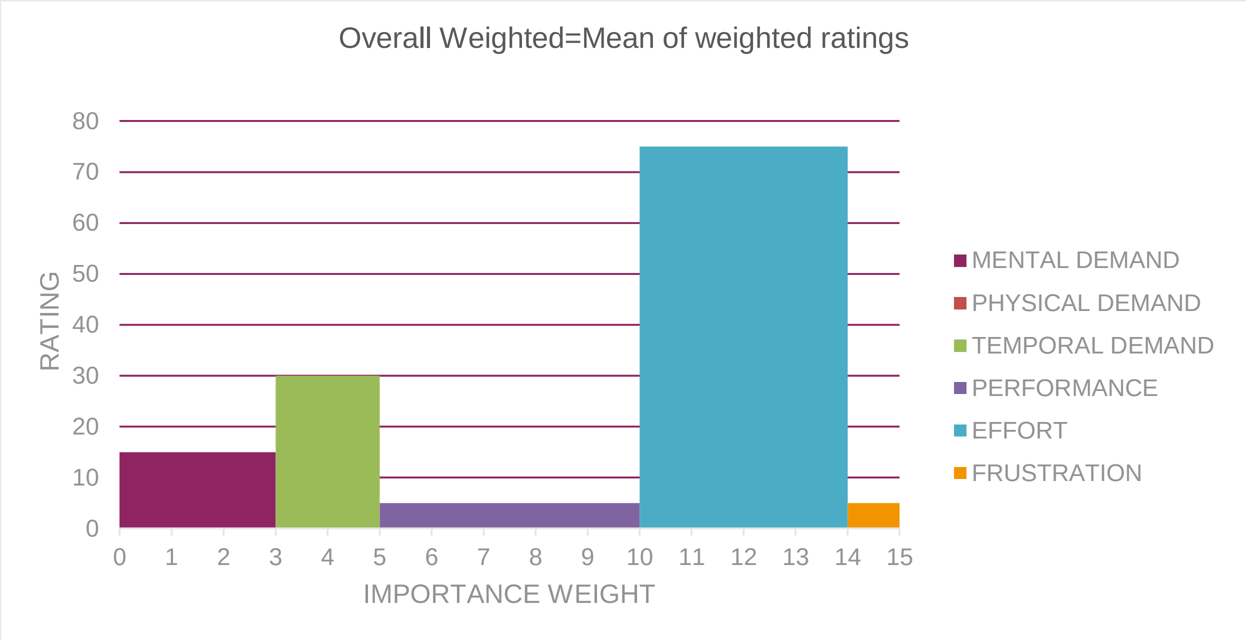

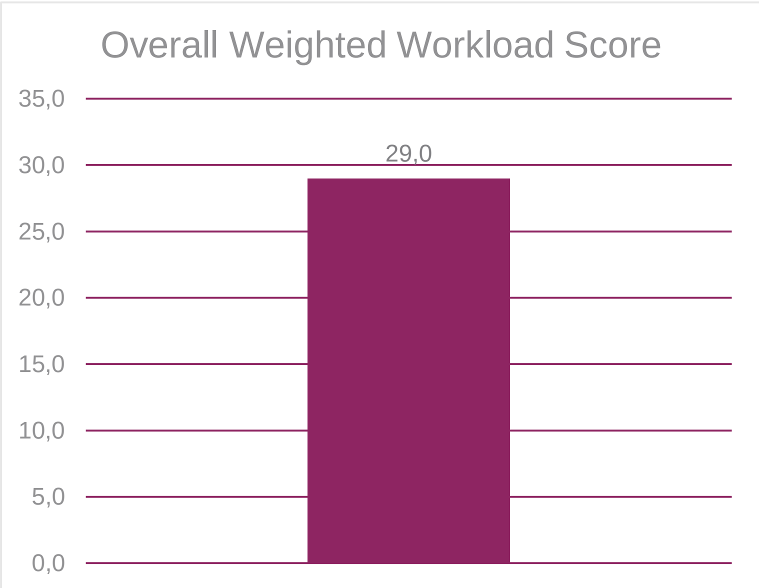

<u>Session 9:</u>

TLX:

