FEDERAL UNIVERSITY OF ESPIRITO SANTO

TECHNOLOGICAL CENTER

POSTGRADUATE PROGRAM IN ELECTRICAL ENGINEERING

KEVIN ANTONIO HERNANDEZ OSSA

DEVELOPMENT AND EVALUATION OF A SIMULATION SYSTEM OF ELECTRIC-POWERED WHEELCHAIRS FOR TRAINING PURPOSES

VITORIA, BRAZIL

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Dissertation submitted to the Postgraduate Program in Electrical Engineering from the Technology Center of the Federal University of Espirito Santo, as a partial requirement for obtaining a Master's Degree in Electrical Engineering focused on Robotics.

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If you want to go fast, go alone.

If you want to go far, go together.

-African Proverb

Acknowledgments

At this point of most researcher's lives, it is inevitable to have intense feelings of wonder, curiosity and even anxiety for what is coming next, however, also a big relief and sense of self-accomplishment for another goal achieved. It is important to realize that although some fundamental abilities and aptitudes are required to finish a life project like this, we couldn't have done it alone.

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Abstract

For some people with severe physical disabilities, the main assistive device to improve their independence in activities of daily living and to enhance overall well-being is an electric-powered wheelchair (EPW). However, a large number of wheelchair users find nearly impossible to drive them with conventional EPW interfaces, so there is a necessity to offer users EPW training.

In this work, the Simcadrom is introduced; which is a virtual reality simulator for EPW safe driving learning purposes, testing of driving skills and performance, and testing of input interfaces.

This simulator uses a standard proportional joystick as the main input interface, and a virtual reality head-mounted display to make the experience with the system more immersive, which can also be used with an eye-tracker device as an alternative input interface and a projector to display the virtual environment (VE).

A sense of presence questionnaire (IPQ), a user experience questionnaire (UEQ), and some statistical tests for performance parameters like: total elapsed time, path following error, and total number of commands were implemented to evaluate this version of the Simcadrom as a reliable simulator capable of providing a VE very similar to reality, where users can learn and improve their skills by driving a virtual EPW while training in the simulator. Afterward, a test protocol was purposed not just for comparing users' performance and driving experience between the VE and RE, but additionally, some hypotheses were established for a deeper evaluation of the developed system.

Considering the overall results, it is concluded here that the Simcadrom simulates a real EPW close enough, so it can be used for virtual training using a joystick and an HMD, or an eye tracker as an alternative interface and a projector. In general, it was well accepted by volunteers and proved to be a system that simulates, very realistically, the usability, kinematics, and dynamics of a real EPW in a VE. It was proven that people can learn and improve their EPW driving skills by doing a training session in the Simcadrom. Furthermore, the skills learned in the training session could be transferred to a real EPW.

Keywords: Simulator; Virtual Reality; Electric-Powered Wheelchair; Training; Joystick; Eye Tracker.

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1. Introduction

Diseases like multiple sclerosis, cerebral palsy, quadriplegia, stroke, spinal cord injury, traumatic brain injury, and some congenital problems can lead to movement disorders that significantly reduce the quality of life. There is a growing population tendency of movement disorders and disabilities in general in the last decades (Lenzi, 2012). According to the last census from the Brazilian Federal Institute of Geography and Statistics (IBGE) in 2010, there were approximately 46 million people with disabilities in the country, reaching almost 24% of the total population, where the related percent of physical disability reached 7%, approximately 13 million people (Censo, 2010).

Movement disorders, as stated in (Finlayson and van Denend, 2003), can significantly reduce the quality of life, decreasing social connections, leading to feelings of emotional loss, reduced self-esteem, isolation, stress, and fear of abandonment.

There is a broad use of therapeutic approaches to overcome impairments, but many people do not continue the necessary exercises due to pain avoidance, pressure of the society, the large amount of simple and repetitive movements, and even the loss of confidence in treatments or loss of commitment (van Dulmen *et al.*, 2007).

For some people with severe physical disabilities, the main assistive device to improve their independence in activities of daily living (ADL) and to enhance overall well-being is an electric-powered wheelchair (EPW). According to the United States census, 3.6 million people currently use a wheelchair for ADL (Brault, 2012). Even so, a large number of wheelchair users find nearly impossible to drive with conventional EPW input interfaces (Fehr, Langbein and Skaar, 2000).

A wide variety of alternative approaches has been proposed for EPW guidance (Bastos-Filho, Kumar and Arjunan, 2014), among special joysticks (Dicianno *et al.*, 2009), EEG (Huang *et al.*, 2012), EMG (Kaiser *et al.*, 2016), gaze tracking (Purwanto, Mardiyanto and Arai, 2009) and hybrid EEG/EMG (Leeb *et al.*, 2011). Additionally, to prevent any safety risks when driving EPW, several algorithms have been developed, including obstacle avoidance technics and autonomous navigation (Martins *et al.*, 2008). However, there is still a necessity to offer input interface customization to new EPW's users and EPW training (Borges *et al.*, 2016).

The use of systems that provide training in virtual reality (VR) scenarios is becoming a potential tool to support and improve rehabilitation outcomes and physical therapies (Song, Guo and Yazid, 2011), due to its wide variety of benefits including safe controlled environments, low cost, and flexibility. In fact, in some studies like in (Thornton *et al.*, 2005), the hypothesis that patients engage better on an enjoyable and straightaway rewarding environment is presented. Furthermore, on a simulator background context, in (Reinkensmeyer and Boninger, 2012) is stated that it is possible to provide more motivating and safe training tasks with quantitative feedback to motivate practice.

There are several VR environment approaches on the literature applied to EPWs whose objectives are concerned with the improvement of driving wheelchair skills, as reported in (Faria, Reis and Lau, 2014). Some good examples include: the proposal of joysticks to improve virtual EPW driving in individuals with tremor (Dicianno *et al.*, 2009); virtual wheelchair simulator with hand motion controller as an interface for reaching tasks (Tao and Archambault, 2016); a cost-effective prototype wheelchair simulator (Headleand *et al.*, 2016) designed to allow children with disabilities to familiarize themselves with a real wheelchair; a simulator for training powered wheelchair maneuvers that indicate improvement in their users (John *et al.*, 2018); a simulator where the spent time and joystick movements are compared between a virtual and real task (Archambault *et al.*, 2011).

In this work, the Simcadrom (Portuguese acronym for Simulator of Electric-Powered Wheelchairs) is presented. It is a VR simulator for EPW driving learning purposes (Adelola, Cox and Rahman, 2009), testing of driving skills and performance (Archambault *et al.*, 2012), aiding in the customization and test of new functionalities and methods in a safe environment (Braga *et al.*, 2008), in addition to testing of input interfaces. This work is part of a research project among the Federal Universities of Espirito Santo (UFES), Uberlândia (UFU), and Amazonas (UFAM), Brazil [12]. This stage of the project is focused more on the development of a safe training system and its technical validation. Future works will focus more on end-user groups with motor disabilities.

Regarding conventional EPWs, joysticks are more alike to regular useful applications. Therefore, a proportional standard movement sensing joystick is selected here as a reference and main guidance input interface for the virtual training system. In addition, an eye/gaze tracking system, from now on called eye tracker (ET), is integrated as an alternative input interface to command the EPW, and tests were conducted to validate the simulator by comparing participants' VR experience and driving performance, with a real EPW driving experience and performance (see Fig. 1).

Fig. 1. Participant testing the real EPW (left) and the virtual one (with the joystick as input interface) in the Simcadrom (right).

The driving performance quantitative parameters for this simulator consider: time spent executing a given task, path following error (Spaeth *et al.*, 2008), and a number of movement commands made with the input interface (Archambault *et al.*, 2012). Moreover, the qualitative part of the simulator evaluation contemplates some user experience questions that participants answered about their experience using the Simcadrom. The Igroup Presence Questionnaire (IPQ) was used to measure their sense of presence in the VE (Schubert, Friedmann and Regenbrecht, 2001a).

Objectives

Thus, the main objective of this work is to develop and evaluate a simulation system for EPWs commanded by a joystick in addition to an alternative input interface for users' training purposes. The specific objectives are:

- Install the necessary instrumentation on an EPW to obtain measurements from its position and its input interfaces.
- Install the necessary equipment and instruments on the EPW to enable its control by an alternative interface based on an eye/gaze tracking device.
- Improve and adapt NTA's laboratory existing virtual environment to specific simulation training system requirements.
- Integrate virtual models of EPW input interfaces into the simulation system.
- Specify and conduct some tests to compare the users' performance and driving experience, using the input interfaces of the real EPW and the virtual ones integrated into the simulation training system.

Hypotheses

Additionally to try to achieve the work's objective regarding the assessment of the users' performance and driving experience, there are other concerns that were addressed regarding the acquisition of driving skills.

Since the idea of developing the Simcadrom was for training users to drive an EPW with a joystick or an alternative input interface like the eye tracker, then we here considered to somehow validate the learning effect while training in the simulator. Therefore, three hypotheses were established and tested here for a deeper analysis:

1. Does the Simcadrom simulates a real EPW close enough so it can be used for virtual training?
2. Do people can learn and improve their EPW driving skills by doing a training session in the Simcadrom?
3. Do the skills learned in the training session in the Simcadrom can be transferred to the real EPW?

The comparisons to evaluate the hypotheses were included in a test protocol designed for a training session with the Simcadrom using a joystick and the eye tracker. This is to see if the system simulates the EPW in a realistic way that let users acquire driving skills during the training, which can be later transferred to the RE, such as addressed by (Ganier, Hoareau, and Tisseau, 2014).

2. Materials, Methods, and Experiment Setup

2.1. Virtual Environment

In this research, some tests were conducted to compare participants´ experience and driving performance, between a real EPW and a virtual one in the Simcadrom. This simulation system for training and testing of EPW input interfaces was designed aiming to provide a driving experience as much realistic as possible. For this reason, a real EPW (from Freedom company) was incorporated into the system for the user to sit on while driving the virtual EPW, with no real movement at all, just for realism purposes. The VE runs on a PC with Windows 10, 8GB of RAM, Intel i7 processor, and an MSI GeForce GTX 1060 graphics card.

The VE of the Simcadrom was created with the Unity 3D game engine (Unity 5.5.0f3 for Windows), from Unity Technologies. In accordance to (Silva and Silva, 2011), it is one of the most adequate software used to create VE, and in (Hjorungdal *et al.*, 2016) it has been considered as an efficient integration platform for training with a virtual EPW.

The VE selected as the testing scenario was the NTA Research Group Laboratory (Assistive Technology Center) of UFES, which was successfully enhanced (see Fig. 2) for simulation training system requirements focused on:

- Integration of virtual models of a joystick and an eye-tracker device as EPW input interfaces;
- A virtual model of an EPW considering kinematics and dynamic effects;
- Generation of high-immersive experience in users;
- Improvement of the realism of the laboratory's virtual model for comparison purposes with the real environment (RE);
- Measurement and register of users' performance in individual comma-separated values (.csv) files.

Fig. 2. Real (left) and virtual (right) NTA Research Group Laboratory.

The other main components of the simulator, when using a Joystick or the Eye Tracker, are shown in Fig. 3 and Fig. 5, respectively.

2.2. Simulator Using a Joystick Interface

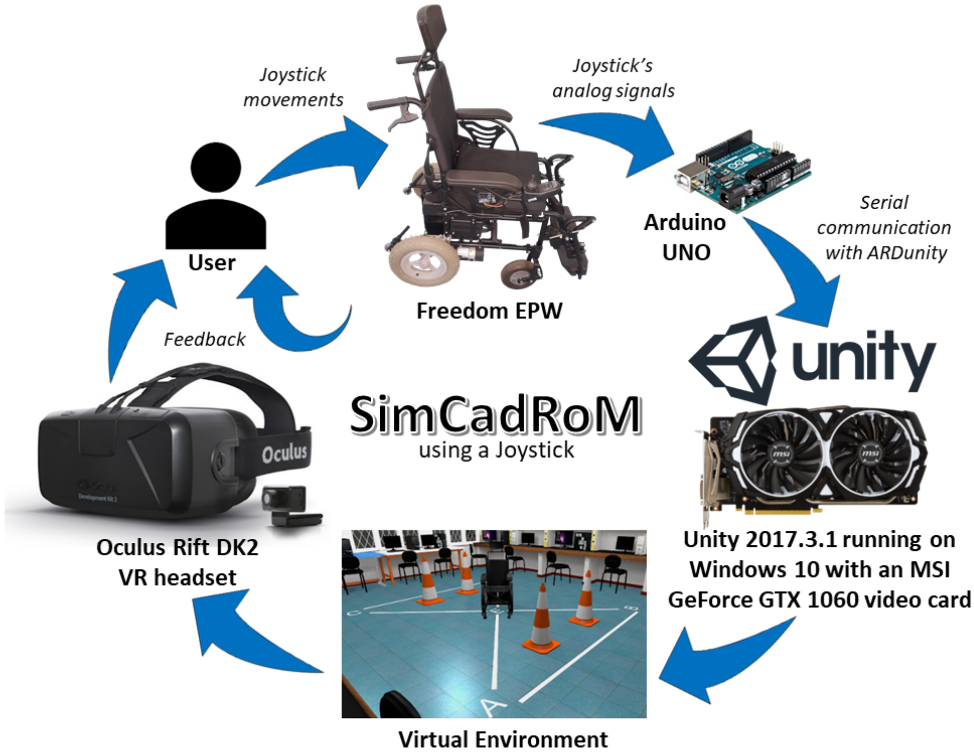

Fig. 3. Main components of the Simcadrom when using a Joystick to command the EPW.

The simulation system with a joystick as input interface uses the actual joystick of the real EPW as the input interface for the virtual EPW. An Arduino UNO board attached to the side of the wheelchair (see Fig. 4) acquires the analog voltage signals from the joystick and sends them to the VE in Unity running on the PC, by USB serial communication using ARDunity Basics libraries.

Finally, the system is equipped with a head mounted display (HMD) to show the user the VE. The device selected was the Oculus Rifts DK2 VR headset, which the user wears while sitting in the real EPW and using its actual joystick, thus, offering a greater immersive VR driving experience controlling the virtual EPW, which can be better compared to driving the real EPW in a real environment (RE) (Dicianno *et al.*, 2009).

Fig. 4. Real Freedom EPW with no movement, where the user sits and uses the joystick as input for the Simcadrom.

2.3. Simulator Using an Eye-Tracker Interface

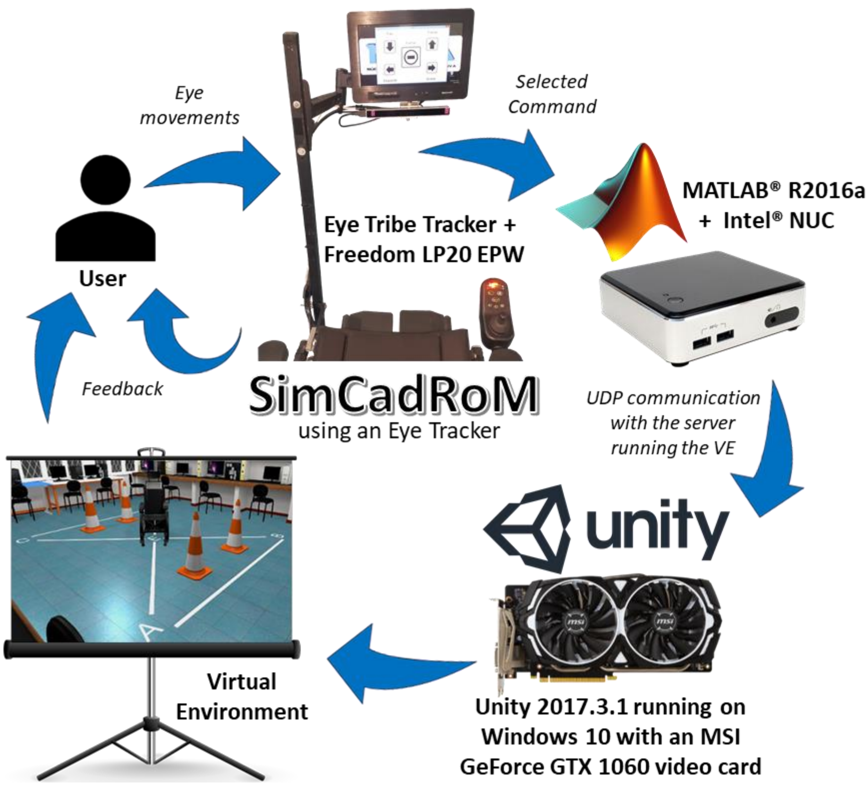

Fig. 5. Main components of the Simcadrom when using Eye Tracker.

For an alternative interface like the eye tracker, the simulation system could not make use of the selected HMD to show the VE to the user and at the same time do eye/gaze tracking, at least not with that VR headset model. Therefore, a practical solution for still providing near real-size visual feedback and an immersive experience was to use a projector and a screen as shown in Fig. 6, while the user sits on a real EPW with no movement.

This second real EPW from Freedom Company that the participant uses with eye tracker is actually the main modified EPW used in this research. The first one shown in Fig. 4 was modified just to acquire joystick signals as input for the virtual EPW when the simulator is used with a joystick interface. In both cases (simulation with a joystick or eye tracker), the real EPWs do not move, they just provide a more realistic feeling for the user. Additionally, the main reasons for using two EPWs were to save time and facilitate the execution of tests in the VE and the RE.

Fig. 6. A participant using the Simcadrom with eye tracker as an input interface.

2.4. Real Instrumented EPW

The main real EPW, shown in Fig. 7 and from now on called just real EPW, was equipped with an LCD screen (1) that displays a navigation software interface for the users to look at and select the direction in which they want the EPW to move or turn (Montenegro-Couto *et al.*, 2018). The screen is secured to a metal bar (3) and can be located at two possible height positions. Below the screen the eye tracker device (2) is attached, whose facing angle can be adjusted for different user’s height as well as the facing angle of the screen.

The eye tracker sends signals by USB serial communication to the mini PC Intel NUC (5) located at the back of the EPW, which can also be controlled by its joystick (10). When the EPW is in "joystick mode" and its joystick is deflected out of a safety zone, the breaks (9) disengage and the EPW moves. This movement is measured by encoders (8), whereas its angular orientation is measured by an IMU (4), specifically an FRDM-FXS-MULTI-B sensor expansion on an FRDM-K64F Freedom Development Platform already used in a previous project for EPW localization (Miranda Lessa, Bastos-Filho and Frizera-Neto, 2017). These measurements are then sent to the mini PC (shown better in Fig. 8) by USB serial communication.

At the back side of the EPW, there are two 12V batteries at the bottom, and from left to right: the mini PC (5), on/off switches (6) for energizing the mini PC and the screen monitor, and a clear acrylic box (7).

