A VR Application for the Analysis of Human Responses to Collaborative Robots*

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Abstract: The increasing number of robots performing certain tasks in our society, especially in the industrial environment, introduces more scenarios where a human must collaborate with a robot to achieve a common goal which, in turn, raises the need to study how safe and natural this interaction is and how it can be improved. Virtual reality is an excellent tool to simulate these interactions, as it allows the user to be fully immersed in the world while being safe from a possible robot malfunction. In this work, a simulation was created to study how effective virtual reality is in the studies of human-robot interaction. It is then used in an experiment where the participants must collaborate with a simulated Baxter to place objects delivered by the robot in the correct place, within a time limit. During the experiment, the electrodermal activity and heart rate of the participants are measured, allowing for the analysis of reactions to events occurring within the simulation. At the end of each experiment, participants fill a user experience questionnaire (UEQ) and a Flow Short Scale questionnaire to evaluate their sense of presence and the interaction with the robot.

1 INTRODUCTION

Robots are gradually moving from highly controlled environments, where they work autonomously and alone, to new ones where the operations are done with human presence to act jointly towards the same task. These new types of robots are known as collaborative robots (Knudsen and Kaivo-oja, 2020).

The industrial environments are good examples of this situation, since a lot of tasks are automated, leading to large areas where robots operate alone, however, as referred by (Liu et al., 2019), in many cases this still needs to be complemented by human manual work. The assembly lines in the automotive and electronic equipment industries are good examples of these situations. Moreover, the repetitive nature of these tasks can cause fatigue and frequently lead to lower back pain situations or spine injuries (Krüger et al., 2009). Introducing a robot collaborator could be an effective measure to help in fighting these problems.

Human-robot collaboration is still far from being effective, and safe, as is the collaboration between humans. The International Federation of Robotics only allows robots and humans to work together if they don't share the same workspace or if they share it but don't act simultaneously. This is due to a major flaw in current day robots, the lack of awareness of their surroundings, in particular, of their partners' actions and feelings, which in turn, leads to the lack of ability to adapt accordingly. As noted by (Çürüklü et al., 2010), robots in the near future will need to react and adapt to the working partner's presence and actions.

Similarly to the case of operators controlling large machines, awareness is a key issue for robots, in particular those that need a lot of strength and speed, since one wrong move can seriously injure or even kill someone in its vicinity. We may say that safety implies strong awareness, but even a careful car driver cannot always predict the next move of a distracted pedestrian. Speed limitations in urban areas have the purpose of reducing the number of (fatal) accidents due to unpredictable human behaviours, the same principle has been applied to collaborative robots. The designation *collaborative robots* refers in most cases to robots whose joint torque or force is reduced to a level where a collision with a human will make it stop while not causing any harm. Other cases are based on turn-taking, frequently enforced by two lateral buttons that the human must press simultaneously

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to ensure that his/her hands are not inside the robot operating volume, while it is moving.

While being a new and interesting trend we may say that this gathering may affect the performance of both robots and humans. Robots have to operate slower and be less powerful to avoid fatal accidents, humans may need to adapt to these new situations and this adaptation may require unexpected cognitive and/or emotional efforts that eventually result in a progressive degradation of their performance and/or physical or mental health. It is therefore important to understand what influence a specific collaborative setup may have in humans, in particular along a workday period.

1.1 Related Works

Human-Robot interaction as a multidisciplinary field emerged in the mid-1990s and early years of 2000. It focuses on understanding the interactions between robots and people and how they can be shaped and improved. Over the years, robots have seen great improvement, with new models constantly making the old ones obsolete with new hardware, cognitive capabilities and more. The vision of this field is to make robots exist in our everyday lives, from helping in the industrial environment and household chores to social robots that can entertain or care for humans. As such, studies on this field focus not just on the short term interactions in the laboratory but also the long-term interactions with systems such as a robotic weight loss coach (Kidd and Breazeal, 2008) that helps track calories consumption to combat obesity. The introduction of this robot in the participants' lives had them tracking their calories consumption and exercising almost twice as long, demonstrating the benefits that robots could have if correctly introduced in our lives. This introduction also raises the importance of the robot's appearance. Facial expressions are a big part of how the user perceives the robot. However, realistic facial expressions can be tough to achieve as humans can intuitively understand when something looks unusual. Leaning more towards the cartoonish and simplistic facial expressions could solve this issue. Systems such as KASPER (Blow et al., 2006) use this idea in the design to approximate the facial expressions without ultra-realism.