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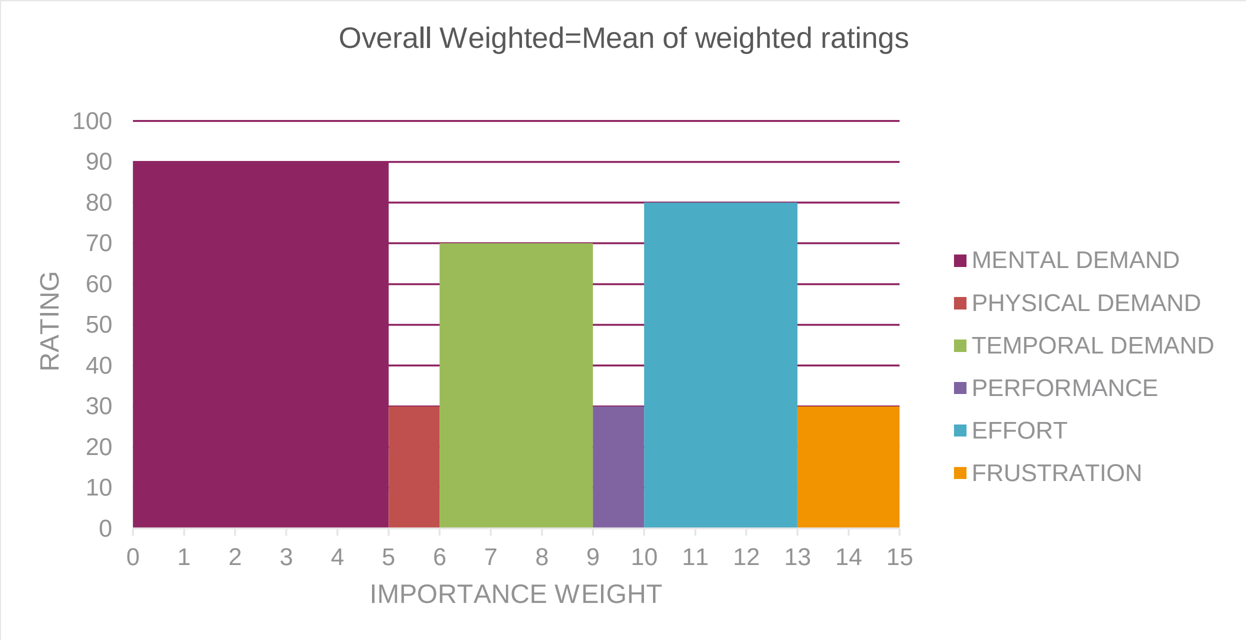