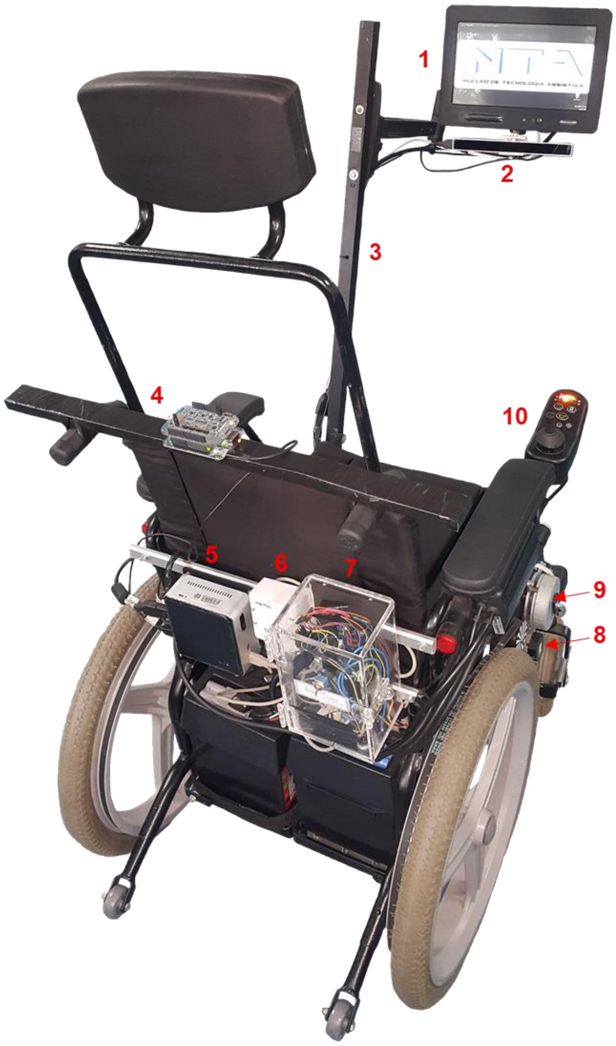

Fig. 7. Instrumented EPW used for tests in the RE and for the VE with Eye Tracker.

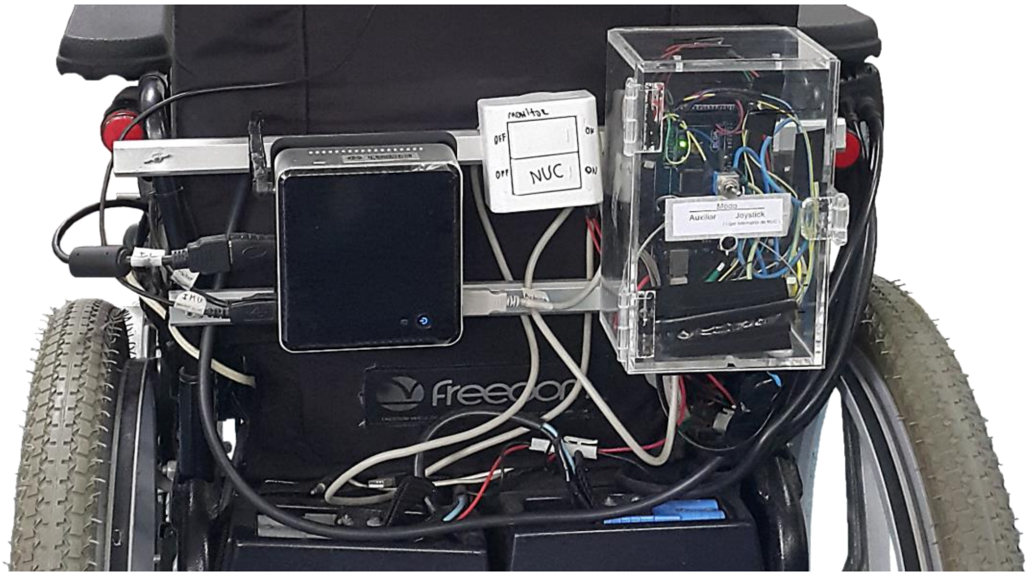

Fig. 8. Back side of the main real EPW.

The acrylic box has a switch on the front for choosing between “joystick mode” and “auxiliary mode”. In joystick mode, the EPW can be driven manually using its joystick and in the auxiliary mode, it is commanded by signals coming from the mini PC to an Arduino MEGA. This Arduino and a low-pass filter circuit are both inside the box and are the ones responsible for generating the analog voltage signals that go to the DC motor driver for commanding the EPW.

The mini PC receives signals from the encoders and IMU in whatever EPW operation mode. It also receives signals from the eye tracker in “auxiliary mode” and from the joystick in the “joystick mode”. In this last case, the joystick signals are acquired by the Arduino MEGA and then sent to the mini PC, which processes and registers all these data on MATLAB/Simulink®.

2.5. Simulink Block Diagram

Fig. 9 presents the MATLAB/Simulink® block diagram programmed in the mini PC for processing and registering the data obtained from the instruments on the real EPW.

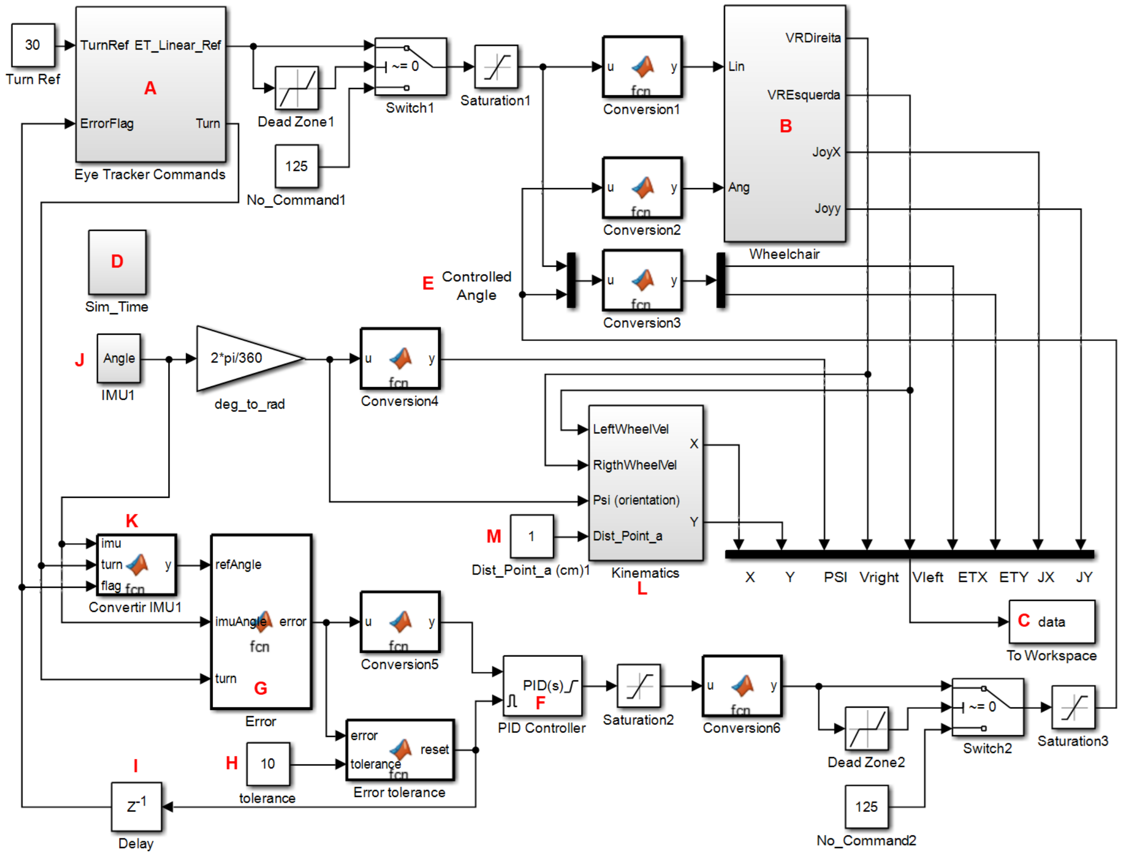

Fig. 9. Simulink® block diagram for signal processing and data registration from measurement instruments and input interfaces.

When the EPW is in “auxiliary mode” and the “ErrorFlag” (A) says that there is still an error, and the EPW has not arrived at its destination, the “Eye Tracker Commands” block (A) sets the linear velocity reference for the EPW and sets the turn-angle reference in the direction of rotation selected by the user on the navigation software interface. For safety reasons, the EPW moves forward or backward a specific preprogrammed distance when the correspondent command is selected. It also rotates clockwise or counterclockwise a fixed preprogrammed amount of degrees, depending on which turning command was selected.

The linear velocity reference “ET_Linear_Ref” (A) goes to the “Lin” input of the “Wheelchair” block (B) after some safety limitations, but it is also exported as the column “ETY” of the “data” time series in the “To Workspace” block (C). The time of the “data” time series comes from the simulation time of the “Sim_Time” block (D). “ETY” and “ETX” are associated with the commands selected by the user while using the eye tracker interface for the real or virtual EPW. The "ETX" is the signal associated with the turn right/left commands while using the eye tracker. This command also called in the block diagram "Controlled Angle" (E), goes to the "Ang" input of the "Wheelchair" block (B) and comes from the output of a PID controller block (F), after passing through some safety limitations.

The PID controller (F) gains were empirically tuned in closed loop aiming for a good performance and trying to get a smooth and slow control action that does not cause big angular position overshoots in the EPW. This controller block has an external "reset" input that is activated whenever the angle error from the "Error" block (G) is less than the "tolerance" error (H). Such "reset" signal is also the "ErrorFlag" for the "Eye Tracker Commands" block (A) after passing through a delay block (I).

The error input of the PID controller block (F) comes from the "Error" block (G) which calculates the difference between the reference angle "refAngle" and the real EPW's angle provided by the IMU from the "IMU1" block (J). Since the angles from the IMU are from 0° to 360° and the reference angle is always the same magnitude but different sign, then the difference between them is calculated depending on the direction of the "turn" input that comes from the "Eye Tracker Commands" block (A). The reference angle "refAngle" is specified in (K) considering the current angle from the IMU, the "Turn Ref" angle, and the "Error flag", which activates whenever the EPW has not got to the reference angle yet (error greater than a tolerance).

The "Wheelchair" block (B) receives the linear and angular velocities references as inputs, which go directly to an "Arduino motor shield" block inside (B) that is used to receive and send data via USB port between Simulink and the Arduino MEGA board. The Arduino MEGA receives these signals and generates the proper analog voltage signals to set the velocity references in the real EPW. The board also receives signals from the encoders all the time, and from the joystick when the EPW is set on "joystick mode". Then, these signals are registered as columns: "JX" (joystick signal in the X-axis), "JY" (joystick signal in the Y-axis), "Vright" and "Vleft" (right and left wheel velocities) in the "data" time series (C).

Lastly, the wheels' velocity signals "Vright" and "Vleft" from the "Wheelchair" block (B) go as inputs to the "Kinematics" block (L) as well as the orientation of the EPW, which is provided by the IMU (J) (converted to radians), and the distance between the wheelchair shaft and the center of the wheelchair "Dist_Point_a (cm)" (M). Then, assuming the kinematics of this wheelchair as a differential drive vehicle, X and Y coordinates of the EPW's position are obtained and registered in the "data" time series (C).

2.6. The Velocity of the EPW Using a Joystick

The eye tracker interface sets discrete velocities references for the EPW, but proportional joysticks are commonly used to change EPW's velocity in proportion to the amount of deflection (typically 0°–18°) of the spring-loaded joystick post, and the wheelchair moves approximately in the direction the handle is pointed. Additionally, features such as dead zone, gain, and axes rotation are also mechanically defined.

Considering all these characteristics, some tests were conducted in order to acquire the analog voltage signals from the real EPW's joystick with the Arduino MEGA board and associate them with the joystick deflections. Then, the original signals from the joystick were emulated by the Arduino through analog voltage output signals generated as PWM values from 0-255, equivalent to a duty cycle from 0-100%, which then went to a low-pass filter circuit connected to the joystick driver board from the EPW.

Finally, various EPW´s velocities were obtained by emulating the joystick at different deflections. A dynamic model of the EPW was not calculated in this project, however, the obtained velocities were registered for different loads since the linear and angular velocities of the real EPW are affected by the wheelchair user's mass (the position where the user sat was not considered).

The obtained data were interpolated in three dimensions (see Fig. 10 and Fig. 11) to get a closer approximation of the angular and linear velocity of the real EPW considering dynamic effects, thus, representing better its behavior in the VE.

The experimental linear and angular velocities obtained of the real EPW for different loads and different joystick's deflections show that the wheelchair's velocities decrease when the user's mass increase, in a symmetrical way for the joystick's deflection in both directions of the X and Y axes around the safety zone (dead zone with no EPW movement).

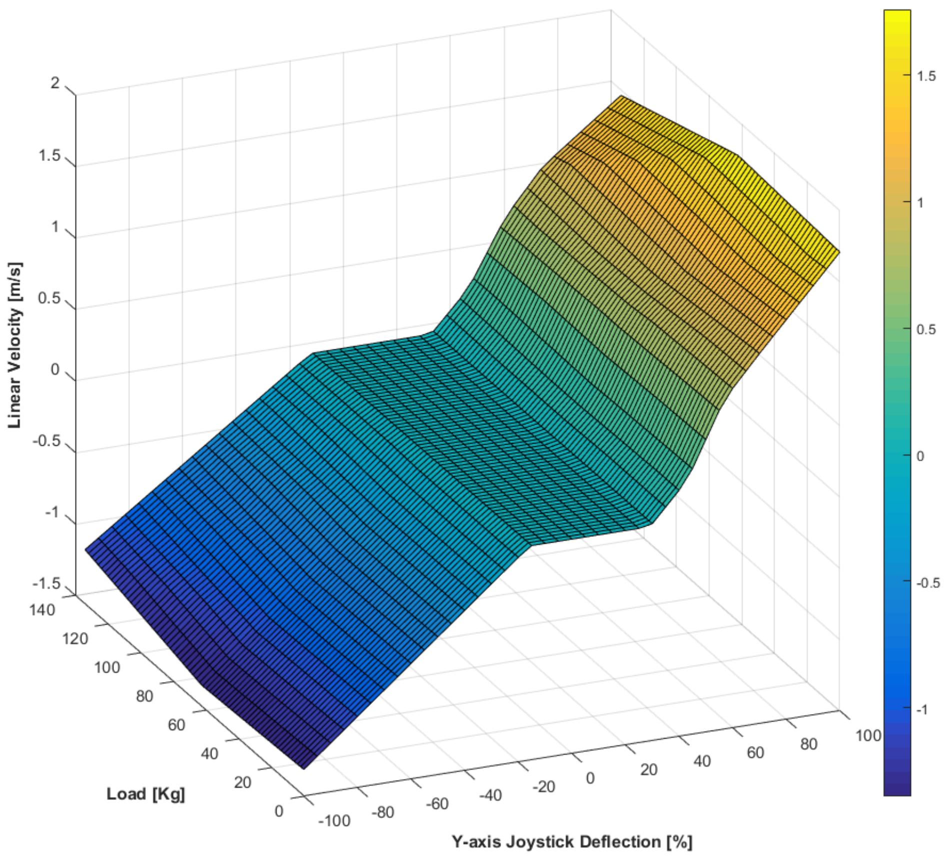

Fig. 10. Experimental linear velocities of the real EPW for different masses and different joystick's Y-axis deflections.

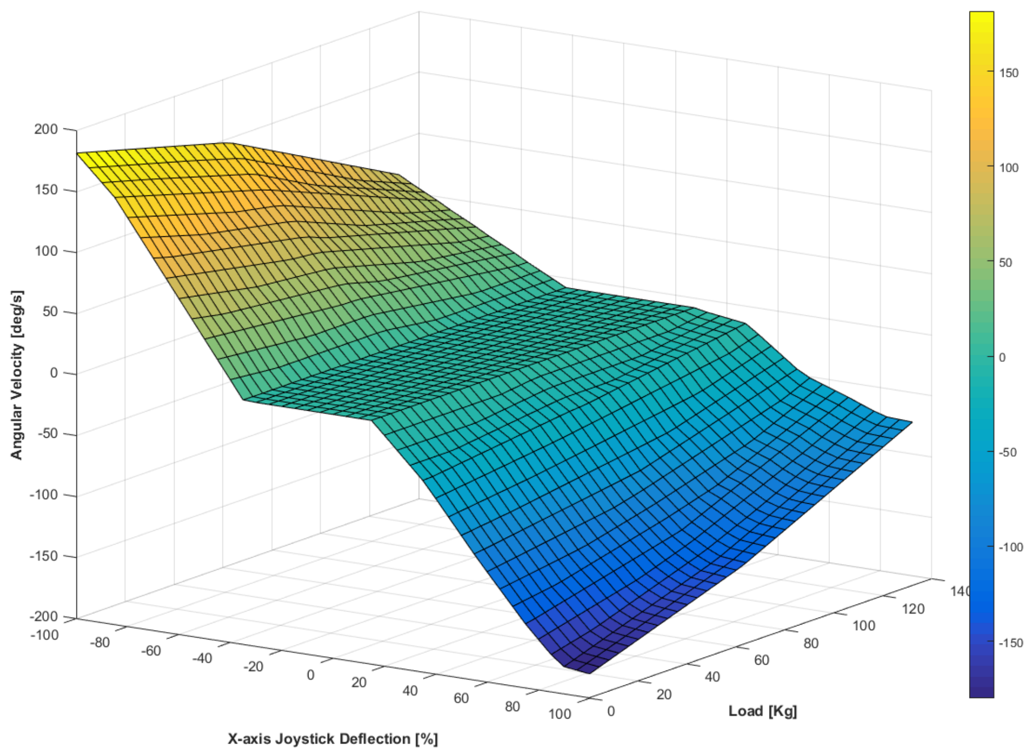

Fig. 11. Experimental angular velocities of the real EPW for different mass and different joystick's X-axis deflections.

Finally, it is important to mention that despite using two joysticks of the same model, one in the RE tests and the other in the VE tests, some differences were noticed. Thus, some software adjustments were made to the signals from the joystick used in the VE so it could emulate better the electrical behavior of the joystick used in the RE tests. Therefore, it is assumed in this project that both joysticks, have an identical behavior.

2.7. Obtention of the Path Following Error

The participants were asked to drive the EPW over the areas marked by the letters in order, to avoid to hit the cones, doing it as fast as they could, and by following the reference path as close as possible. Data of an example trial from a participant using a joystick is shown in Fig. 12, where the reference path and the traveled path by the real EPW are presented.

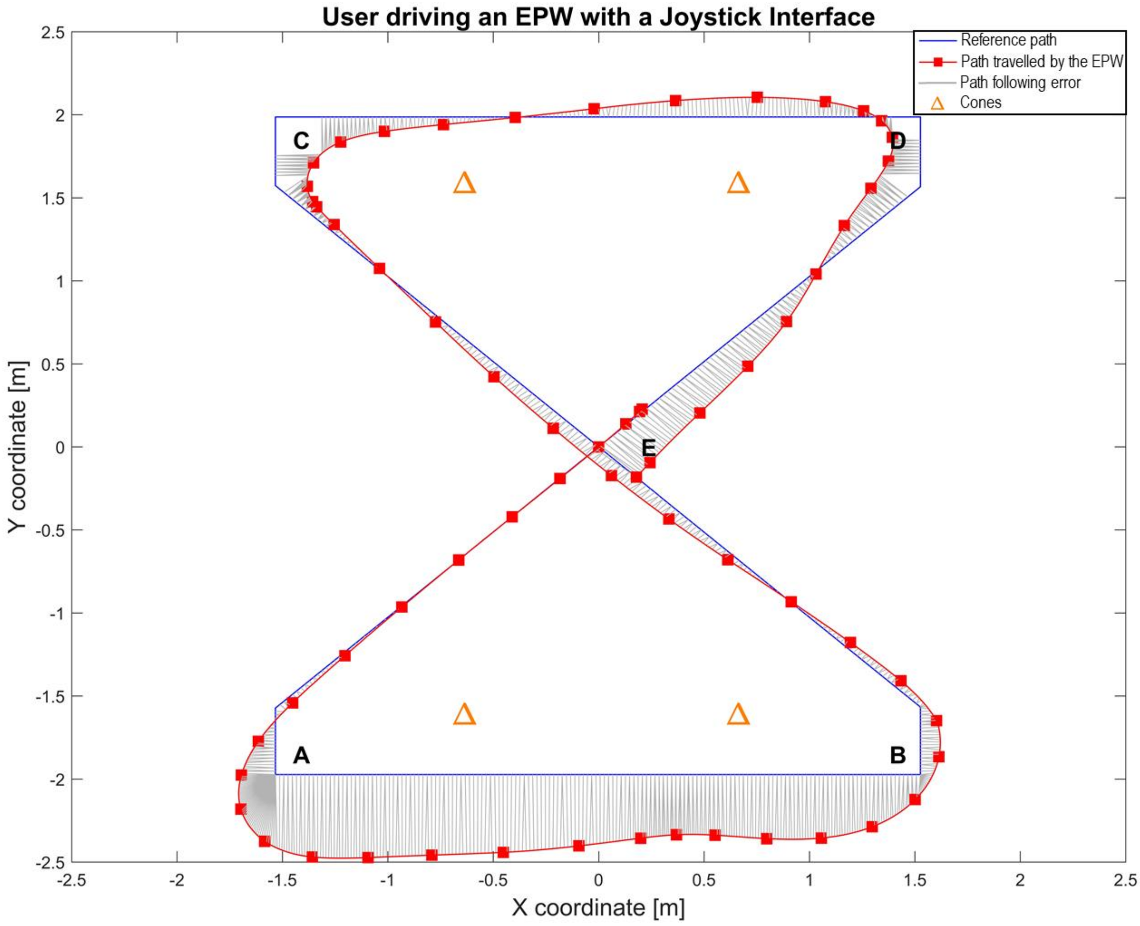

Fig. 12. The path followed by the real EPW using a joystick.