As mentioned previously, the growth of the HRI field leads to an increase in the number of collaborative robots being introduced in our society, which in turn raises the need to study and improve the security and efficiency of human-robot interactions. Several works validate the use of VR to reach this goal for different types of interactions, be it in handing over and receiving objects from a robot partner (Duguleana et al., 2011) or controlling a robot arm (de Giorgio et al., 2017). Regarding the improvement of HRI safety, different solutions are presented to this problem. Applications such as ”beWare of the Robot” (Matsas and Vosniakos, 2017) tackle the safety issues through ”emergencies” or warning signals in the form of visual and auditive stimuli.

Instead of warning the user, another way to tackle the safety issues is to adapt the robot's movements. This can be achieved through a ”digital twin” environment, where the physical environment is directly transcribed to a digital one, allowing for part or all of the logic to be in the digital environment. The robot can then use this system to avoid the human or even stop entirely (Maragkos et al., 2019).

The introduction of biological signals in HRI can improve the quality of the interaction. For instance, it can allow the user to control a robot using a brain-machine interface (Bi et al., 2013) or allow the robot to recognise the human's mental state and physical activities through sensors monitoring heartrate, muscle activity, brainwaves through EEG, nose temperature and head movement (Al-Yacoub et al., 2020).

In particular, electrodermal activity (EDA) is one of the leading indicators of stress. There are various techniques and open-source software that can be used to analyse such signals (Lutin et al., 2021). More recently, deep learning algorithms alongside the ”classical” statistical algorithms can be used to make more complex analysis (Aqajari et al., 2020).

1.2 Contribution and Article Structure

The presented work proposes a solution to study a human-robot collaboration scenario in Virtual Reality. The presented solution consists of a simulated environment that the user can visualize and interact with via a head-mounted display (HMD). It explores a ROS (Stanford Artificial Intelligence Laboratory et al., 2020) Motion Planning, manipulation and control tool named MoveIt to animate a model of Baxter robot to which the user interacts. The created system is then explored in a pilot study to evaluate how the participants react to distractions in their simulated workplace, and how they feel about the interaction with the robot.

This paper is organized as follows: section 2 describes the main goal of this work and the considerations taken. The architecture and implementation of the created system are presented in section 3. Section 4 introduces the pilot study performed with the system created and provides an assessment and discussion on the outcome. Finally, section 5 concludes the article.

2 VR FOR COLLABORATIVE ROBOTS INTERACTION ANALYSIS

The goal of this work is to create a system to study human-robot interaction and use it to analyse how distractors may affect a human performing a collaborative task with a robot. The system consists of a virtual environment where the user interacts with a simulated Baxter robot, cooperating to complete simple tasks. During these interactions, the user's reactions to the robot's actions, such as posture and physiological signals, namely, electrodermal activity, and electrocardiogram are recorded to support the evaluation of users' reactions to the disturbing events purposely added.

The use of Virtual Reality to study human-robot collaboration has the clear advantage of providing clean, repeatable and safe support to create counterparts of live experiences (Duguleana et al., 2011). This is perfect for analysing how adequate an environment or an interactive system is for human use. Besides safety, these approaches may have economical advantages as they enable the validation of hypotheses without risking any kind of material losses due to inadequate usage, or do any type of predictive analysis of what will be the outcome of the introduction of a change, such as a collaborative robot, in a specific point of the production process.

There is however the question of knowing if the user behaviours in a VR-based environment are different from the ones in a real situation.

Although other factors may contribute to the mismatch of the above, the immersion level and sense of presence are two crucial aspects since the results obtained in a VR-based test will not be accurate if a high sense of immersion and presence is not achieved.

For this reason, it is necessary to evaluate these factors as perceived by each user, along with the interactive task under analysis, to enable the prediction of the accuracy of the task-related parameters under estimation. This is commonly done through the application of self-response questionnaires such as UEQ and flow short scale questionnaires and by evaluating the user's reactions, as will be analysed later.

Another important aspect to take into account is the realism of the robots' movements. To obtain results comparable to real situations, the simulated robot has to behave like a real one in a real environment. Whenever possible, the use of a controller that mimics or matches as close as possible that of the real robot will bring some guarantee that in what concerns the perception of robot motions by the user will be similar to the real case.

3 ARCHITECTURE, IMPLEMENTATION AND SCENARIO

The implementation of the above resulted in a scenario around the Baxter robot supported by a modular architecture (figure 1) composed of three main elements:

- The BaxterVR application developed on Unity™.
- MoveIt - a ROS-based motion planning and controller for real robots.
- A data acquisition system developed over the Labstreaminglayer (LSL) (Swartz Center for Computational Neuroscience, 2021) framework.