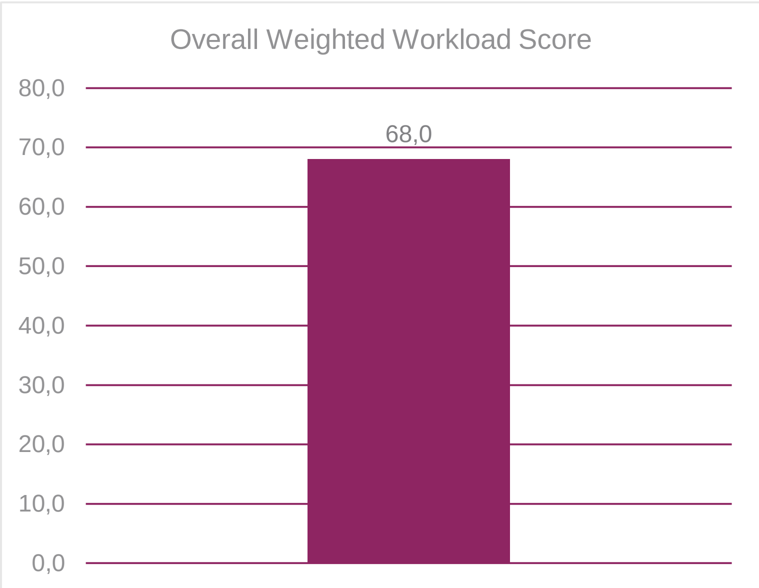

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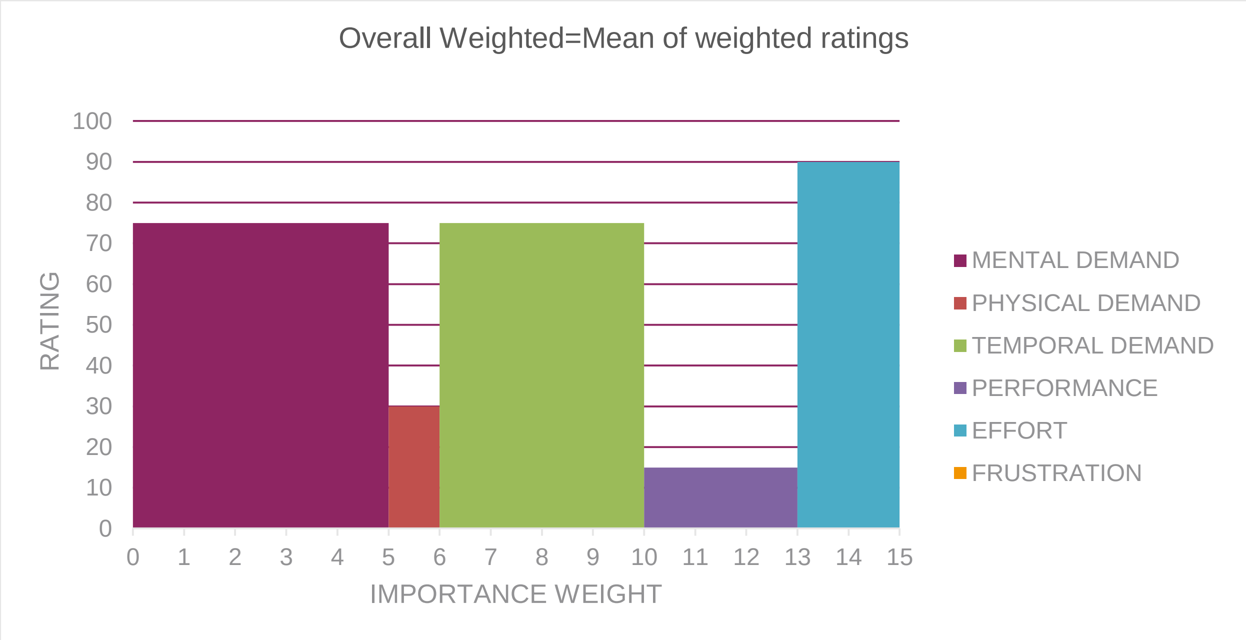
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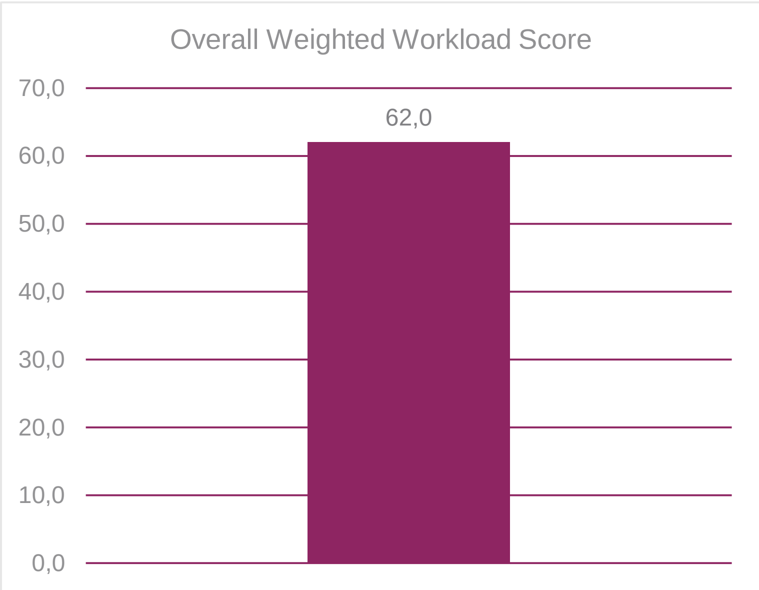
RATING
100
90
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
IMPORTANCE WEIGHT
MENTAL DEMAND
PHYSICAL DEMAND
TEMPORAL DEMAND
PERFORMANCE
EFFORT
FRUSTRATION


Overall Weighted Workload Score
70,0
60,0
50,0
40,0
30,0
20,0
10,0
0,0
62,0

II) Survey: Virtual Reality background questionnaire

Virtual reality background questionnaire

Circle the right answer

1) Have you ever heard about virtual reality?

   I know very well Often Once Never

2) Are you interested in virtual reality?

   Yes No

3) Have you ever tried the HTC Vive?

   Yes No

4) Have you ever tried the CAVE 2?

   Yes No

5) Have you ever tried other devices for virtual reality?

   Yes No

6) If yes can you indicate which ones?

   – – –
   – – –

7) Do you carry glasses?

   Yes No

8) Have you some issues with the stereoscopic vision?

   Yes No

9) Have you some other eyes problems? If yes can you indicate which ones?

   Yes No

   – – –
   – – –

10) Have you some other problems (not eyes problems)? If yes can you indicate which ones?

   Yes No

   – – –
   – – –

11) Do you play video games?

   Pro Gamer Often Occasionally Never

III) Survey: Feedback

Feedback

Circle the right answer

1) What do you think about the device?

   Bad Useless Ok Good Amazing

2) How was the immersion?

   Bad Ok Good Amazing/Excellent

3) How was the interaction (way to grab the cube)?

   Bad Ok Good Amazing/Excellent

4) What do you think about the mean of locomotion (teleportation (HTC VIVE) or joystick(movement))?

   Bad Useless Ok Good Amazing/Excellent

5) Do you have some idea of new interactions or means of locomotion?

   –

   –

6) What do you prefer collaborative task and single task? Why?

   Collaborative task Single task

   –

   –

7) What do you think about Virtual Reality for collaborative task?

   Bad Useless Ok Good Amazing/Excellent

8) (Only if you have tried the both device) What do you prefer between the CAVE and the HTC VIVE (in general not for these experiment particularly)?

   CAVE HTC VIVE No opinion

9) Have you felt some motion sickness?

   A lot *(stop the experiment)* Some *(can continue the experiment)* Little bite Not at all

10) Have you encountered some other issues or do you have some comments?

   –

   –

IV) Completion Rate :

Completion Rate

	User Cave Name:	User Vive Name:
Demo	/12	/12
Single	/46	/46
Collaborative	/41	/41

V) TLX Manual:

This manual can be download at this URL :

http://humansystems.arc.nasa.gov/groups/tlx/downloads/TLX_pappen_manual.pdf