Fig. 12 also shows error lines, calculated as Euclidean distances, coming from the traveled path to the nearest point in the correspondent segment of the reference path. Every calculated distance was then considered as an error amplitude and was registered in a time series to produce an error signal as the one presented in Fig. 13.

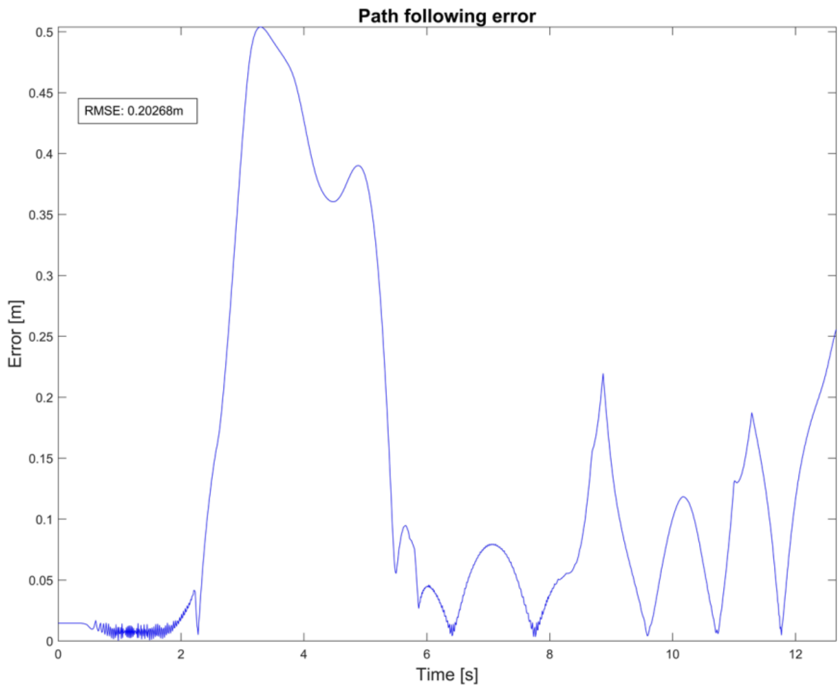

Fig. 13. Path following error from the real EPW using a joystick.

Consequently, the root-mean-square error (RMSE) was obtained from this signal and registered for every participant using a joystick in the VE and in the RE.

2.8. Obtention of the total number of commands

In this work, two different input interfaces that command the EPW are used and although they cannot be compared directly because of their different characteristics, they are being measured in the same unit, which is the number of commands required by the participant to drive the EPW using those interfaces. Then, the total number of commands and the way it is obtained here is useful for next input interfaces that can be added to the simulation system.

The commands generated by the eye tracker interface can be counted easily, such as shown in Fig. 14, as they generate discrete commands in the X or Y axes.

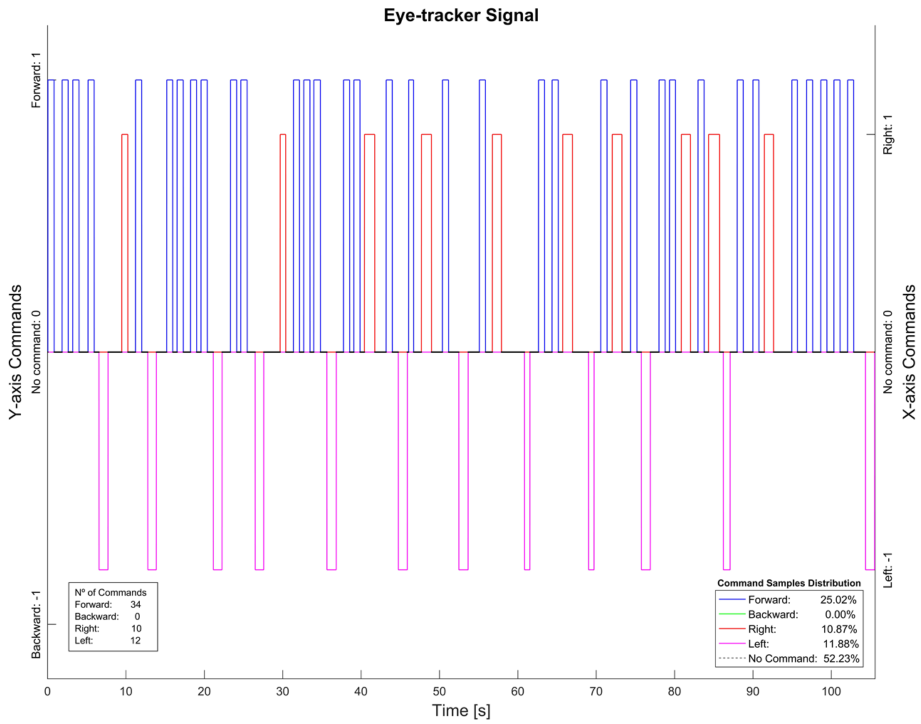

Fig. 14. Classification of commands from the eye-tracker interface while driving the real EPW.

In the case of an input interface that generates analog voltage signals in the X and Y axes like a joystick (as shown in Fig. 15), identifying a command is not that evident, even less considering the dead zone the real EPW has for safety reasons.

Therefore, it is proposed here to implement a simple classifying algorithm for the samples from the joystick's signals as shown in Fig. 16, where the X and Y-axes signals are considered to be in rectangular coordinates which then are converted to polar coordinates to get their magnitude and angle of deflection of the joystick. Afterward, this is used to detect if a sample belongs to a command, meaning that its magnitude is above the dead zone, and then specifying whether it is a forward, backward, right, or left command, depending on its angle.

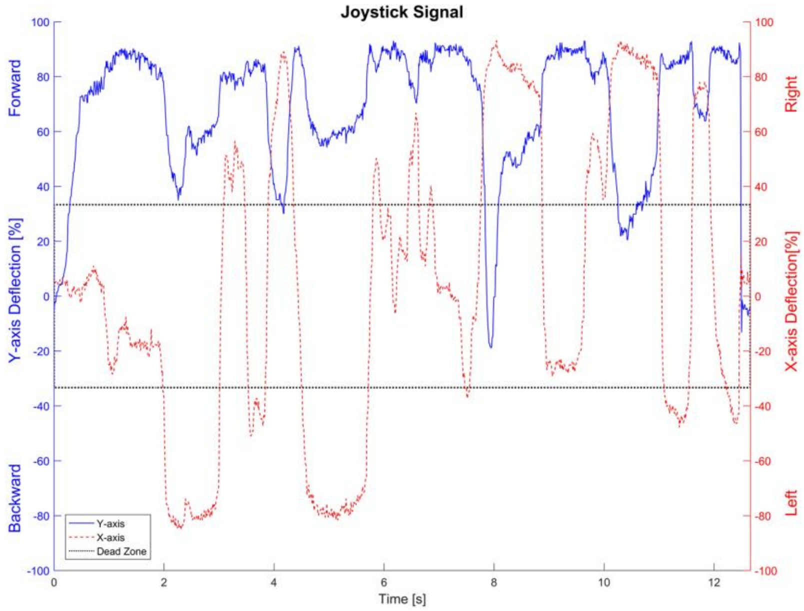

Fig. 15. Joystick's X and Y-axes signals while driving the real EPW.

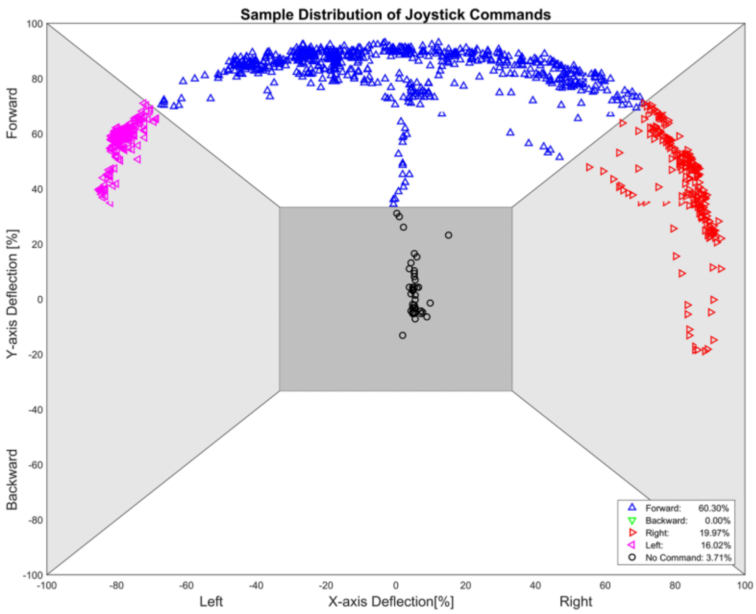

Fig. 16. Samples from joystick signals generated while driving the real EPW, distributed in commands.

After that, Fig. 17 was obtained by implementing the classification of samples procedure to the joystick's X and Y-axes signals along the elapsed time during the tests, where the beginning of a command was detected and the end of it was considered to be when the command changed to another one or when no command was detected. Finally, the total number of commands during the trial can be counted.

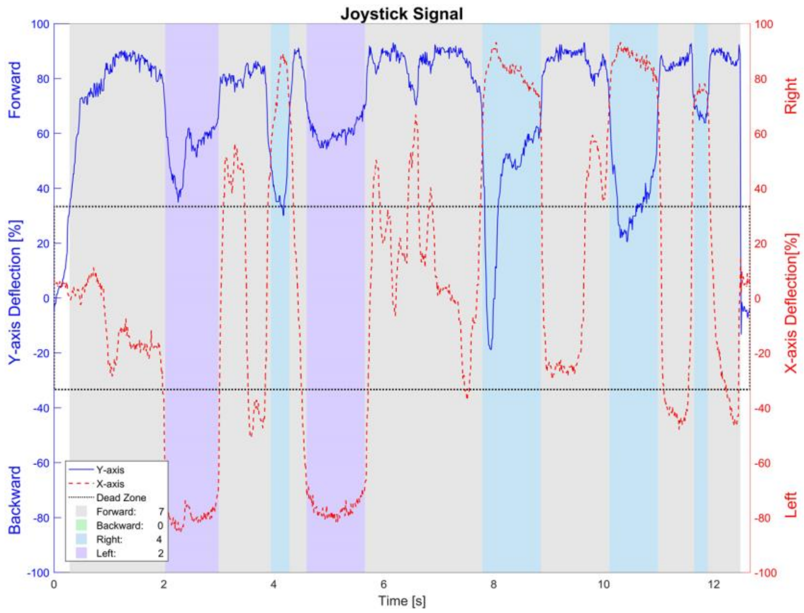

Fig. 17. Classification of commands from Joystick's signals while driving the real EPW.

2.9. Experiment Setup

The simulator was evaluated qualitatively by both a user experience questionnaire (UEQ) and the IPQ, and quantitatively by doing statistical test comparisons between participant's driving performance parameters: time spent executing a given task, path following error, and number of movement commands made with the input interface. The comparisons to evaluate the established hypotheses were included in a test protocol designed for the training session with the Simcadrom using a joystick and the eye tracker.

The test protocol designed for the experiments, that involves VR, was approved by the Federal University of Espirito Santo Ethics Committee (protocol number 2264126 of September 7, 2017). In the proposed protocol, the participants needed to follow a path with the EPW, starting at point E, in the middle of the NTA Research Group Laboratory, and then passing through points A, B, C, D and then returning to E as indicated by the marks on the floor shown in Fig. 2. The participants were instructed to drive the real and virtual EPW by keeping the wheelchair along the center of each path segment of the path and to complete it as quickly and as accurately as possible.

2.10. Participants Selection

Twenty healthy participants, without any physical impairment, were recruited from UFES. Ten of them used a joystick as the input interface during the tests, and the other ten used an eye tracker as an alternative interface.

Participants were between 18 and 36 years old and weighted between 45 and 120 Kg. Inclusion criteria consisted of having normal or corrected vision, and for the case of the group that used a joystick, the participants were right-handed and had their right arm and right hand able to control the EPW with its joystick. These participants also required proprioception and dexterity at joints to efficiently use the proportional control, such as done in (Mahajan *et al.*, 2012). The participants were asked if they could perform the tests on both RE and VE and were told they could leave at any time.

The 20 participants were divided into four groups (n=5) as presented in the test protocol in Fig. 18, where one group was using the joystick and trained in the VE, named "VJ" from (virtual joystick). The second one is called "RJ" because they used the joystick and trained in the real EPW. The third one was using the eye tracker and training in the VE, called "VET" (virtual eye tracker). The last group is "REJ", they used the eye tracker and trained in the real EPW.

Homogeneity is assumed since the following characteristics, that are being considered in this study as relevant, are presumed to affect each group's performance in the same proportion:

- The groups of participants "VJ" and "RJ" had very similar mean weight (81,4 ± 15,12 Kg and 80,6 ±15,73 Kg), as well as the "VET"/ "RET" groups (65,6 ±10,25 Kg and 67,0 ± 15,47 Kg).
- None of the participants needed an EPW or had driven one in at least a year.
- Two out of five participants from each "VJ" and "RJ" groups had used an HMD like Oculus Rift before at least once in the last year.
- Two out of five participants from each "VET" and "RET" groups had used the eye tracker before at least once in the last year.
- Four out of five participants from each "VJ", "RJ", "VET" and "RET" groups played "First-Person Shooter" games before at least once in the last year.
- One out of five participants from the "VJ", "RJ" and "VET" groups did not know how to drive a motor vehicle.

2.11. Test Protocol

The participants from the "VJ" and "VET" groups were asked for the training session, to drive the virtual EPW following the specified reference path six times such as done by (Ganier, Hoareau, and Devillers, 2013), with less than five minutes between trials. Then, for the seventh trial, the final test for their training, they were asked to drive the real EPW in the RE. This same procedure was done for the "RJ" and "RET" groups, beginning in the RE and the final test in the VE, for counterbalancing the influence the order of the tests could have on the results.

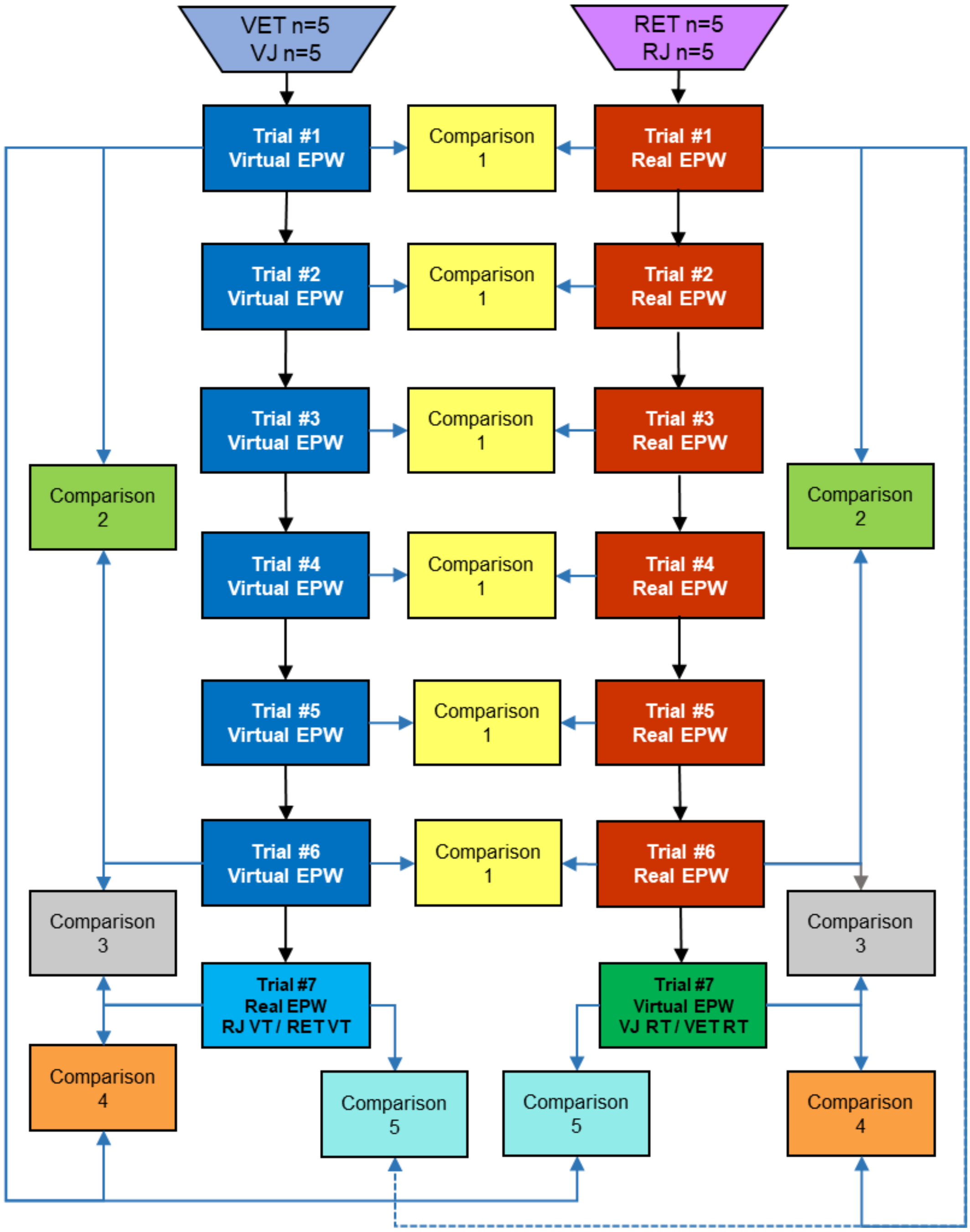

Fig. 18. Test protocol.

2.12. Comparisons in the Test Protocol

The data obtained from the measurements of each group of participants were considered to be different for each of their respective trials since a learning effect was presumed, i.e. data from the first trial of one of the four specified group of participants should not be assumed to belong to the same measurements from the second trial of the same group of people.