The BaxterVR application allows the users to explore a collaborative robot scenario and interact with it via a handheld controller, as will be described later. This application communicates with MoveIt, the robot planner and controller supported by a ROS (Robot Operating System) connection. BaxterVR also uses an LSL connection for enabling the synchronous registration of the generated events and biosignals such as GSR (galvanic skin response) and heart rate, which are captured by two other applications that use the same protocol.

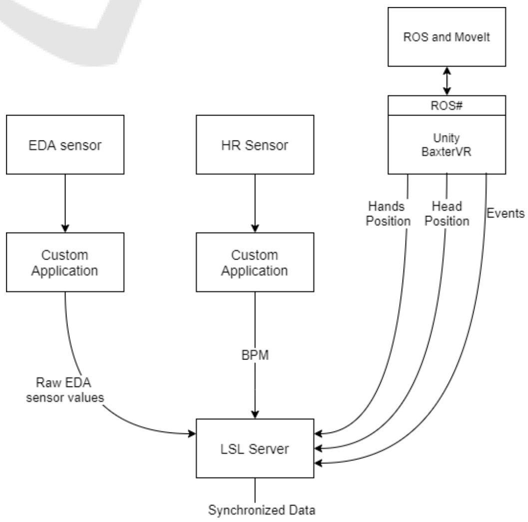

Figure 1: System architecture.

3.1 Implementation

To handle the communications between BaxterVR and MoveIt, a total of three ROS nodes were created. Their purpose is to handle the robot joint angles to BaxterVR, transmit information about the VR objects, such as their positions, and orientations to MoveIt, and handle requests to move the robot using an action server.

BaxterVR publishes the necessary information about the objects in the environment, such as position, orientation and size to the corresponding ROS node, which uses the Planning Scene ROS API to add them to the planning scene. The scene objects that are relevant for the movement calculations are represented in MoveIt as boxes. Using Rviz it is possible to visualize them as green boxes (figure 2). In this case, the objects are the two conveyor belts standing next to Baxter that will be presented in section 3.2. To reduce the communication overload, objects' positions are updated only if their changes are above a given threshold.

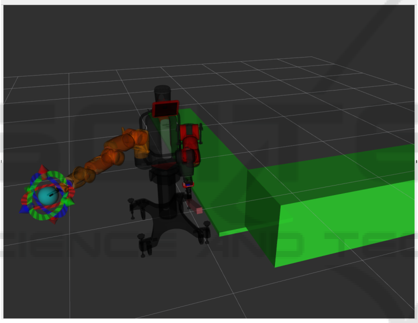

Figure 2: Rviz Visualization.

To publish the robot arms joint angles to BaxterVR, two separate topics are used, one for each arm, with a custom message containing seven values, corresponding to each of the seven joints, obtained using a MoveIt interface.

The BaxterVR simulation needs to be able to make requests to MoveIt to control the robot. It also requires the ability to preempt or cancel these requests, for example when the object being picked up moves. Periodic feedback is also necessary to synchronize the actions on both sides, such as attaching a picked-up object to Baxter's end effector in Unity's side at the same time it is attached in MoveIt. A ROS action is the perfect fit for the previous description and as such, a ROS action server was created to control the simulated Baxter robot. When it receives a request, it sends the necessary information to the motion planner using the Motion Planning API. BaxterVR from its side can issue the following requests:

- Move the end-effector to a specific position.
- Move the end-effector to a specific position using a Cartesian path.
- Pick up an object, given its position.
- Detach an object from a robot end-effector.
- Change the speed of the arms.

As mentioned previously, the robot needs to react to changes in the environment, such as movements of the object being picked up. With the Motion Planning API, it is possible to make asynchronous requests to the motion planner and cancel executing requests, however, it does not provide a simple way to know the status of a request being executed. A solution to this problem is to monitor the result action topic from the action that MoveIt uses to communicate with the motion planner, as this topic is only published when the motion is concluded while also giving information about its success.

3.1.1 Rosbridge and ROS#

Unity, being the support for the development of BaxterVR applications, does not directly support the connection to ROS. However, a lot of efforts have been made over the last few years toward this goal (Hussein et al., 2018) and it is now possible to use Rosbridge on the ROS side and ROS# on the Unity side to make this connection.

Rosbridge (or rosbridge_suite) is a standard ROS library that provides a JSON interface so that non-ROS programs can send commands to ROS. ROS# makes use of this interface using a Unity Asset Package to give Unity-based applications the ability to communicate with ROS. This includes publishing and subscribing to topics, communicating through services and actions, and even use custom messages. ROS# also introduces some important robotics functionalities such as importing a robot through a Universal Robot Description Format (URDF) file. In this project, this functionality was used to import Baxter's model.