Since the data from each group of participants is divided by their trials, a comparison, named "Comparison 1", between "VJ" and "RJ", or "VET" and "RET", was done between each trial with its correspondent to aid in finding how close the virtual experience is to the real one.

Once the "VJ" and "VET" groups finished the six trials in the VE and the "RJ" and "RET" groups finished their final trial in the VE, the participants were asked to fulfill the IPQ test in Portuguese (instrument properly validated in different cultural contexts) (Vasconcelos-Raposo *et al.*, 2016), to measure their sense of presence in the VE. And after they all finished the whole test (seven trials), they were asked to answer the UEQ (5-point Likert scale) about their experience using the Simcadrom. These questionnaires also helped in finding how close the virtual experience is to the real one.

In order to evaluate the other hypothesis, about people learning by doing a training session and transferring the acquired knowledge to the opposite environment, some comparisons were considered into the protocol. "Comparison 2" helps to measure if there was any learning effect by calculating whether the trial six measurements from a group of people were significantly better than the ones from trial one of the same group.

Presuming that people learned in the training session and that the VE is similar to the RE, "Comparison 3" helps in finding out if the acquired skills of a group of people after trial six are maintained in trial seven in the other environment. "Comparison 4" is also based on the previous assumptions and tells if the learning effect from trial one is extended until trial seven.

Finally, "Comparison 5" estimates how good were the measurements from trial seven, in contrast with the measurements from the first trial of the opposite environment. In other words, these final measurements, that were obtained from the trial in an environment that is the opposite to the one where the group trained, are compared to the measurements from the first trial of the other group of people in that same environment, but with no training, e.g. trial seven of the "VJ" group, also named "RJ VT" (from RE using Joystick, after Virtual Training), was compared to trial one of the "RJ" group.

3. Results and Discussion

In this section, the results from the above-mentioned protocol test were analyzed as quantitative and qualitative parameters to find out: how similar the Simcadrom experience was to a real EPW driving experience; if people learn EPW driving skills by doing a training session in the simulation system or not; whether those skills were transferred to the RE or not.

The following subsections present the statistical analysis from the measurements obtained. These subsections are divided in the elapsed time, path following error, and number of commands, for both VE and RE. The measurement data and statistics are shown in detail in tables for the elapsed time of the virtual and real tests using a joystick, only as an example. Since the statistical procedure for the other parameters and the eye-tracker interface was the same, detailed tables are not going to be referenced, however, they are presented in the appendices. Thereafter, the data from the questionnaires are presented.

In some cases, more than one dependent or independent statistical test of the difference of two means was conducted for the same data set. Therefore, the probability of making type I errors (family-wise error rates) while performing multiple hypotheses tests may increase.

Some methods have been proposed to circumvent the problem, due that as the number of tests increases, so does the likelihood of a type I error. The Bonferroni correction is one of the most popular methods widely used in various experimental contexts, as it adjusts probability (p) values because of the increased risk of having falsely rejecting null hypotheses when making multiple statistical 't' tests. However, this method has been criticized for testing the wrong hypothesis, and for reducing the chance of a type I error, but at the expense of a type II error (Armstrong, 2014) .

Thus, one of the limitations of this investigation is that the increase in family-wise error rate across the reported statistical analyses was not controlled (Gignac, 2018). Overall, we consider this research relatively preliminary and encourage replication.

3.1. Elapsed Time During the Test in the VE and RE

The elapsed time to drive the EPW along the reference path, going from point E to A, B, C, D, and E again in the RE and VE (see Fig. 2), was defined as the first quantitative parameter to compare driving performance and was registered per trial for each participant. The mean of the total elapsed times and their standard deviations were calculated for every trial of each of the four groups (n=5): "VJ", "RJ", "VET", and "RET".

Time Analysis Using a Joystick

In the case of the tests in the VE and RE using a joystick interface, the elapsed times are presented in Table 1 and Table 2, respectively. Since the test protocol does not intend to infer the behavior of the entire population based on its results, a population standard deviation was implemented.

Table 1. Elapsed times for virtual training using a joystick.

Participant	VJ elapsed times [s] per trial during the training						RJ VT [s]
	1	2	3	4	5	6	7
1	35,22	27,63	25,26	27,47	26,32	25,24	29,09
2	55,06	36,66	35,27	36,96	30,73	33,80	37,03
3	33,18	26,06	27,36	25,77	26,84	26,21	35,77
4	48,25	33,91	-	39,08	36,06	34,47	39,36
5	74,07	42,91	50,23	35,65	32,13	34,86	45,47
Mean	**49,16**	**33,43**	**34,53**	**32,99**	**30,42**	**30,92**	**37,34**
SD	**14,87**	**6,14**	**9,80**	**5,34**	**3,59**	**4,26**	**5,31**

Table 2. Elapsed times for real training using a joystick.

Participant	RJ elapsed times [s] per trial during the training						VJ RT [s]
	1	2	3	4	5	6	7
6	25,23	23,96	24,99	23,97	23,08	23,02	30,27
7	35,89	35,11	35,20	30,37	28,37	30,99	41,27
8	36,41	38,42	35,03	39,93	36,25	32,37	71,84
9	45,31	33,44	39,29	32,31	32,04	26,22	28,01
10	45,99	35,40	32,12	34,12	30,50	28,83	58,37
Mean	**37,77**	**33,27**	**33,33**	**32,14**	**30,05**	**28,29**	**45,95**
SD	**7,58**	**4,92**	**4,75**	**5,19**	**4,34**	**3,36**	**16,82**

Both mean values of the elapsed times from Table 1 and Table 2 are about the same range and as can be seen in Fig. 19, both curves have a similar form and a decreasing tendency (negative slope).

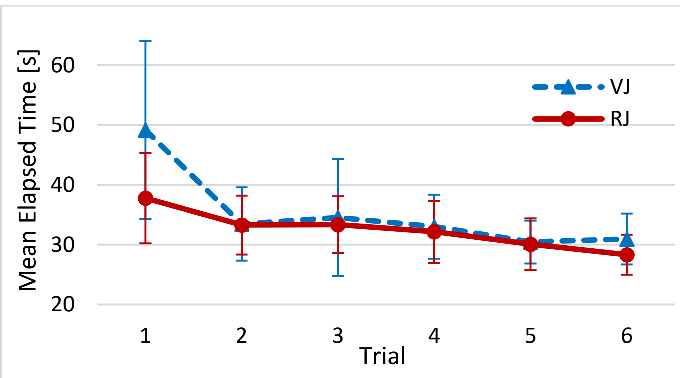

Fig. 19. Mean elapsed time values for real and virtual training using a joystick.

These values were compared between trials in Table 3 to see whether their difference is statistically significant or not. In the "RJ-VJ" row, the difference between the elapsed time values of the "RJ" and the "VJ" groups was calculated for each trial of the training session independently (one value was missing in trial three).

As we are interested in the mean values and the sample number was small (n=5), then a Shapiro-Wilk test was conducted to see if those differences had a normal distribution so that a student's t-test could be applied.

Table 3. Elapsed time statistical test for virtual and real training with a joystick (Comparison 1).

Trial	**1**	**2**	**3**	**4**	**5**	**6**
RJ-VJ [s]	-9,99 -19,17 3,23 -2,94 -28,08	-3,67 -1,55 12,36 -0,47 -7,51	-0,27 -0,07 7,67 - -18,11	-3,5 -6,59 14,16 -6,77 -1,53	-3,24 -2,36 9,41 -4,02 -1,63	-2,22 -2,81 6,16 -8,25 -6,03
SW	0,976	0,868	0,837	0,761	0,689	0,914
Critical Wα	0,806	0,806	0,806	0,762	0,686	0,806
p-value	**0,915**	**0,258**	**0,155**	**0,038**	**0,012**	**0,490**
F	3,852	1,556	4,538	1,060	1,458	1,614
Critical F	6,388	6,388	6,591	6,388	6,388	6,388
Num df	4	4	3	4	4	4
Den df	4	4	4	4	4	4
p-value	**0,110**	**0,339**	**0,089**	**0,478**	**0,362**	**0,327**
t	1,365	0,043	0,213	0,227	0,131	0,970
df	8	8	7	8	8	8
Critical t	2,306	2,306	2,365	2,306	2,306	2,306
p-value	**0,209**	**0,967**	**0,837**	**0,826**	**0,899**	**0,361**

The Shapiro-Wilk test showed that those differences can be assumed to have a normal distribution since a p-value greater than a level of confidence of 0,01 was obtained for the six trials, moreover, a p>0,05 was found for four of those trials.

After the normal distribution condition was assumed to be met, a Fisher's F-test of equality of variances was performed to find out whether the data's variance from each pair of trials from the RE and VE could be considered equal or unequal. This way, the proper t-test to apply could be better determined. In this case, Table 3 shows that the time data from Table 1 and Table 2 can be considered to have equal variances (p>0,05) between each pair of trials.

Finally, an unpaired t-test assuming equal variances showed enough evidence to accept the null hypothesis (p>0,05). There is no statistically significant difference between the data obtained from the total elapsed times of each pair of trials during the training sessions in the VE and RE.

Following, Fig. 20 displays the mean elapsed times from the first, sixth and seventh (final) trials of the training session with a joystick in the VE and RE.

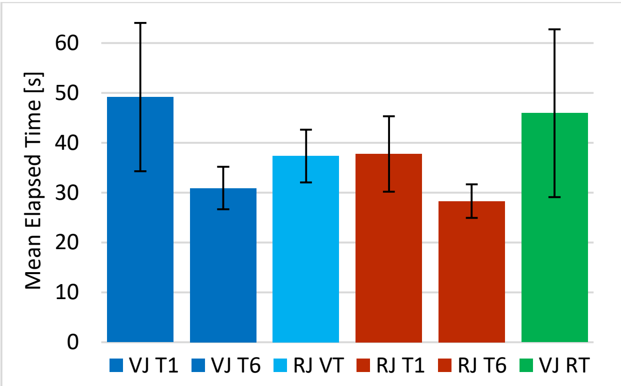

Fig. 20. Mean elapsed times of trials 1, 6 and 7 from the VE and RE using a joystick.

The first trial in the VE (“VJ T1”) and RE (“RJ T1”) are measurements of performance without any previous training, using time as a parameter. “VJ T6” and “RJ T6” are the times at the end of the training session for the “VJ” and RJ” groups, respectively. As expected, these times decreased after training as shown in Fig. 19, and their variability decreased as well.

Lastly, “RJ VT” (RE with joystick after virtual training) seemed greater in time than “VJ T6”, lower than “VJ T1”, and about the same than “RJ T1”. A very similar thing happened with “VJ RT” (VE with joystick after real training), seemed greater than “RJ T1” and “RJ T6”, and almost equal to “VJ T1”, even in variability. However, these differences were analyzed and presented in Table 4. All these comparisons were previously shown in Fig. 18.

In “Comparison 2”, a paired one-tailed t-test was applied between the first and sixth trials of the VE and also in the RE. Results rejected the null hypothesis ($p<0,05$), indicating that the elapsed times from the first trial (no training) were significantly greater than the ones after the training session of the same groups of people.

In “Comparison 3” a paired two-tailed t-test was done for each group between the times acquired in trial six and the ones from the final trial, to see if the learned skills of a group of people after trial six, somehow were maintained in trial seven in the other environment. Results revealed that there was a significant difference between times from “VJ T6” and “RJ VT” ($p<0,05$), but the null hypothesis could not be rejected for “RJ

T6" and "VJ RT" (p>0,05), which means that there is not enough evidence to say that the elapsed times of "VJ RT" were significantly different than those of "RJ T6".

Table 4. T-test of mean elapsed time. Comparison 2, 3, 4 and 5 from the VE and RE using a joystick.

Comparison #	Between	Mean [s]	Variance [s^2]	t-test type	t	Critical t	df	p-value
2	VJ T1 VJ T6	49,156 30,916	276,458 22,717	Paired one-tailed	3,166	2,132	4	**0,017**
3	RJ VT VJ T6	37,344 30,916	35,200 22,717	Paired two-tailed	4,214	2,776	4	**0,014**
4	VJ T1 RJ VT	49,156 37,344	276,458 35,200	Paired one-tailed	2,215	2,132	4	**0,046**
5	RJ T1 RJ VT	37,766 37,344	71,764 35,200	Unpaired one-tailed equal variances	0,091	1,860	8	**0,465**
2	RJ T1 RJ T6	37,766 28,286	71,764 14,071	Paired one-tailed	2,656	2,132	4	**0,028**
3	VJ RT RJ T6	45,952 28,286	353,539 14,071	Paired two-tailed	2,460	2,776	4	**0,070**
4	VJ RT RJ T1	45,952 37,766	353,539 71,764	Paired one-tailed	0,969	2,132	4	**0,194**
5	VJ T1 VJ RT	49,156 45,952	276,458 353,539	Unpaired one-tailed unequal variances	0,285	1,860	8	**0,391**

"Comparison 4", which is also based on the learning effect assumption, compares if measurements from trial one are significantly greater than those of trial seven with a paired one-tailed t-test. Results showed that after the virtual training, the obtained mean elapsed time from the "RJ VT" was significantly smaller (p<0,05) than the time from "VJ T1", as expected. Nonetheless, this was not the case in the opposite order, where the time from "RJ T1" was not significantly different than the time from "VJ RT".

Finally, "Comparison 5" estimated that the measurements from trial seven, in contrast with the measurements from the first trial in the opposite environment, had no significant difference (p>0,05) by implementing an unpaired one-tailed t-test, whose variances were assumed equal or unequal depending on F-test p-values at the 0,05% level. In the case of the times obtained by "RJ VT", the group of people using a joystick in a real EPW for the first time after training in the VE, their variance was considered to be equal (F(4,4)=2,04) to the one of "RJ T1". And for "VJ RT", their variance was unequal

(F(4,4)=1,28) to the variance of the "VJ T1" groups. Thus, there is not enough evidence to see a significant progress reducing the elapsed times after a training session in the VE nor RE.

Time Analysis Using Eye Tracker

The times that participants took to complete the test in the VE and RE using eye tracker are reported in Appendix A as well as the tables with the statistical information about the comparisons made. It can be easily noticed from those tables that following the reference path in the tests using the eye-tracker interface with its driving modality defined above (see 2.5) took more time than driving the EPW with a joystick as it was expected. Moreover, when plotting their mean values as presented in Fig. 21, it can be observed that both curves, therefore, both EPW in the VE and RE, have a similar behavior but there is a difference between them, which is greater than in the joystick case in Fig. 19.

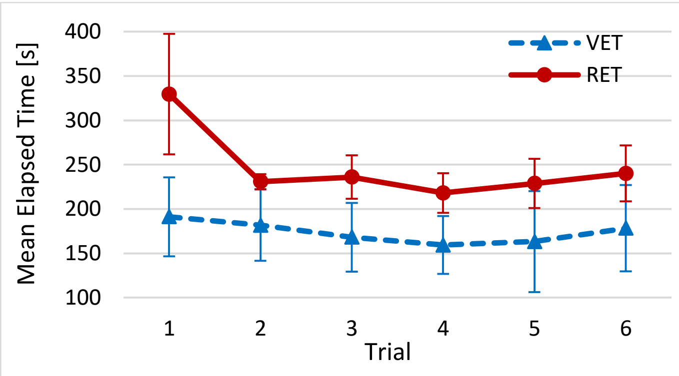

Fig. 21. Mean elapsed time values for virtual and real training using eye tracker.

These values were compared between trials to see whether their difference is statistically significant or not, following the same procedure from the time analysis when using a joystick interface. "Comparison 1" of these normally-distributed data (p>0,05) revealed with an unpaired t-test that there is no statistically significant difference (p>0,05) between the mean of the total elapsed times during the training session in VE and RE using eye tracker in trials 2, 5, and 6, however, the null hypothesis was rejected (p<0,05) for trials 1,3, and 4.

Next comparisons from 2 to 5 for the mean values of the six trials shown in Fig. 22 are also reported in Appendix A. It can be said from "comparison 2" that there was no significant difference (t(3)=0,779, p=0,246) between mean times from "VET T1" and "VET T6", however, when training in the RE, the times from "RET T1" were significantly greater (t(4)=2,326, p=0,04) than those of "RET T6" after training.

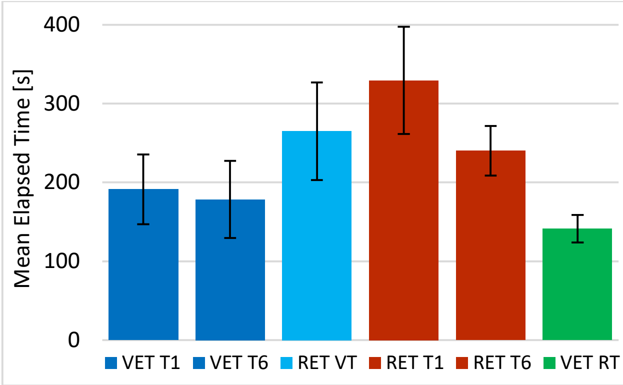

Fig. 22. Mean elapsed times of trials 1, 6 and 7 from the VE and RE using eye tracker.

“Comparison 3” showed that there is a significant difference (p<0,05) between “VET T6” and “RET VT”, and between “RET T6” and “VET RT”, which clearly suggests that, at least for the time parameter, the performance was not maintained when a group of participants trained with eye tracker in one environment and then tried the other one.

Additionally, it was obtained from “comparison 4” that the mean time in “RET VT” was significantly greater (t(3)=3,233, p=0,024) than the mean time in “VET T1”. However, times from “RET T1” are in average greater (t(4)=5,777, p=0,002) than the ones from “VET RT”. Then, “comparison 4” confirmed the same behavior seen with “comparison 2”, in which there was an improvement of times just when training with the eye tracker in the RE and not in the VE. This suggests that driving the EPW with the eye tracker in the VE was somehow easier than driving the real EPW with the same interface.

Although a difference can be noticed between the mean times obtained in “RET VT” (RE after training in the VE) and “RET T1” (RE with no previous training), results from “comparison 5” showed there was no significant difference (t(8)=1,404, p=0,099) between them. But, the mean time from “VET T1” was significantly greater (t(7)=2,025, p=0,041) than the time from “VET RT”, which suggests that the training in the RE with eye tracker helped participants from the RET group to perform better in the VE than the VET group.

3.2. Path Following Error During Tests in the VE and RE

The RMSE value from the error generated when participants tried to follow the reference path in the VE and RE (showed in Fig. 2) was registered per trial for each participant and used as the second quantitative parameter to compare the participants driving performance.

Path Following Error Using a Joystick

A mean of the RMSE values was calculated for the “VJ” and “RJ” groups per trial (see Appendix B) and presented in Fig. 23.

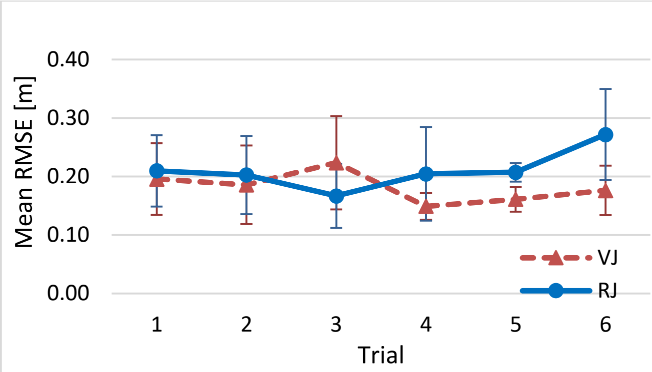

Fig. 23. Path following error for virtual and real training using a joystick.

The statistical tests indicate that the differences between the mean values per trial can all be assumed to have a normal distribution ($p>0.02$) and that there is enough evidence to say there were no significant differences in RMSE values between the trials from the VE and the RE using a joystick ($p>0.05$), except for trial five, where the null hypothesis was rejected ($t(7)=3.213$, $p=0.015$). This suggests that the path following error was similar between the VE and RE using a joystick (“Comparison 1”). A more detailed analysis based on the values shown in Fig. 24 was done for the other comparisons.

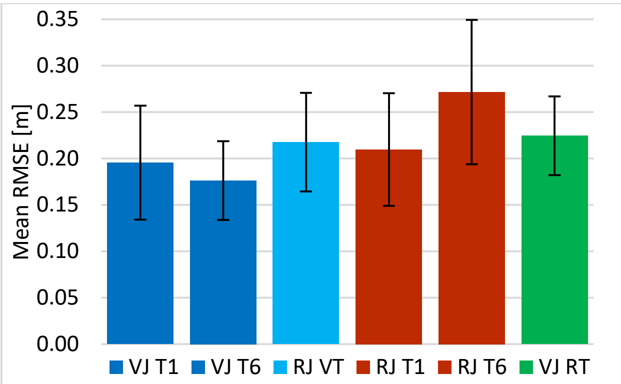

Fig. 24. Path following error of trials 1, 6 and 7 from the VE and RE using a joystick.

The statistical tests in Appendix B revealed that there was no improvement of the path following error during the training using a joystick since there was no significant difference ($p>0.05$) between none of the mean values per trials in the VE nor RE. Although an error increment in “RJ T6” can be evidenced, it is not significant ($t(3)=0.904$, $p=0.216$).

Path Following Error Using Eye Tracker

Fig. 25 shows the mean of the RMSE values per trial in VE and RE using eye tracker, which are reported with statistical tests in Appendix C.

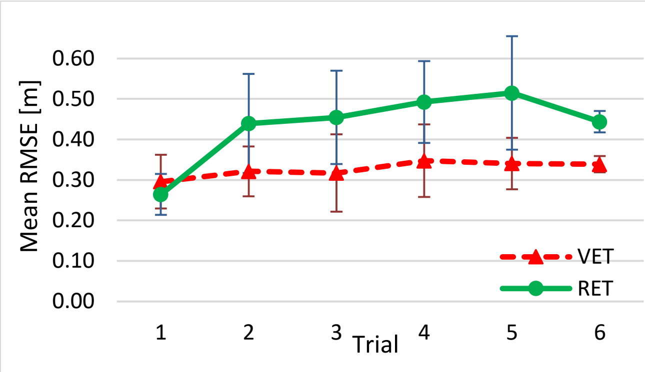

Fig. 25. Path following error for virtual and real training using eye tracker.

In a similar way to the case of the joystick interface, the differences between the RMSE mean values per trial using eye tracker can all be assumed to have a normal distribution ($p>0.02$). Also, there is enough evidence to say there were no significant differences in RMSE values between the trials from the VE and the RE ("comparison 1") using eye tracker ($p>0.05$), except for trial six, where the null hypothesis was rejected ($t(6)=5.491$, $p=0,002$). A deeper analysis was done, based on the values shown in Fig. 26.

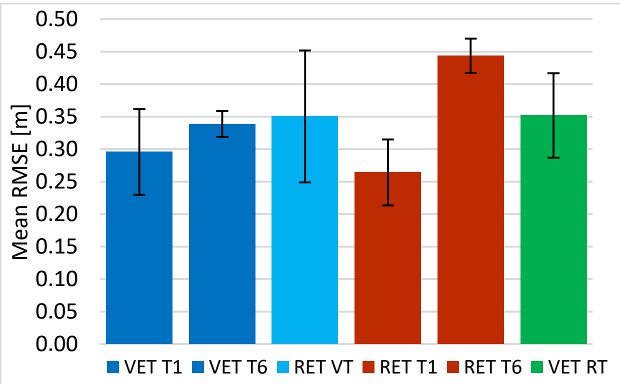

Fig. 26. Path following error of trials 1, 6 and 7 from the VE and RE using eye tracker.

The statistical tests indicated in "comparison 2" and "comparison 4" that there was no improvement of the path following error during the training in the VE ($p>0.05$), but revealed that the RMSE mean value in "RET T6" and "VET RT" was significantly greater ($p<0.05$) than the first trial "RET T1".

There was no significant difference ($p>0.05$) between the sixth and final trials ("comparison 3"), suggesting that the performance of the group of participants was maintained in the opposite environment.

Finally, there was no significant difference ($p>0.05$) of the path following error measurements between driving for the first time the EPW with no training, and driving the same EPW for the first time with previous training in the opposite environment ("comparison 5"), i.e. between "RET T1" and "RET VT", and between "VET T1" and "VET RT".

Some of these path-following error results with a joystick and eye tracker were unexpected, as some of them seemed to get worse during the training. However, they can be explained if the decrement of the elapsed times values is considered. This suggests that, in average, the participants prioritized more doing the given tasks faster each time than worrying about following close the reference path.

Also, it was noticed during the experiments that some participants were more careful following the reference path just at the first trials during the training; some others were more careful in the RE than in the VE. This could be due to the lack of consequences in the VE if an obstacle is hit. In that case, there is only a hit obstacles counter for monitoring purposes.

3.3. Total Number of Commands Made During Tests in the VE and RE

The total number of commands generated when participants tried to follow the reference path in the VE and RE were obtained and registered per trial for each participant and used as the third quantitative parameter to compare the participants driving performance.

Total Number of Commands Using a Joystick

The commands made by the participants using a joystick in the VE and RE ("VJ" and "RJ") are reported in Appendix D along with their correspondent statistical tests information.

The samples obtained from the joystick signals in the VE and RE were classified into effective commands (excluding no-command samples) and distributed in percentages in Appendix F, and presented in Fig. 27, where the initials stand for each command direction (forward, backward, right, or left) per group of participants.

In Fig. 27 it can be noticed that driving the EPW along the reference path, which has two curves to the left and two to the right, had more samples of right commands than left commands. This suggests that the real EPW has a tendency to go to the left and the participants compensated that by driving more to the right in order to go straight when they wanted to go forward, which can also be noticed in Fig. 16.

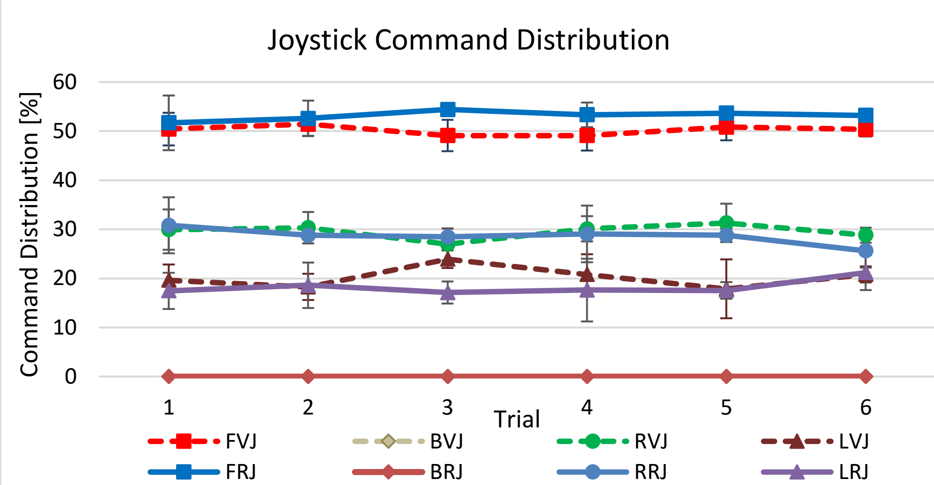

Fig. 27. Distribution of samples from effective commands using a joystick.

However, although the real EPW presented that behavior, the same was evidenced in the virtual EPW. In fact, the percentages of samples per command were very similar between the VE and RE. For a deeper analysis, the mean values of the total number of commands made in the VE and RE are plotted in Fig. 28 per trial.

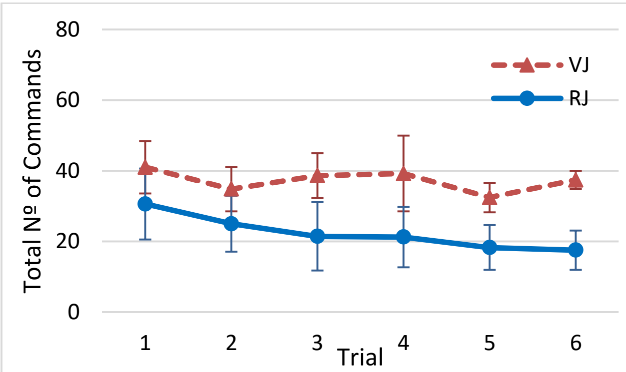

Fig. 28. Total number of commands made for virtual and real training using a joystick.

The differences between the “VJ” and “RJ” curves are considered to be normally distributed ($p>0.05$). Furthermore, “VJ” and “RJ” were significantly statistically different ($p<0.05$) when compared between trials, except for trial one and two where the null hypothesis was accepted ($p>0.05$). This “comparison 1” indicates that most of the training driving the EPW in the VE using a joystick required more commands than driving it in the RE.

Additionally, when comparing trial one with trial six (“comparison 2”), Fig. 29 also suggests no improvement, no difference ($p>0.05$), for the “VJ” group. Moreover, there is no significant difference ($p>0.05$) between the number of commands made in any trial (“comparison 3” and “comparison 4”) by the “VJ” group, nor with the first trial in the RE “RJ T1” (“comparison 5”).

That was not the case for the "RJ" group training in the RE, where the number of commands in "RJ T1" was significantly greater ($p<0.05$) than "RJ T6", suggesting a training improvement ("comparison 2") in the number of commands required.

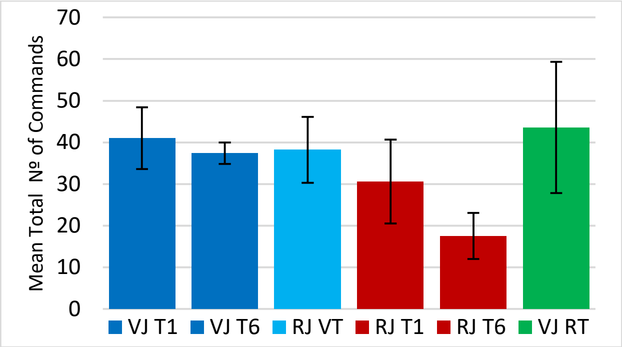

Fig. 29. Mean total number of commands made in trials 1, 6 and 7 from the VE and RE using a joystick.

Even though there was an improvement in the number of commands made with a joystick in the RE training, the first trial in the VE ("VJ RT") of the same group of participants had no significant difference ($p>0.05$) in total number of commands with "VJ T1" ("comparison 5") nor "RJ T1" ("comparison 4"). What is more, the number of commands in "VJ RT" was significantly greater ($t(3)=3.349$, $p=0.044$) than the one in "RJ T6" ("comparison 3").

The number of commands made by the "VJ" group using a joystick followed the same behavior as their path following error, with no change evidence, as there was with the elapsed time during the training. On the other hand, the number of commands made by the "RJ" group using a joystick followed a similar behavior as their elapsed times, clearly showing a relation between them.

Total Number of Commands Using Eye Tracker

The commands made by the participants using eye tracker in the VE and RE ("VET" and "RET") are reported in Appendix E along with their correspondent statistical tests information.

The samples obtained from the eye-tracker signals in the VE and RE were classified in commands and distributed in percentages in Appendix G and showed in Fig. 30, where the initials stand for each command direction (forward, backward, right, or left) per group of participants.

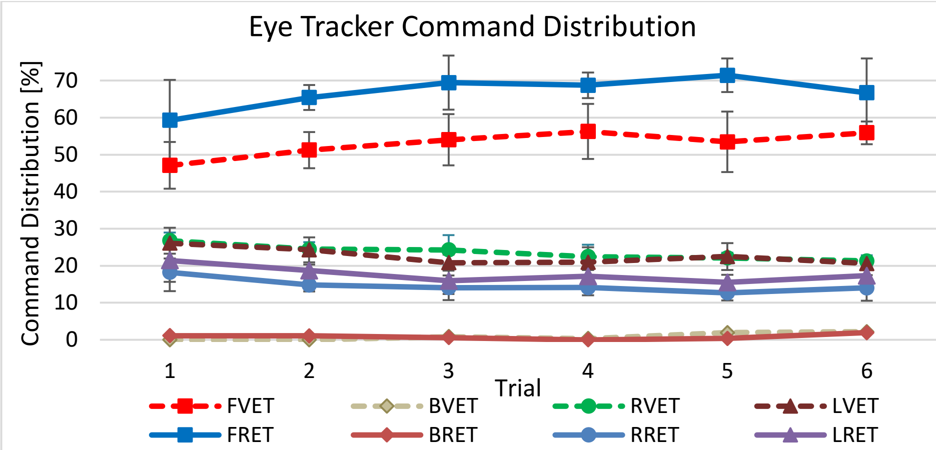

Fig. 30. Distribution of samples from effective commands using eye tracker.

In Fig. 30 it can be noticed that the percentages of samples per command presented a similar distribution between the VE and RE. It is worth mentioning that commands for turning right and left presented a similar distribution between the VE and RE as well, demonstrating that the control of the EPW rotation played an important role.

However, it seemed like there was a difference in the number of commands for going forward. Then, for a better understanding, the mean values of the total number of commands made in the VE and RE per trial are presented in Fig. 31.

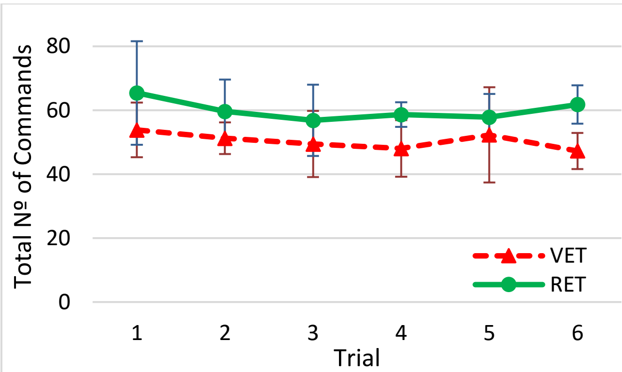

Fig. 31. Total number of commands made for virtual and real training using eye tracker.

The differences between the “VET” and “RET” curves are considered to be normally distributed ($p>0.05$). Moreover, “VET” and “RET” were not significantly statistically different ($p>0.05$) when the means of total number of commands were compared between trials (“comparison 1”), except for trial six where the null hypothesis was rejected ($t(6)=3.06$, $p=0.022$). This indicates that most of the training driving the EPW in the VE using eye tracker required the same amount of commands than driving it in the RE. Additionally, Fig. 32 shows there was an improvement in the commands made during the virtual training (“comparison 2”), since “VET T1” was significantly greater ($t(3)=2.858$, $p=0.032$) than “VET T6”.

On the other hand, there was no difference (t(3)=0.509, p=0.323) between “RET T1” and “RET T6” in the RE, suggesting that there was no training, since the “comparison 2” compares only the first and sixth trials. However, the first five trials in the RE were not significantly different than the trials in the VE, in which an improvement in commands could be demonstrated.

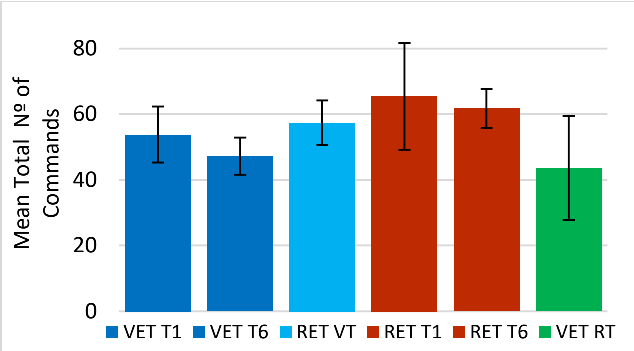

Fig. 32. Mean total number of commands made in trials 1, 6 and 7 from the VE and RE using eye tracker.

It can also be said from this figure that the commands in “RET VT” had no difference (p>0.05) with “VET T1” (“comparison 4”) nor “RET T1” (“comparison 5”), and when compared with “VET T6” (“comparison 3”) the null hypothesis was almost rejected (t(3)=3.108, p=0.053). This could indicate that the simulator required fewer commands than the RE when using eye tracker since there was an improvement during the training in the VE, which was also manifested in the reduction of variability in “RET VT” compared to “RET T1”.

“RET T6” and “RET T1” were significantly greater (p<0.05) than “VET RT” (“comparison 3” and “comparison 4”), indicating an improvement in the VE. Furthermore, “VET T1” was also significantly greater (t(8)=2.25, p=0.027) than “VET RT” (“comparison 5”), suggesting that the training in the RE helped the “RET” group get the task done in the VE with fewer commands than the “VET” group in their first trial.

3.4. Sense of Presence Questionnaire

Right after finishing the task in the VE, the participants answered the questions from the IPQ shown in Table 5. The items used in the survey split into distinct factors:

- General presence (G1), as the highest-loading item in the IPQ;
- Spatial presence (SP), emphasizing the importance of actions in the VE;
- Evaluations of the interaction or involvement (INV) as a manifestation of the attention component of the presence experience;
- Judgments of realness (REAL) (Schubert, Friedmann and Regenbrecht, 2001b) as a comparison between driving the virtual EPW and the real one.

All items are rated from 0 to 6; the greater the score, the greater the overall sense of presence using the Simcadrom. Questions related to items with an asterisk (SP2, INV3, and REAL1) have reversed wording; therefore, its score had to be reversed as well in order to work with means.

Table 5. Question for each IPQ item.

Item name	Questions
G1	In the computer-generated world, I had a sense of "being there".
SP1	Somehow, I felt that the virtual world surrounded me.
SP2*	I felt like I was just perceiving pictures.
SP3	I did not feel present in the virtual space.
SP4	I had a sense of acting in the virtual space, rather than operating something from outside.
SP5	I felt present in the virtual space.
INV1	How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?
INV2	I was not aware of my real environment.
INV3*	I still paid attention to the real environment.
INV4	I was completely captivated by the virtual world.
REAL1*	How real did the virtual world seem to you?
REAL2	How much did your experience in the virtual environment seem consistent with your real-world experience?
REAL3	How real did the virtual world seem to you?
REAL4	The virtual world seemed more realistic than the real world.

The obtained mean score with its corresponding standard deviation for each IPQ item are shown in Fig. 33 for the participants that used an HMD and a joystick, and in Fig. 35 for those who used a projector and eye tracker. Furthermore, the overall results per factors are presented in Fig. 34 for the group that used an HMD, and in Fig. 36 for those who used a projector.

Sense of Presence Using an HMD and a Joystick

Fig. 33 presents the highest dispersion and a mean of 3.5 in the item INV3, which is still considered an acceptable score. Also, most IPQ factors and most of their items show satisfactory results (mean above 4 in a 0 to 6 scale) when using an HMD and a joystick (see Fig. 34). In fact, the simulator provided a high sense of presence with those conditions, since the mean of the general sense of presence and spatial presence factors were above five points.