3.1.2 Synchronous Biosignals Acquisition

To identify reactions to the distracting events in the BaxterVR application both the user's electrodermal activity (EDA) and heart rate (HR) are acquired and stored. EDA is acquired using a Bitalino board (da Silva et al., 2014) with a sampling rate of 1kHz using, whereas HR frequency is obtained using Polar H10 heart rate sensor, both of them using in house developed applications that establish the LSL bridge with these Bluetooth-enabled devices.

The development of the Unity Based application (BaxterVR) included support for Lab Streaming Layer (LSL) for enabling the capture of the evolution of hand and head coordinates, and registering the occurrence of the events described in the next section (3.2). This LSL support was also included in the development of both the Polar H10 and the Bitalino application.

The synchronous signals acquisition is handled by LabRecorder, the LSL recording application, which receives the timestamped streams and stores them. One of the major advantages of this framework is that all the recorded data streams can then be related as they share the same clock reference. LSL has another big advantage, which is the easy integration of new data sources in data collecting experiments.

3.2 A Collaborative Robot Scenario

The designed scenario mimics an industrial environment where the human executes a task in collaboration with a robot. As with any real environment, unrelated events will happen that may lead to distractions of the user contributing to errors and/or fatigue.

The basis of the current scenario consists of the robot picking objects from a conveyor belt and handing them to the human partner. The human, in turn, has to grab these objects and place them in boxes following a given protocol. To grab the objects the human has to reach over to them with the controller and press a button that closes the virtual hand and attaches the object to it. This method to interact with the object was considered to be the most natural option since to press the button the user has to close its hand around the remote as if grasping a real object.

To move around the simulation the human has two options, move in real life or use a joystick. The main objective is for the users to move mainly in real life and use the joystick to make small adjustments so that the virtual room better adequates to the real one. In the simulation, the users always start at the centre of the room, independently of their position in the real room. As such, in an extreme example, if the simulation is started while the user is standing next to a wall in real life, he can no longer move in the direction blocked by the wall without the joystick.

For exploring different situations, the Baxter robot has two different approaches for interacting with the human: it can either hand the object to the human and wait for him/her to grab it or drop the object on the ground as soon as it reaches the delivery position (figure 3). Dropped objects break into pieces once they touch the ground, so the human has to wait until Baxter picks and hands another one.

Figure 3: Baxter dropping an object.

The scenario is organized in increasing difficulty levels aiming at analysing their effect on the user performance. The task of delivering an object was made purposely complex so that it requires the user to focus on it to successfully complete a level.

As previously mentioned, one of the objectives of this experiment is to understand how distractions in the surrounding environment affect the user. With this in mind, three types of events were created to redirect the attention of the participant during the experiment.

Event Type 1: Thirty seconds into the experiment, and every minute after that, a door opens at one side of the room, with the appropriate sound, and a robot cart appears, transporting a box (figure 11). It moves across the room until it reaches another door, exiting the room.

Event Type 2: Another event is a box that appears in a conveyor belt on the corner of the room in random time intervals between 15 and 35 seconds (figure 4). A loud alarm can be heard when it appears as well as the sound of the conveyor belts moving.

Event Type 3: Lastly, when there are only thirty seconds left to complete the level, the clock on the wall starts ticking and flashing red (figure 8).

Despite failing the level when the timer runs out, the user does not automatically fail the entire test. Each level is evaluated individually, and even after failing, he must deliver all the objects to pass to the next level.

Figure 4: Distracting box.

This scenario was designed to be simple (figure 6) so that it is processed fast enough to not cause any discomfort to the user while at the same time containing elements similar to the ones found in an industrial environment such as conveyor belts or transporter robots. As already mentioned, the main objective is to grab the objects handed by Baxter and place them inside a box (figure 5). The objects are simple rectangular bars and can be of four different colours, blue, orange, green or indigo and have to be placed inside a box with the corresponding colour. To obtain a box, the user must press a button with the corresponding colour. Once a box has one or two objects inside, to score, the user has to deliver it by placing it on top of an elevator and pressing a button (figure 7). On one of the walls, there is a whiteboard that displays information about the current level, more specifically, how much time is left, the score, objects missed and the difficulty level (figure 8).

Figure 5: User placing an object inside the box.

Figure 6: Surrounding environment.

The simulation has a total of five levels. The robot speed increases with each level, starting at 50% of the maximum speed, raising 10% per level. To successfully complete a level, the user must deliver a preset amount of objects within two minutes. The number of objects to deliver increases one per level and starts at one object.