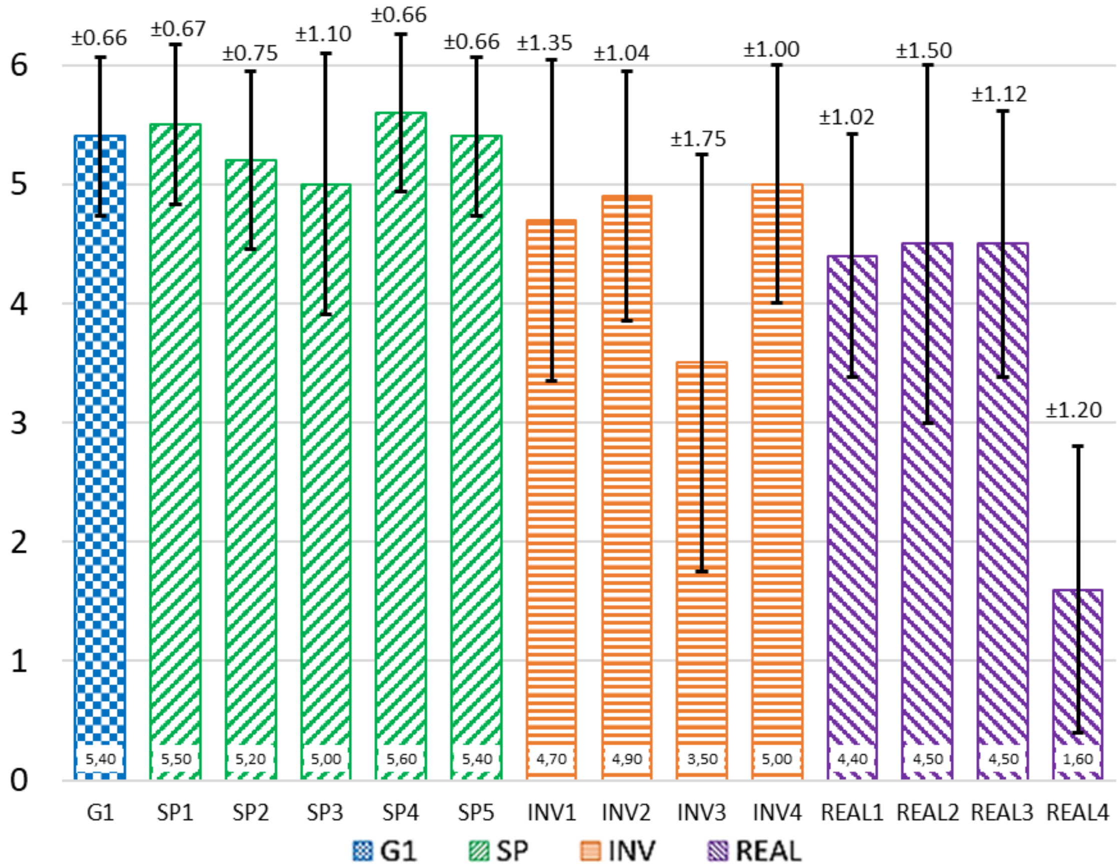

Fig. 33. Results for each IPQ item after driving the virtual EPW using an HMD and a joystick.

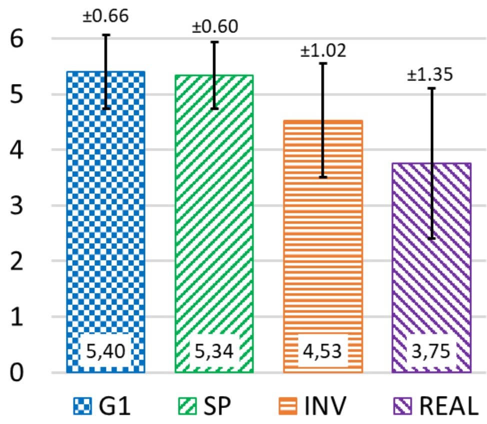

Fig. 34. Mean and standard deviation of each IPQ factor after driving the virtual EPW using an HMD and a joystick.

Sense of Presence Using a Projector and Eye Tracker

When using a projector and eye tracker, the simulation system did not provide a sense of presence score as high as when it used an HMD and a joystick, and also presented more variability (see Fig. 35). However, it still obtained satisfactory results since the mean values of its general sense of presence (G1) and spatial presence (SP) factors were higher than four, and the involvement (INV) and realness (REAL) factors above three points (see Fig. 36).

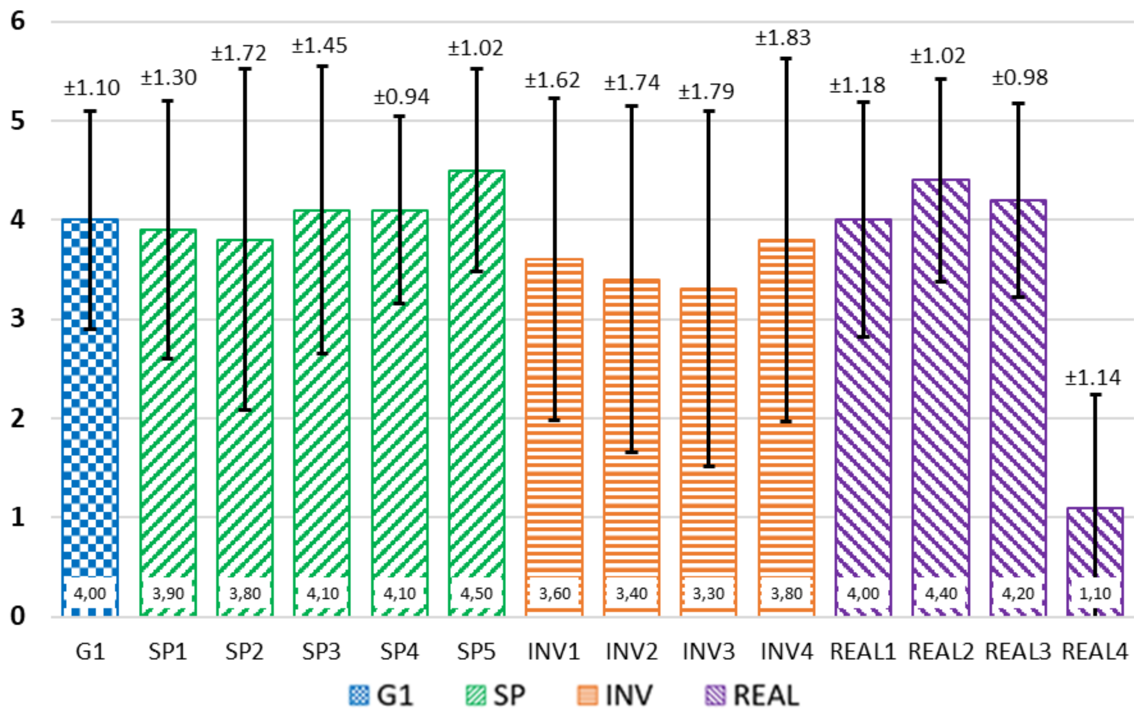

Fig. 35. Results for each IPQ item after driving the virtual EPW using a projector and eye tracker.

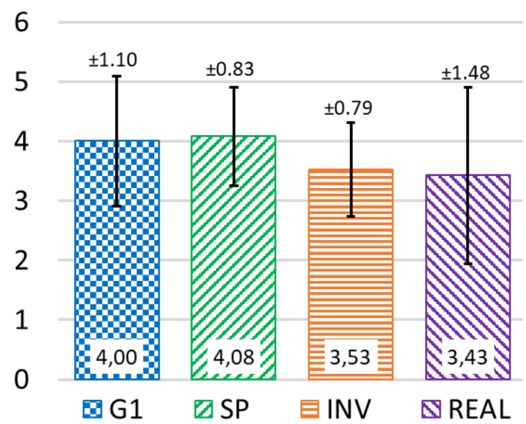

Fig. 36. Mean and standard deviation of each IPQ factor after driving the virtual EPW using a projector and eye tracker.

We believe that sitting in a real EPW while performing some tasks in the VE increases the sense of immersion associated with the INV factor, however, external noises inside our lab could have been enough distraction for the participants to make them maintain part of their attention in the real world. Perhaps, the inclusion of isolating headphones for the participants could lead to higher "INV" factor results.

Because of the state of currently available VR technology, it is not really expected to have high scores in the REAL4 items, since the VE is not intended to be more realistic than the RE. Yet, the overall scores for each IPQ factor and most of the IPQ items showed satisfactory results for both tests using an HMD with a joystick, and a projector with an eye tracker.

3.5. User Experience Questionnaire

After completing the IPQ, a user experience test of nine questions was performed, in which the participants had to specify their level of agreement or disagreement on a symmetric agree-disagree 5-point Likert scale. Results are shown in a diverging stacked bar chart, such as suggested by (Robbins and Heiberger, 2011) in Fig. 37 for the “VJ” and “RJ”, and in Fig. 38 for the “VET” and “RET” groups.

These user experience questions showed satisfactory results in users’ acceptance of the Simcadrom as an EPW simulator for training, since participants reported that the experience in the VE felt similar to the real one, which is consistent with the IPQ results; they felt that using previously the virtual EPW helped them complete the task in the RE; and most of them felt that completing the task in the VE was easy.

On the other hand, thanks to the counterbalancing experiment design, it could be noticed that completing the task in the RE felt easier using a joystick than using the eye-tracker interface. Driving the EPW with this interface is indeed more difficult, however, the participants who used it reported that using previously the virtual or real EPW helped them more to complete the task in the opposite environment than the group of people that used a joystick.

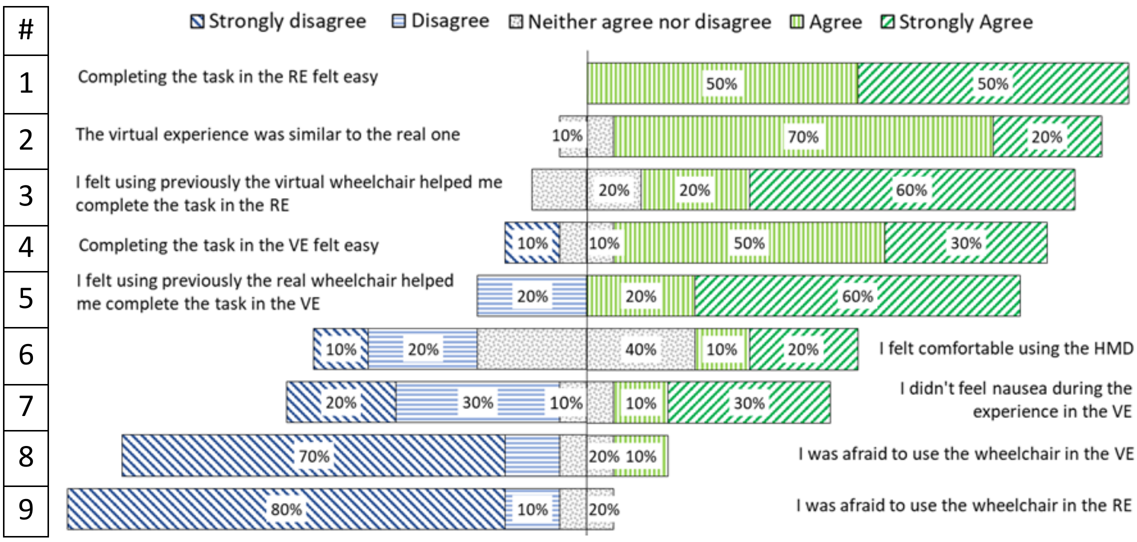

Fig. 37. Results of participants’ agreement-disagreement level for each user experience question for the groups that used a joystick in the VE and RE.

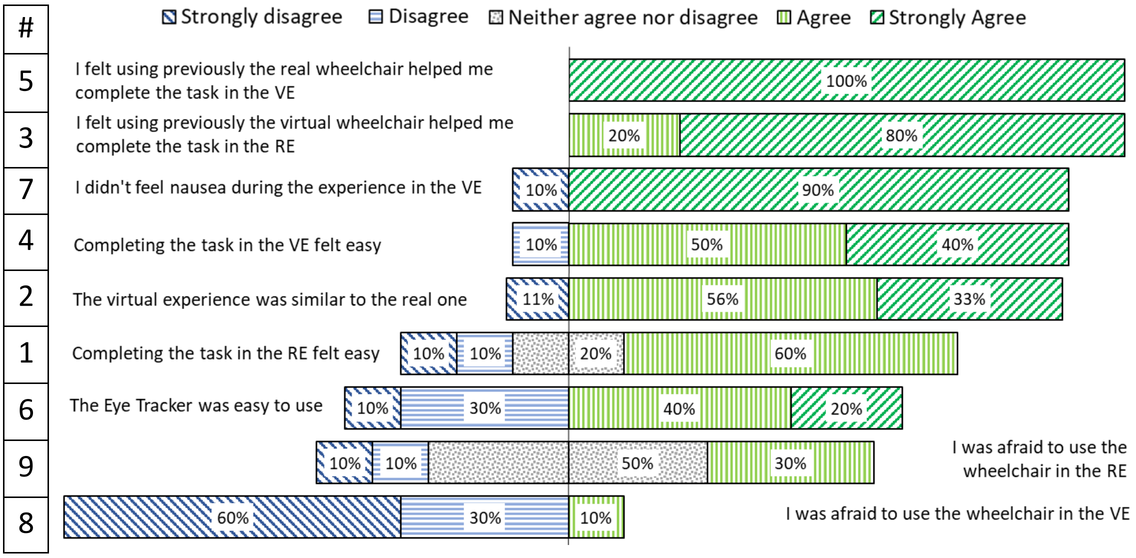

Fig. 38. Results of participants' agreement-disagreement level for each user experience question for the groups that used eye tracker in the VE and RE.

Although there were neutral opinions in the easiness of the use of the eye-tracker interface, none of the participants felt afraid of using the EPW in the VE. On the other hand, the RE some participants felt afraid driving the EPW using eye tracker, whereas those who used a joystick did not.

Half of the participants that used the HMD and a joystick indicated they felt nausea, while 90% of the participants that used a projector and eye tracker did not experience it. Considering also the neutral opinions about the comfort of the HMD, this suggests that the tests with HMD caused the participants to experience some dizziness symptoms.

We assume this last result is independent of the HMD VR technology, since similar conclusions were obtained in a previous work where the system had a better graphics card (NVIDIA GeForce GTX 1080 Ti) and an HMD with better characteristics (HTC Vive). As long as the users perceive the illusion of movement just with their eyes, with almost no participation of their vestibular system, is likely for them to feel some level of dizziness, and although not everyone felt dizzy, this could represent a big setback for long training sessions. Moreover, the dizziness associated with the use of the HMD also explains why not everyone felt comfortable using it.

4. Conclusions

This work presented the Simcadrom, a simulation system developed to command a virtual electric-powered wheelchair (EPW) for testing of input interfaces and driving training purposes. This simulator uses a standard proportional joystick as the main input interface and a virtual reality head-mounted display to make the experience with the system more immersive. An eye-tracker device was also evaluated as an alternative input interface together with a projector to display the virtual environment (VE).

Virtual Environment

The virtual environment of this simulator consisted of a preexisting virtual model of NTA's laboratory, which was successfully enhanced for simulation training system requirements focused on:

- Integration of virtual models of a joystick and an eye-tracker device as EPW input interfaces;
- A virtual model of an EPW considering kinematics and dynamic effects;
- Generation of high-immersive experience in users;
- Improvement of the realism of the laboratory's virtual model for comparison purposes with the real environment (RE);
- Measurement and register of users' performance in individual comma-separated values (.csv) files.

Real EPW

In order to compare participants' performance while using a real EPW with the virtual one in the Simcadrom, the real EPW was instrumented for:

- Manual or auxiliary driving mode;
- Driving the EPW using an onboard eye-tracker system as an alternative interface;
- Joystick and eye-tracker signals acquisition;
- Position and orientation acquisition;

Finally, a test protocol was proposed not just for comparing users' performance and driving experience between the VE and RE, but additionally, some hypotheses were established for a deeper evaluation of the developed system.

Evaluation

A sense of presence questionnaire (IPQ), a user experience questionnaire (UEQ), and some statistical tests for performance parameters like: total elapsed time, path following error, and total number of commands were implemented to evaluate this version of the Simcadrom as a reliable simulator capable of providing a VE very similar to reality, where users can learn and improve their skills by driving a virtual EPW while training in the simulator. Afterward, some comparisons were made to see if the skills learned could be transferred to the real EPW.

4.1. Hypothesis 1: Virtual Experience Similar to Reality

The UEQ showed satisfactory results in users' acceptance of the Simcadrom as an EPW simulator for training, since participants reported that none of them felt afraid of using the EPW in the VE, most of them felt that completing the task in the VE was easy, and the experience in the VE felt similar to the real one (see section 3.5). This is consistent with the IPQ results which revealed a very realistic representation in the VE of the real experience using the EPW for both tests using an HMD with a joystick, and a projector together with the eye tracker. Furthermore, these results show clearly that using an HMD increases the sense of presence, making the experience more immersive and realistic.

Simulator Using a Joystick and an HMD

Participants reported they did not felt afraid driving the EPW in the RE using a joystick, and the simulator satisfactorily represented the kinematics of the real EPW since statistical tests between each pair of trials from the training sessions in the VE and RE ("comparison 1") indicated there was no statistically significant difference ($p>0.05$) between the means of the total elapsed times (see section 3.1) and between most of the means of the path following errors (RMSE) (see section 3.2).

Also, most of the training driving the EPW in the VE using a joystick required more commands than driving it in the RE using another joystick. However, the percentages of samples per command were very similar between the VE and RE (see section 3.3). This suggests that the simulator represented well the behavior of the real EPW, but it seems like the joystick used in the VE still was more sensitive than the one in the real EPW, which indicates the simulation system did not get to represent the real EPW at an acceptable level concerning the total number of commands parameter. This will require to tune better the emulation done (see section 2.6) for the joystick in the real EPW with the more sensitive joystick in the EPW used for the VE.

Simulator Using Eye Tracker and a Projector

When the simulator used a projector and the eye tracker, the real EPW could not be exactly represented in regard to the time parameter, since three out of six means of elapsed times per pair of trials (1,3, and 4) were significantly different ($p<0.05$) between the RE and the VE (see section 3.1). However, the parameters selected for measuring performance are interrelated and no statistically significant difference ($p>0,05$) was found between the path following error in most of the trials from the VE and the RE ("comparison 1") (see section 3.2).

Although there were neutral opinions in the easiness of the use of the eye-tracker interface (see section 3.5), the percentages of samples per command presented a similar distribution between the VE and RE. Moreover, it was found no statistically significant difference ($p>0.05$) in the total number of commands with eye tracker between most of the trials ("comparison 1") during the training in the VE and the RE (see section 3.3), suggesting that the simulator represented the interface-wheelchair relation very well in the VE as it required the same amount of commands to complete the task in both of them.

Conclusion of Hypothesis 1

Considering the overall results, it is concluded that the Simcadrom simulates a real EPW close enough so it can be used for virtual training using a joystick and an HMD, or an eye tracker as an alternative interface and a projector.

4.2. Hypothesis 2: Improvement During a Training Session

Simulator Using a Joystick and an HMD

When the simulator was used during the training with a joystick and an HMD, participants improved their total elapsed times as indicated by the test results (see section 3.1) where their times in the first trial (no previous training) were significantly greater ($p<0.05$) than their times in the sixth trial (after training).

The total number of commands did not show any improvement during the virtual training with a joystick, nevertheless, a reduction in the number of commands was evidenced during the training in the RE (see section 3.3). Even though this could be explained by the fact that there was a significant difference in the total number of commands per trials between the VE and the RE, such as mentioned before, still no reduction tendency was observed in the tests for the VE.

Simulator Using Eye Tracker and a Projector

When the simulator was used with the eye tracker and a projector, there was no evidence of improvement of the total elapsed times during the training in the VE. On the other hand, the counterbalanced tests showed an improvement of time in the RE during the training (see section 3.1). Nevertheless, considering that the null hypothesis was rejected ($p<0,05$) for trials 1,3, and 4 between the VE and RE, this suggests that driving for the first time the EPW in the VE using eye tracker was somehow too easy in comparison with the first time in the RE, and there was not enough room for improvement.