The objects handed by the robot arrive periodically on a conveyor belt next to Baxter, being their sequence of colours of complete random order (figure

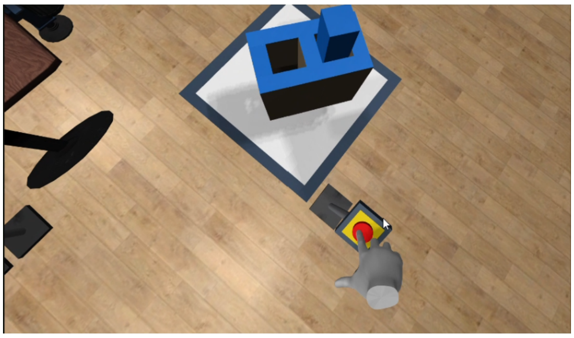

Figure 7: User delivering a box with one object.

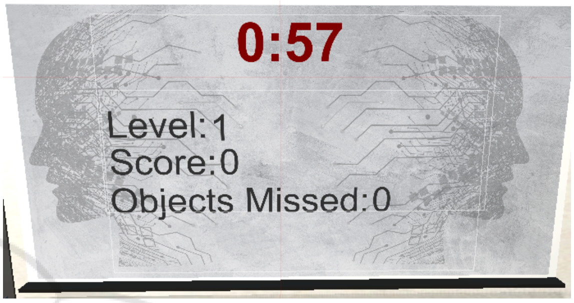

Figure 8: Score Board.

9). When an object gets to the pre-defined position, close to Baxter, the conveyor belt stops for a moment, waiting for the robot to grab it (figure 10). If Baxter starts the grabbing movement, the conveyor belt doesn't move until the object is grabbed, otherwise, two seconds later, it starts moving again and the object is lost. If the robot picks the object and hands it to the user, it must be grabbed so that Baxter can pick up another or, if at level three or above, the human must pick the object before the robot reaches the delivery position, otherwise it will fall to the ground and get broken into pieces.

Figure 9: Conveyor belt that delivers the objects to Baxter.

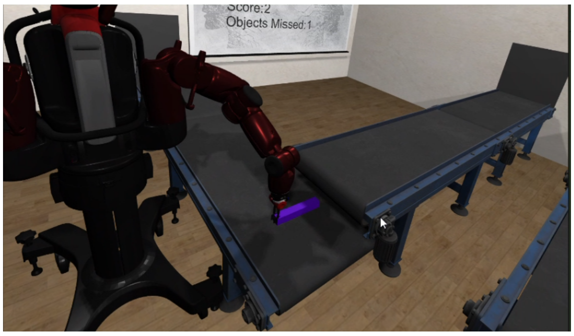

Figure 10: Baxter picking up an object.

Figure 11: Transporter robot.

4 A PILOT EXPERIMENT

Using the system described previously, a pilot experiment was conducted to understand how the users react to the distractions while interacting with a robot in an industrial environment and how they feel about the interaction.

Since this experiment focuses on VR interaction, an important aspect to take into account is the equipment to use to allow the user to experience the application created.

There is currently a vast number of HMDs on the market. The technical evolution of processors and displays for the smartphones industry has created the necessary support for new all-in-one headsets, such as Oculus Quest, or Vive Focus. These products have seen recently a dramatic improvement in terms of the enclosed processing power, battery autonomy, and display quality. Nevertheless, the tethered existing versions still enable the use of high-end graphics-enabled computers both to process and display contents, without requiring extensive optimisation efforts or sacrificing any aspect of graphical quality. Another important advantage of these PC connected devices is the possibility of establishing simple communications with other software packages running on the same machine. These reasons led to the development of the BaxterVR application targeting Oculus Rift™, exploring the compatibility mode of Oculus Quest devices through a USB-C (Oculus Link) connection with the computer running the application.

This is particularly convenient as it enables ROS-MoveIt, LSL-data collectors, and the BaxterVR application to share the same powerful machine and exploit simplified and reliable communications between them.

In this study, the participants interact with the simulated robot described previously, while their biological signals are recorded. In the end, they answer a UEQ questionnaire (Laugwitz et al., 2008), a Flow Short Scale Questionnaire (Rheinberg et al., 2006) and a few open answer questions to allow the participants to give any opinion that cannot be established by the questionnaires, such as if they had motion sickness and what was the cause.

Figure 12: Gender distribution of the participants.

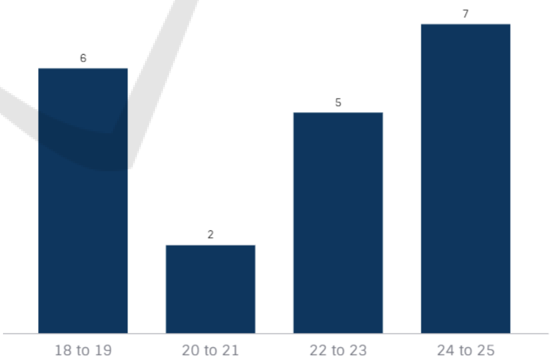

Figure 13: Age distribution of the participants.

This pilot experiment had the participation of 20 volunteer students of MSc and PhD courses with a gender distribution of 35% female and 65% male (figure 12), and ages between 18 and 25 years old (figure 13).

The protocol followed in the experiment was the following:

1. Disinfect all the equipment used.
2. The participant is introduced to the experiment,

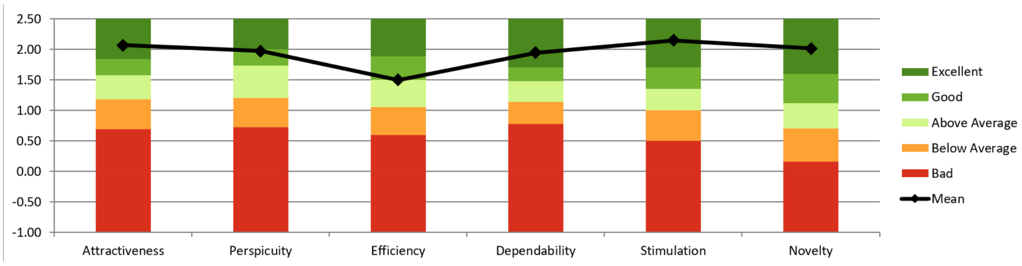

Figure 14: UEQ Questionnaire results.

explained what he/she has to do to successfully conclude each level and what data is going to be collected and how.

3. The participant reads and signs a consent.
4. The EDA and HR sensors are placed on the participant.
5. The participant puts on a hygienic mask for the VR system and the VR system itself.
6. The simulation is started and the participant should play it following the given rules and trying to complete each level.
7. If at any time the participant starts feeling uncomfortable with the experiment, the procedure should immediately stop. Otherwise, he/she should finish the simulation without any kind of interruption.
8. When the simulation ends, either because the participant concluded the final level or because it was stopped early, ask if he/she wants to play again and is asked his/her opinion on the simulation.
9. The participant fills a User Experience Questionnaire and a Flow Short Scale Questionnaire to evaluate the simulation and answers four open answer questions.

4.1 Analysis of the Questionnaires

From the analysis of the UEQ questionnaire, the highest rating categories were dependability, stimulation and novelty with ”Excellent”, then attractiveness and perspicuity with ”Good” and finally, efficiency with ”Above Average” (figure 14).

One of the most interesting results is the low rating of the Efficiency category, compared to the others. When asked the opinion about the simulation most people said that the robot seemed slow on the later levels. In reality, the robot was moving faster than in the first levels, however, the participants seem to get used to the task they have to perform and end up finishing it before the robot grabs another piece. In the case of this simulation, the efficiency category can also be thought of as the efficiency of the interaction, since the perception of the robot being slower than it should, translates into a low efficiency rating.

The Flow Short Scale questionnaire evaluates three aspects of the simulation on a scale of 1 to 7: flow, anxiety level and challenge level. Flow level indicates if the user is feeling engaged and focused while engaged in the activity. If the flow level is high, the participants find the activity intrinsically interesting and take pleasure and enjoyment when involved in it. Anxiety level translates to how much anxiety the users felt and challenge level indicates if the challenges presented were too difficult (7) or too easy (1). Table 1 presents an average and the standard deviation of the flow, anxiety and challenge level. According to the results, the challenge level seems to be perfectly adequate, with a score of 4 and a relatively low standard deviation of 0.458. The anxiety level has the lowest value with 3.85, meaning that the participants were not in high levels of anxiety during the simulation. However, it presents a significant standard deviation of 1.512. This is partially due to some of the anxiety scores being a lot higher than the average, with values reaching 5, 6 or even 7. Most of these high scores are from the participants that were using the joystick for moving in the VR environment, and consequently, reported motion sickness. On the other hand, most of the lowest scores on anxiety were reported by the participants that felt that the robot was too slow. Lastly, a flow score of 5.525 out of 7 means that the participants liked the activity and the simulation and felt engaged and focused, although some aspects could be improved.

In the open answer questions, the users were asked to describe the interaction with the robot; what were the main difficulties; what caused the most distraction; and, at last, suggestions to improve the simulation.