This could be also supported by the fact that some participants reported they felt afraid driving the EPW in the RE using eye tracker; some others disagreed with "completing the task in the RE felt easy", and others disagreed with the eye tracker being easy to use. In contrast, they reported that completing the task in the VE felt easy (see section 3.5).

There was an improvement in the commands made during the virtual training using the eye tracker, but no improvement was obtained in the RE by comparing the first and sixth trial, suggesting that there was no training evidence in the test conditions, although the first five trials in the RE were not significantly different than the trials in the VE, in which an improvement in commands could be demonstrated (see section 3.3).

Conclusion of Hypothesis 2

Because of the way the test protocol was designed, for most participants, reducing their total elapsed times during the training was more important than reducing their path following error. Therefore, this ended up not being a good comparison parameter, at least not in these tests' conditions, since it did not show noticeable improvements of the path following error during the training. There was no significant difference ($p>0,05$) between none of the mean values per trials in the VE or RE using a joystick nor eye tracker (see section 3.2).

It is worth mentioning that six trials were not enough to notice improvements or even just changes for all comparison parameters in every condition. However, when the simulator used a joystick and an HMD, it proved to be useful for training participants and improved their total elapsed times completing the tasks. Also, participants reduced the total number of commands they made during the virtual training using the eye tracker. Consequently, people can learn and improve EPW driving skills by doing a training session in the Simcadrom.

Still, half of the participants that used the HMD indicated they felt nausea, whereas 90% of the participants that used a projector did not experience it. This suggests that the tests with HMD caused the participants to experience some dizziness symptoms. Although not everyone that used the HMD felt dizzy, this could represent a big setback for long training sessions.

4.3. Hypothesis 3: Skills Transferred to the Opposite Environment

Simulator using a Joystick and an HMD

When the simulator was used during the training with a joystick and an HMD, the mean elapsed time obtained after the virtual training seemed not to be maintained in the RE, however, this last obtained time in the RE (“RJ VT”) was significantly smaller than the values from the first trial in the VE (“VJ T1”) (see section 3.1), suggesting that the learning process continued even in the RE. On the other hand, the participants' performance measured in time in the RE was maintained when using the virtual EPW after the training in the RE.

Still, the measurements from trial seven, in contrast with the measurements from the first trial in the opposite environment, had no significant difference. Additionally, the same was noticed for the total number of commands and for the path following error, as it is strongly related to the time parameter. Thus, there is not enough evidence to see a significant progress by reducing neither the elapsed times, the path following error (see section 3.2), nor the total number of commands made with the joystick (see section 3.3) after a training session in the VE or RE.

Simulator Using Eye Tracker and a Projector

For the time parameter, the performance was not maintained the same when a group of participants trained with the eye tracker in one environment and then tried the other one. The mean time in the last trial after training in the VE (“RET VT”) was significantly greater than the mean time in the first trial in the VE of the same group before training (“VET T1”). However, in the opposite case, the first elapsed time obtained before training in the RE (“RET T1”) was in average greater than the one from the last trial after training (“VET RT”).

This confirmed the same behavior seen before, during the training, as there was an evident improvement of times just when training with the eye tracker in the RE and not in the VE (see section 3.1). This suggests that driving the EPW with the eye tracker in the VE was somehow easier than driving the real EPW with the same interface, also suggesting that the learning process in the RE continued even in the VE.

Furthermore, there was no difference noticed between the mean times obtained in the RE after training in the VE and the times obtained in the RE with no previous training. However, the benefits of training were noticeable in the opposite order. The mean time from the first trial in the VE with no previous training was significantly greater than the time from the first trial in the VE after training, indicating that the training in the RE with eye tracker helped participants to perform better in the VE than those without training.

Since it seemed like, in average, the participants in the proposed test protocol prioritized more doing the given tasks faster each time than worrying about following close the reference path, subsequently, the path-following error presented unexpected results indicating no improvement of this parameter during or after the training in the VE nor the RE. Nevertheless, there was no significant difference between the sixth and final trials, suggesting that the performance of the group of participants was at least maintained in the opposite environment (see section 3.2).

There was no difference between the number of commands made in final trial after training in the VE (“RET VT”) and the previous trials during the training in the VE, nor even with the first trial in the RE (“RET T1”) of the other group. However, there was evidence of a reduction in the number of commands during the training in the VE, and the variability in “RET VT” was reduced in comparison with “RET T1” (see section 3.3).

This suggests that the simulator required fewer commands than the RE when using eye tracker, yet there was at least a sign of transfer of skills from the VE to the RE, considering the mean and variance reduction of the number of commands in “RET VT” compared to “RET T1”. This was also confirmed by the results in the opposite environment where the number of commands during the training in the RE were significantly greater than the final trial in the VE (“VET RT”), indicating an improvement in the VE after training in the RE. Furthermore, the first trial in the VE without training (“VET T1”) was also significantly greater than “VET RT”, suggesting that the training in the RE helped the participants get the task done in the VE with fewer commands than the group with no previous training.

Conclusion of Hypothesis 3

There were small signs of skills being transferred after the virtual training with a joystick. It was also noticed that completing the task in the RE felt easier by the participants than using the eye-tracker interface.

Driving the EPW with the eye tracker is indeed more difficult, however, the participants who used it reported using previously the virtual or real EPW helped them more to complete the task in the opposite environment than the group of people that used a joystick.

Those training benefits were also confirmed above by the elapsed time and number of commands parameter for eye tracker, therefore, the skills learned in the training session in the Simcadrom can be transferred to the real EPW, yet some improvements in the test protocol are required to evidence that more for the joystick interface. Furthermore, it was mentioned before that although six trials can be considered an acceptable parameter for the test protocol, it may not be enough trials to see improvements in all parameters, and even if they are, they may not be enough to notice a skill transfer to the opposite environment regarding any parameter.

5. Contributions and Future Works

During this master's program, various works from our laboratory were properly integrated into this research, creating added value to the whole project. Additionally, thanks to collaboration and teamwork between colleague researchers, the following contributions were done:

5.1. Contributions

The work done in this master explored the development of a simulation system to command a virtual EPW for testing of input interfaces and driving training purposes. The system was evaluated in comparison with the driving experience and performance in a real EPW.

The development of this simulator system properly integrated and considered previous and future research projects in its design, to become a ready-to-use research platform that has a lot of potential since it can be a useful tool for prescribing the appropriate EPW or input interface for people with motor disabilities.

A major contribution of this work is that the simulator could have any VE, but it was of the author's interest to evaluate the system with the least disturbing variables involved. Therefore, a virtual model of the NTA's laboratory was enhanced and used for comparison purposes with the actual real environment.

Also, for the best of the author's knowledge, it seems like most of the related works do not have a test protocol that uses as many quantitative measurement parameters for comparison purposes with the real EPW, perhaps to avoid the complexity associated with instrumenting an EPW.

This work also contributes with a novel approach when comparing input interfaces by proposing a command classification method to get the number of movement commands made with a joystick so it could be somehow compared to the number of commands made with an alternative input interface like the eye tracker, and it will be also useful for comparing with other interfaces in future research.

5.2. Publications

Conference Proceedings

- **Hernandez-Ossa, K. A.,** Montenegro-Couto, E. H., Borges-Longo, B., Frizera, A., & Bastos-Filho, T. F. (2018). Virtual Reality Simulator for Electric Powered Wheelchairs using a Joystick. In *XXVI Congresso Brasileiro de Engenharia Biomédica*. Buzios, Brazil.

- Romero-Laiseca, M. A., Morelato, L., **Hernandez-Ossa, K. A.**, Frizera, A., & Teodiano F. Bastos-Filho. (2018). Design and Development of Hardware and Software to Command a Motorized Exercise Static Bike. In XXVI Congresso Brasileiro de Engenharia Biomédica. Buzios, Brazil.
- Montenegro-Couto, E. H., **Hernandez-Ossa, K. A.**, Bissoli, A. L. C., Sime, M., & Bastos-Filho, T. F. (2018). Towards an assistive interface to command robotic wheelchairs and interact with environment through eye gaze. In Anais do V Congresso Brasileiro de Eletromiografia e Cinesiologia e X Simpósio de Engenharia Biomédica. Uberlândia, Minas Gerais: Even3. https://doi.org/10.29327/cobecseb.78867
- **Hernandez-Ossa, K. A.**, Longo, B., Montenegro-Couto, E., Romero-Laiseca, M. A., Frizera-Neto, A., & Bastos-Filho, T. (2017). Development and pilot test of a virtual reality system for electric powered wheelchair simulation. In 2017 IEEE International Conference on Systems, Man, and Cybernetics (SMC) (pp. 2355–2360). Banff, Canada: IEEE. Retrieved from http://ieeexplore.ieee.org/document/8122974/
- **Hernandez-Ossa, K. A.,** Longo, B., Montenegro-Couto, E., Romero-Laiseca, M. A., Frizera-Neto, A., & Bastos-Filho, T. (2017). Desenvolvimento de um sistema de realidade virtual para treinamento de uso de cadeira de rodas motorizada k. In XIII Simpósio Brasileiro de Automação Inteligente (pp. 680–685). Porto Alegre, Brazil.
- Montenegro-Couto, E. H., **Hernandez-Ossa, K. A.**, Moya, V., Floriano, A., Slawiñski, E., & Bastos-Filho, T. (2017). Implementação de controlador PD-like e de impedância para uma cadeira de rodas teleoperada com atraso de tempo e. In XIII Simpósio Brasileiro de Automação Inteligente (pp. 1508–1513). Porto Alegre, Brazil.

Awards

Recipient of the Emerging Leaders in the Americas Program (ELAP) scholarship by the Canadian Bureau for International Education (CBIE) to do an internship as a visiting graduate student at the Faculty of Rehabilitation Medicine in the University of Alberta, CA, 2018. Supervisors: Martin Ferguson-Pell, Ph.D., C.Phys. & Kim Adams, Ph.D., PEng.

Local Television News

- Bissoli, A. L. C., Coelho, Y.L., Sime, M., **Hernandez-Ossa, K. A.**, & Bastos-Filho, T. F. Projeto de pesquisador da UFES ganha prêmio internacional. Bom dia ES - Globo. Vitória - ES, Brazil, August 10th 2016. http://g1.globo.com/espirito-santo/bom-dia-es/videos/t/edicoes/v/projeto-de-pesquisador-da-ufes-ganha-premio-internacional/5224188/
- **Hernandez-Ossa, K. A.**, Montenegro-Couto, E. H., Bissoli, A. L. C., Ramirez, A., Fizera, A., & Bastos-Filho, T. F. Professores e alunos da UFES ganham prêmio internacional por criação de equipamentos. G1 - Globo, Vitória - ES, Brazil, August 30th 2017. https://g1.globo.com/espirito-santo/educacao/noticia/projetos-de-professores-e-alunos-da-ufes-ganham-premio-de-incentivo-do-google.ghtml

- **Hernandez-Ossa, K. A.**, Montenegro-Couto, E. H., Bissoli, A. L. C., Ramirez, A., Fizera, A., & Bastos-Filho, T. F. UFES realiza projeto para mudar situação de deficientes físicos. Folha Vitória, Vitória – ES, Brazil, August 30th 2017. http://www.folhavitoria.com.br/videos/2017/08/150413790391955736.html

5.3. Future Works

The simulator does not necessarily need to use a virtual reality headset to offer an acceptable immersion experience. Therefore, more tests are in progress, where the Simulator Sickness Questionnaire (Kennedy *et al.*, 1993) and IPQ are being used for comparing the nausea symptoms and immersion effects from different display technologies like an HMD, LCD, and a projector.

Moreover, in this work it is assumed that sitting in a real EPW while performing some tasks in the VE increases the involvement factor (INV), however, external noises inside our lab could have been enough distraction for the participants to make them maintain part of their attention in the real world. More tests are being done including headphones. Besides, virtual sounds simulating the real EPW sounds are being improved. Perhaps, also including noise-canceling or isolating headphones for the participants could lead to higher “INV” factor results.

It was noticed that six trials were not enough to notice improvements or even just changes for all comparison parameters in every condition. Also, it is worth mentioning that the number of trials to see improvements during the training may not be the same for noticing skills transfer to the opposite environment. Then, future works will explore in a modified test protocol, the inclusion of more trials and/or more time between them.

The path following error was the parameter that less provided information in the tests conducted. Modifying the protocol, so that it can have more importance for the participants is an option as some improvement and a stronger relation with other parameters can be noticed.

Driving the EPW in the VE using eye tracker was somehow too easy in comparison with the real EPW, leaving not enough room for improvement during the training. Considering that driving the real EPW with eye tracker is not as easy as doing so with a joystick, perhaps by enhancing more the way the real EPW is driven with the eye-tracker interface can allow more consistent results between the VE and RE, and between both input interfaces.

Analyzing collisions during the training can also reveal important information regarding improvement of driving skills in future research.

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Appendices

Appendix A. Elapsed times for virtual and real training using the eye tracker.

Table 6. Elapsed times for virtual training using the eye tracker.

Participant	VET elapsed times [s] per trial during the training						RET VT [s]
	1	2	3	4	5	6	7
11	178,83	253,35	158,70	190,19	155,39	144,37	286,26
12	135,92	147,57	137,27	129,68	131,39	161,84	212,19
13	259,59	180,30	233,96	205,20	274,86	262,03	372,54
14	190,32	187,21	143,06	148,71	136,62	145,16	200,09
15	-	139,85	-	123,13	118,71	-	253,63
Mean	**191,17**	**181,66**	**168,25**	**159,38**	**163,39**	**178,35**	**264,94**
SD	**44,40**	**40,21**	**38,74**	**32,74**	**56,97**	**48,81**	**61,88**

Table 7. Elapsed times for real training using the eye tracker.

Participant	RET elapsed times [s] per trial during the training						VET RT [s]
	1	2	3	4	5	6	7
16	399,74	242,89	267,16	199,84	272,68	193,33	129,82
17	396,98	218,06	196,41	241,51	223,06	259,70	174,67
18	296,55	226,83	238,26	183,86	246,33	225,16	126,62
19	217,89	230,09	224,05	228,10	200,36	236,11	142,83
20	336,10	236,30	254,05	236,94	201,11	286,44	132,64
Mean	**329,45**	**230,83**	**235,99**	**218,05**	**228,71**	**240,15**	**141,32**
SD	**67,93**	**8,43**	**24,54**	**22,40**	**27,72**	**31,49**	**17,54**

Table 8. Elapsed time statistical test for virtual and real training with eye tracker (Comparison 1).

Trial	1	2	3	4	5	6
RET-VET [s]	220,91 261,06 36,96 27,57 -	-10,46 70,49 46,53 42,88 96,45	108,46 59,14 4,3 80,99 -	9,65 111,83 -21,34 79,39 113,81	117,29 91,67 -28,53 63,74 82,4	48,96 97,86 -36,87 90,95 -
SW	0,822	0,960	0,905	0,868	0,860	0,861
Critical Wα	0,806	0,806	0,806	0,806	0,806	0,806
p-value	**0,148**	**0,808**	**0,436**	**0,259**	**0,228**	**0,264**
F	2,194	22,768	2,657	2,136	4,224	2,563
Critical F	9,117	6,388	6,591	6,388	6,388	6,591
Num df	4	4	3	4	4	3
Den df	3	4	4	4	4	4
p-value	**0,272**	**0,005**	**0,184**	**0,240**	**0,096**	**0,193**
t	3,100	2,394	2,814	2,958	2,062	2,025
Critical t	2,365	2,776	2,365	2,306	2,306	2,365
df	7	4	7	8	8	7
p-value	**0,017**	**0,075**	**0,026**	**0,018**	**0,073**	**0,083**

Table 9. T-test of mean elapsed time. Comparison 2, 3, 4 and 5 from the VE and RE using eye tracker.

comparison #	**Between**	**Mean [s]**	**Variance [s^2]**	**t-test type**	**t**	**Critical t**	**df**	**p-value**
2	VET T1 VET T6	191,165 178,35	2628,952 3177,046	Paired one-tailed	0,779	2,353	3	0,246
3	RET VT VET T6	267,77 178,35	6329,451 3177,046	Paired two-tailed	4,028	3,182	3	0,028
4	RET VT VET T1	267,77 191,165	6329,451 2628,952	Paired one-tailed	3,233	2,353	3	0,024
5	RET T1 RET VT	329,452 264,942	5768,313 4787,076	Unpaired one-tailed equal variances	1,404	1,860	8	0,099
2	RET T1 RET T6	329,452 240,148	5768,313 1239,525	Paired one-tailed	2,326	2,132	4	0,040
3	RET T6 VET RT	240,148 141,316	1239,525 384,5462	Paired two-tailed	6,596	2,776	4	0,003
4	RET T1 VET RT	329,452 141,316	5768,313 384,5462	Paired one-tailed	5,777	2,132	4	0,002
5	VET T1 VET RT	191,165 141,316	2628,952 384,5462	Unpaired one-tailed equal variances	2,025	1,895	7	0,041

Appendix B. Path following error in virtual and real training using a joystick.

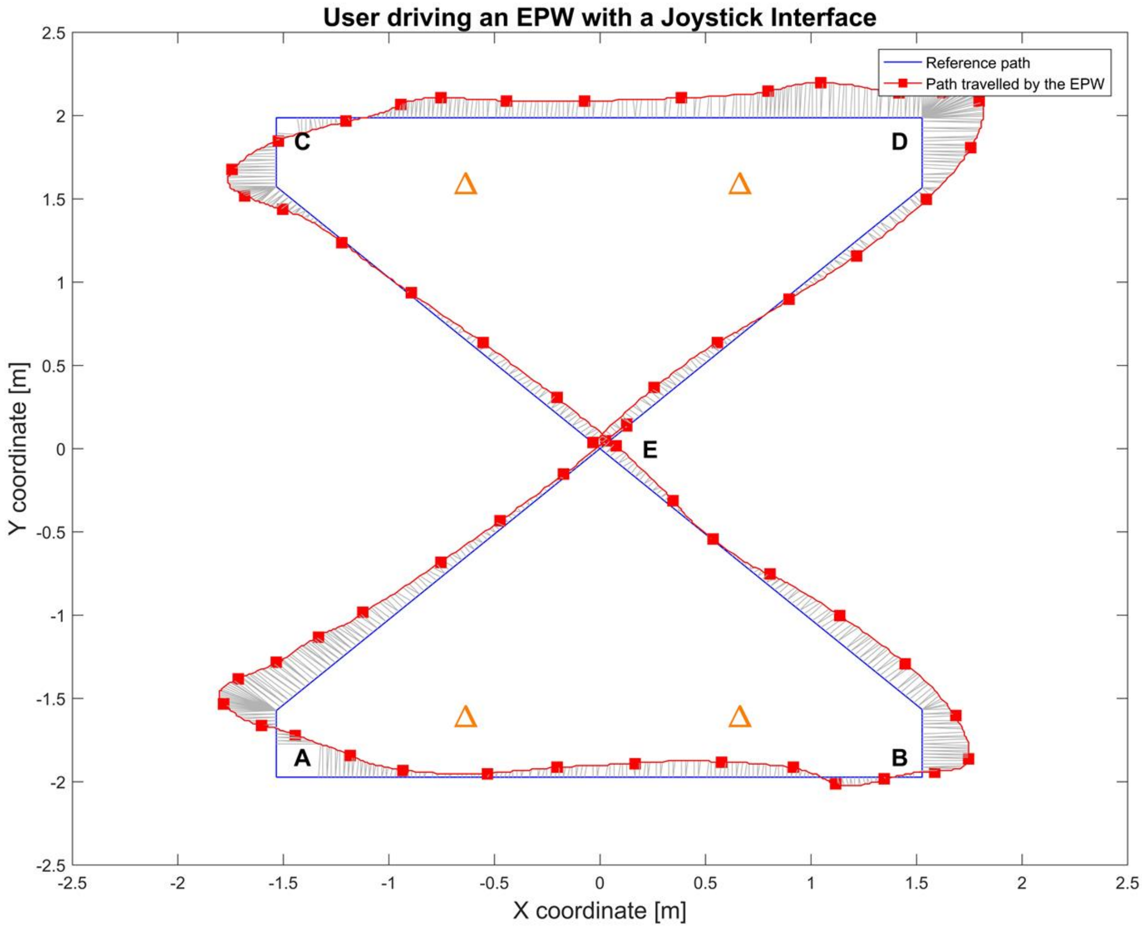

Fig. 39. The path followed by the virtual EPW using a joystick.