When asked to evaluate the surrounding distractions, the result was that the ticking clock and some of the surrounding noises were the most distracting elements. Some participants even ignored completely the existence of the transporter robot. The reason for this is that they were focused on the interaction and the task they had, which involved a lot of visual analysis.

Concerning the interaction with the robot, as mentioned previously, most people felt like it was too slow, especially in the later levels. Some people also reported that it felt like something was wrong when the robot stopped waiting for them to grab the object, dropping it on the ground instead. This interaction is intended and is meant to test if it is more natural to have the robot behave like it is aware of the human, waiting for him to grab the object, or behaving like a traditional robot that is just doing its task without considering the collaborating partner. The results are within the expectations, meaning that, even though interacting with a non-sentient robot, the human still feels like the interaction is more natural if the robot reacts to his actions instead of doing a pre-planned task.

One of the main complaints about this experiment was related to the movement inside VR. The participants have two ways to move inside VR, either by using a joystick or by moving in real life. The real space where the experiment takes place was roughly the same size as the working space inside the simulation. This led to two kinds of behaviours from the participants, some would move in real life, concluding the experiment without touching the joystick, others moved almost exclusively with the joystick because they were afraid to bump into something in real life.

Table 1: Results from the Flow Short Scale Questionnaire.

	Average	Standard Deviation
Flow	5.525	0.667
Anxiety	3.85	1.512
Challenge	4	0.459

4.2 Biological Signals

As mentioned previously, this experiment includes the recording of electrodermal activity and heart rate of the participants. Later the acquired data is to be processed for further analysis. As an example, the raw data collected from Bitalino's EDA sensor is converted to microsiemens using a formula provided in Bitalino's Electrodermal Activity (EDA) Sensor User Manual (PLUX - Wireless Biosignals, 2020). Figure 15 (top) shows an example of a recorded EDA signal and figure 16 the HR of the same participant. The blue vertical lines on figure 15 correspond to a specific event: the clock starts ticking.

As one of the objectives of this work is to try to identify the influence of the simulation events on the subject's anxiety and stress, we expect to observe the corresponding response in the acquired bio-signals.

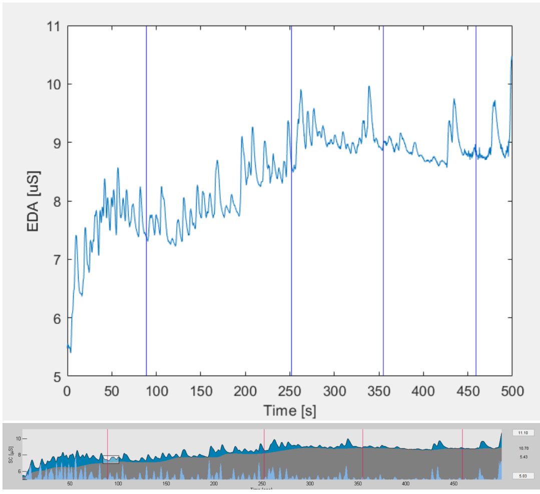

Figure 15: Top: EDA signal of a participant. Bottom: Continuous Decomposition Analysis of the EDA signal.

Nevertheless, these signals do not have any kind of absolute scale as their baselines and responses vary from person to person. For example in what concerns EDA signals can be divided into two parts: the tonic component, or Skin Conductance Level (SCL) which changes only slightly within tens of seconds, and the phasic component or Skin Conductance Response (SCR). The SCR represents a rapid change that happens shortly after the onset of a stimulus, usually 1 to 5 seconds, and thus, it can be used to detect a possible reaction to an event. When a response occurs in the absence of a stimulus, it is called a non-specific SCR.

To perform analysis on this signal, the free open-source software Ledalab was used (Benedek and Kaernbach, 2010a; Benedek and Kaernbach, 2010b). The recorded signal is noisy and is recorded at a high sample rate, so before the actual processing, it is necessary to first downsample it and apply a moving average smoothing.

The filtered signal can then be analysed using a Continuous Decomposition Analysis, extracting the tonic and phasic activities (figure 15 (bottom)). In the case of the example given (figure 15), event-related activations are detected in the first, second and fourth events. We can confirm these results through visual analysis. After the first event (figure 17), a sudden change in the skin conductance is verified with latency between 2 and 3 seconds. This is in accordance with the results obtained, which indicate an SCR after the first event, with a latency of 2.7 seconds. In figure 18 it is possible to recognise the reaction of five participants the first time the clock started ticking. The event is represented by a vertical black line and the conductivity values of each participant are rel-

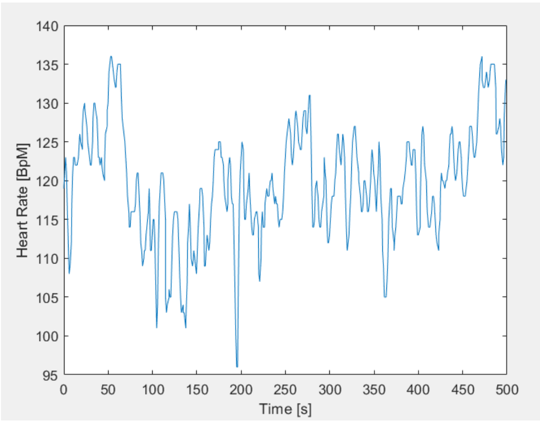

Figure 16: HR of a participant.

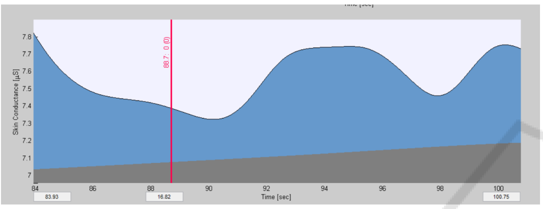

Figure 17: EDA response decomposition after the first event: Gray: tonic component, Blue: phasic component.

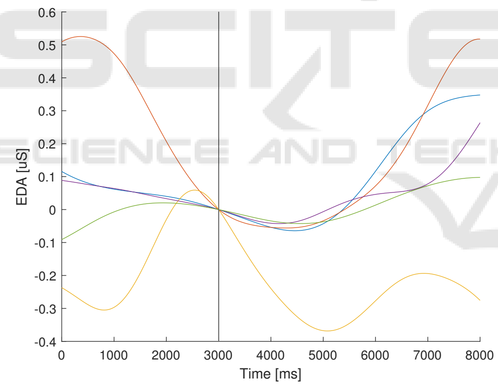

Figure 18: EDA responses to the clock ticking event, for 5 participants.

ative to the conductivity measured when the event occurred.

At the time of the event, the EDA of all participants was decreasing and in a window of 1 to 4 seconds after the event it changed its behaviour, presenting a positive slope variation. These correspond to SCRs, which indicate a reaction to the ticking clock.

5 CONCLUSIONS

From this pilot experiment, we can extract some valuable information, even if only the questionnaires were processed completely for the whole group of participants. First, from the UEQ questionnaire, we conclude that the overall looks and interaction in the simulation is satisfactory. This is an important aspect to take into account because the more people test a product, the more reliable the results are, and having them enjoy the time spent with that product is a means to attract more people into testing it.

Analysing the answers, the high results of the attractiveness, perspicuity and stimulation categories, together with the opinions of the participants, lead us to believe that the objective of providing an adequate VR-based alternative to real scenario experiments was achieved. The lower score on the efficiency category reveals that the interaction is less efficient than desired, as mentioned previously. Given that the robot arm is moving at the maximum recommended speed in the last difficulty level, one way to speed up the interaction and improve its efficiency would be to use both of Baxter's arms. In an ideal situation, the robot would be waiting for the human to complete his task and not the other way around. This way the human would not feel like the robot was holding him back, but instead, feel like it was helping him.

The fact that most participants almost ignored the existence of the transporter robot was not expected, but it reveals that their focus was towards the interaction and the task at hand, which ultimately is a good thing. On the other hand, the ticking clock and surrounding sounds causing the most distraction, suggest that the most efficient distractions in these types of experiments rely heavily on auditory queues.

Another aspect to take into account when dealing with virtual reality applications is the surrounding space. Although having enough physical space to move around, some users still prefer to move with a joystick due to the fear of bumping into an object. Moving with the joystick in most cases causes motion sickness, especially if the user relies exclusively on this type of motion. The option of using the joystick to move in the simulation was left to the user so that they could make small adjustments to their position in VR to better adequate it to the real-world space. The fact that some users chose to rely only on this type of movement was unexpected, but since it can influence the results, in future work, this possibility should be removed.

One detail that also induced stress to some users, mainly the same users that used only the joystick movement, was the wire that connects the Oculus Quest to the computer and the fear they would become entangled. To have the best possible results, the space that the users have to move around should be bigger than the one in the simulation and, ideally, the simulation should be able to run using only a wire-free headset so that the users can move around freely without worrying about cables.

Future work will include a deeper analysis of the acquired biosignals and relate them to user movements and events responses recorded for the whole group of participants. It would also be interesting to use a signal to detect anxiety such as eyes movements.

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