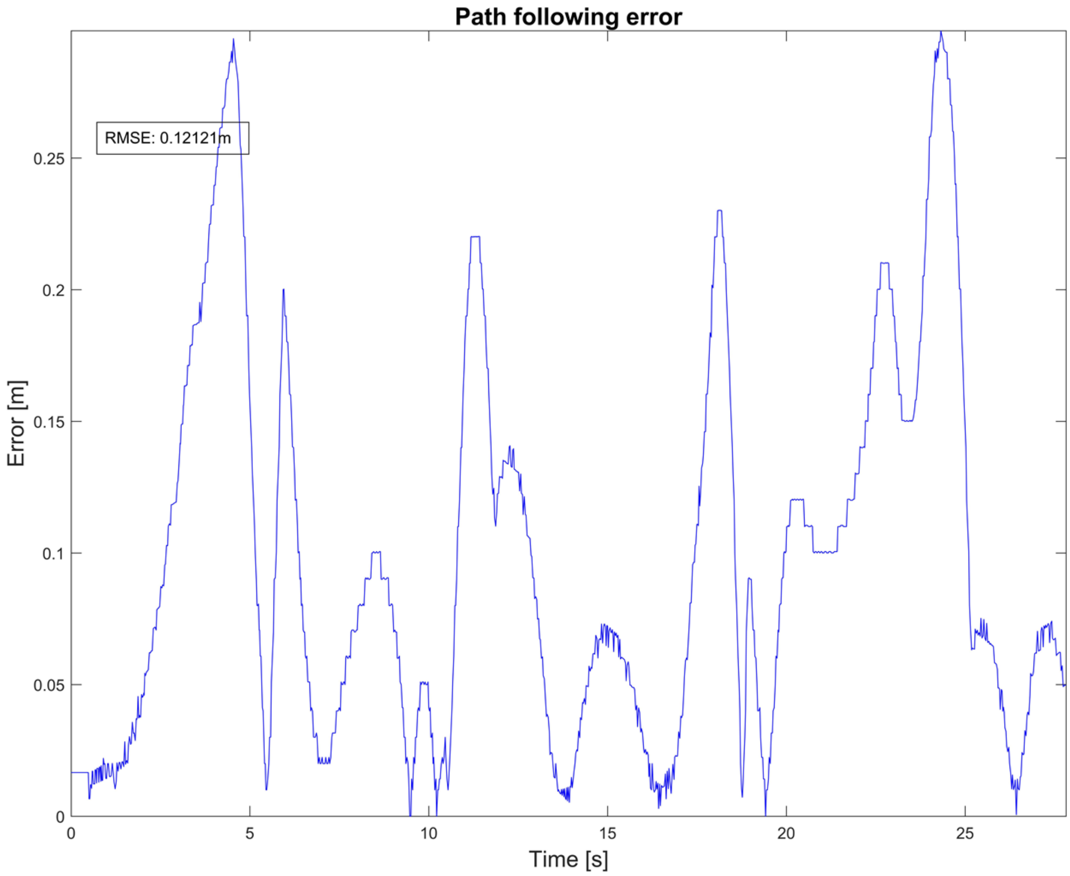

Fig. 40. Path following error from the virtual EPW using a joystick.

Table 10. Path following error for virtual training using a joystick.

Participant	VJ RMSE [m] per trial during the training						RJ VT [m]
	1	2	3	4	5	6	7
1	0,2338	0,1816	0,2030	0,1262	0,1627	0,1333	0,2489
2	0,1456	0,1214	0,1975	0,1695	0,1650	0,2003	0,1951
3	0,2352	0,1705	0,1584	0,1185	0,1212	0,1328	0,1339
4	0,2617	0,3128	0,3798	0,1543	0,1831	0,2444	0,2920
5	0,1011	0,1406	0,1783	0,1757	0,1724	0,1690	0,2175
Mean	**0,1955**	**0,1854**	**0,2234**	**0,1488**	**0,1609**	**0,1760**	**0,2175**
SD	**0,0613**	**0,0672**	**0,0798**	**0,0228**	**0,0211**	**0,0424**	**0,0530**

Table 11. Path following error for real training using a joystick.

Participant	RJ RMSE [m] per trial during the training						VJ RT [m]
	1	2	3	4	5	6	7
6	0,1587	0,1477	0,1215	0,1326	0,1869	0,2090	0,2321
7	0,2150	0,1502	0,1244	0,1401	-	-	0,1760
8	0,1766	0,2619	0,2709	0,3504	0,2312	0,3992	0,1992
9	0,3252	0,3034	0,1670	0,2257	0,2077	0,2085	0,3012
10	0,1720	0,1487	0,1499	0,1727	0,2027	0,2697	0,2138
Mean	**0,2095**	**0,2024**	**0,1667**	**0,2043**	**0,2071**	**0,2716**	**0,2244**
SD	**0,0608**	**0,0668**	**0,0547**	**0,0801**	**0,0159**	**0,0778**	**0,0425**

Table 12. Path following error statistical test for virtual and real training with a joystick (Comparison 1).

Trial	1	2	3	4	5	6
RJ-VJ [m]	-0,075	-0,034	-0,082	0,006	0,024	0,076
	0,069	0,029	-0,073	-0,029	-0,165	-0,200
	-0,059	0,091	0,112	0,232	0,110	0,266
	0,064	-0,009	-0,011	0,071	0,025	-0,036
	0,071	0,008	-0,028	-0,003	0,030	0,101
SW	0,745	0,947	0,854	0,827	0,822	0,984
Critical Wα	0,715	0,806	0,806	0,806	0,806	0,806
p-value	**0,027**	**0,713**	**0,207**	**0,132**	**0,120**	**0,953**
F	1,018	1,010	2,125	12,285	1,648	3,581
Critical F	6,388	6,388	6,388	6,388	9,117	6,591
N df	4	4	4	4	4	3
D df	4	4	4	4	3	4
p-value	**0,493**	**0,496**	**0,242**	**0,016**	**0,355**	**0,125**
t	0,325	0,359	1,172	1,332	3,213	2,070
Critical t	2,306	2,306	2,306	2,571	2,365	2,365
df	8	8	8	5	7	7
p-value	**0,754**	**0,729**	**0,275**	**0,240**	**0,015**	**0,077**

Table 13. T-test of path following errors. Comparison 2, 3, 4 and 5 from the VE and RE using a joystick.

Comparison #	**Between**	**Mean [m]**	**Variance [m²]**	**t-test type**	**t**	**Critical t**	**df**	**p-value**
2	VJ T1	0,195	0,005	Paired one-tailed	0,536	2,132	4	0,310
	VJ T6	0,176	0,002					
3	RJ VT	0,217	0,004	Paired two-tailed	1,917	2,776	4	0,128
	VJ T6	0,176	0,002					
4	RJ VT	0,217	0,004	Paired one-tailed	0,622	2,132	4	0,284
	VJ T1	0,195	0,005					
5	RJ VT	0,217	0,004	Unpaired one-tailed equal variances	0,198	1,860	8	0,424
	RJ T1	0,210	0,005					
2	RJ T6	0,272	0,008	Paired one-tailed	0,904	2,353	3	0,216
	RJ T1	0,208	0,006					
3	RJ T6	0,272	0,008	Paired two-tailed	0,558	3,182	3	0,616
	VJ RT	0,237	0,002					
4	VJ RT	0,224	0,002	Paired one-tailed	0,719	2,132	4	0,256
	RJ T1	0,210	0,005					
5	VJ RT	0,224	0,002	Unpaired one-tailed equal variances	0,776	1,860	8	0,230
	VJ T1	0,195	0,005					

Appendix C. Path following error in virtual and real training using eye tracker.

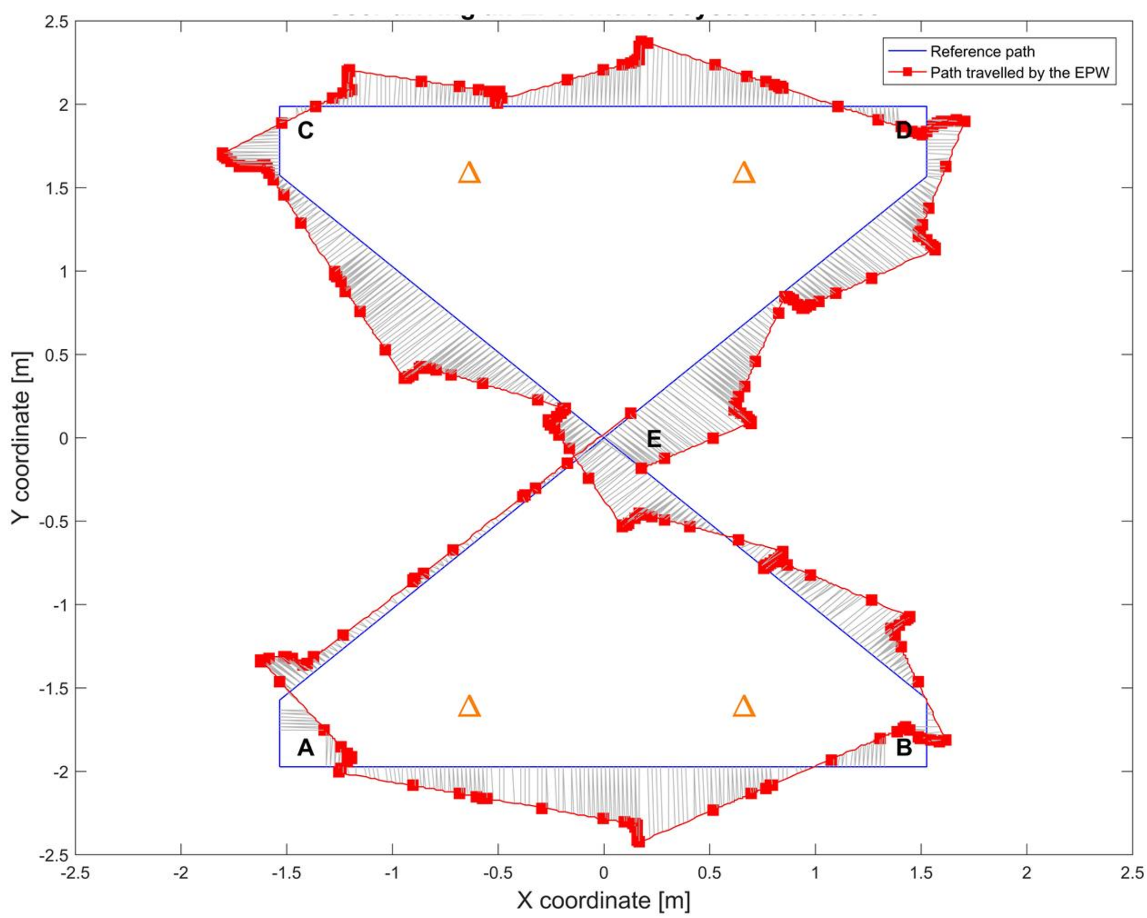

Fig. 41. The path followed by the virtual EPW using eye tracker.

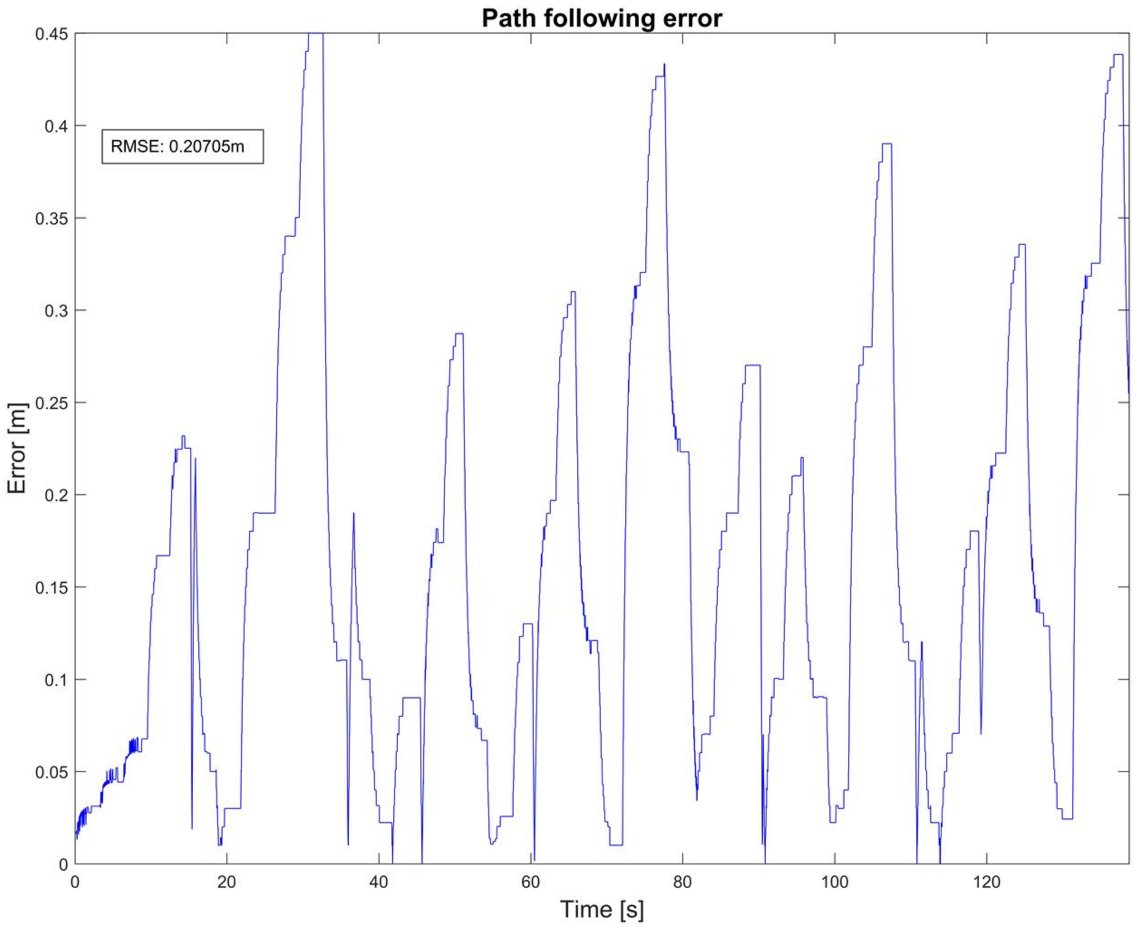

Fig. 42. Path following error from the virtual EPW using eye tracker.

Table 14. Path following error for virtual training using eye tracker.

Participant	VET RMSE [m] per trial during the training						RET VT [m]
	1	2	3	4	5	6	7
11	0,30	0,38	0,34	0,40	0,33	0,33	0,2804
12	0,21	0,25	0,34	0,28	0,32	0,33	0,3193
13	0,37	0,35	0,46	0,50	0,44	0,37	0,5243
14	0,24	0,24	0,17	0,26	0,27	0,32	0,3947
15	0,36	0,38	0,27	0,30	-	-	0,2335
Mean	**0,2957**	**0,3212**	**0,3170**	**0,3474**	**0,3406**	**0,3388**	**0,3504**
SD	**0,0662**	**0,0616**	**0,0954**	**0,0895**	**0,0637**	**0,0199**	**0,1017**

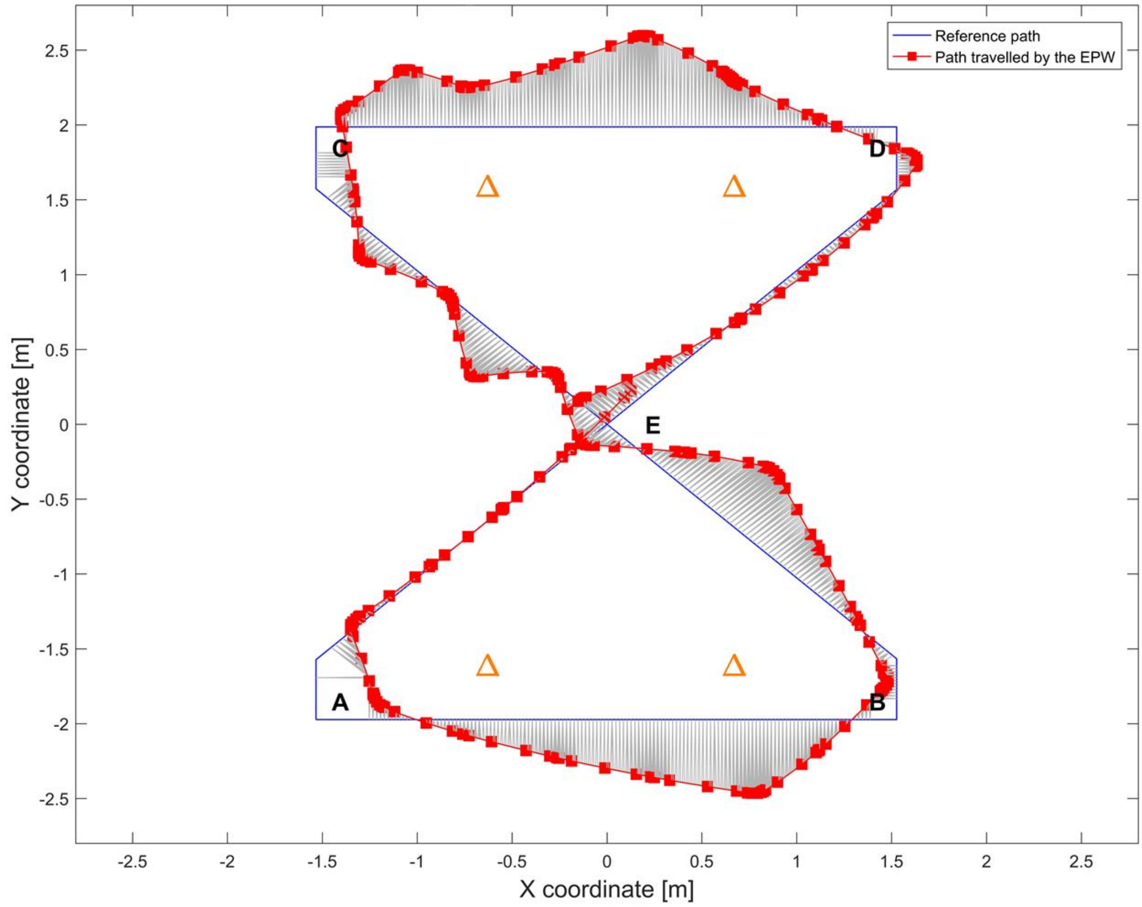

Fig. 43. The path followed by the real EPW using eye tracker.

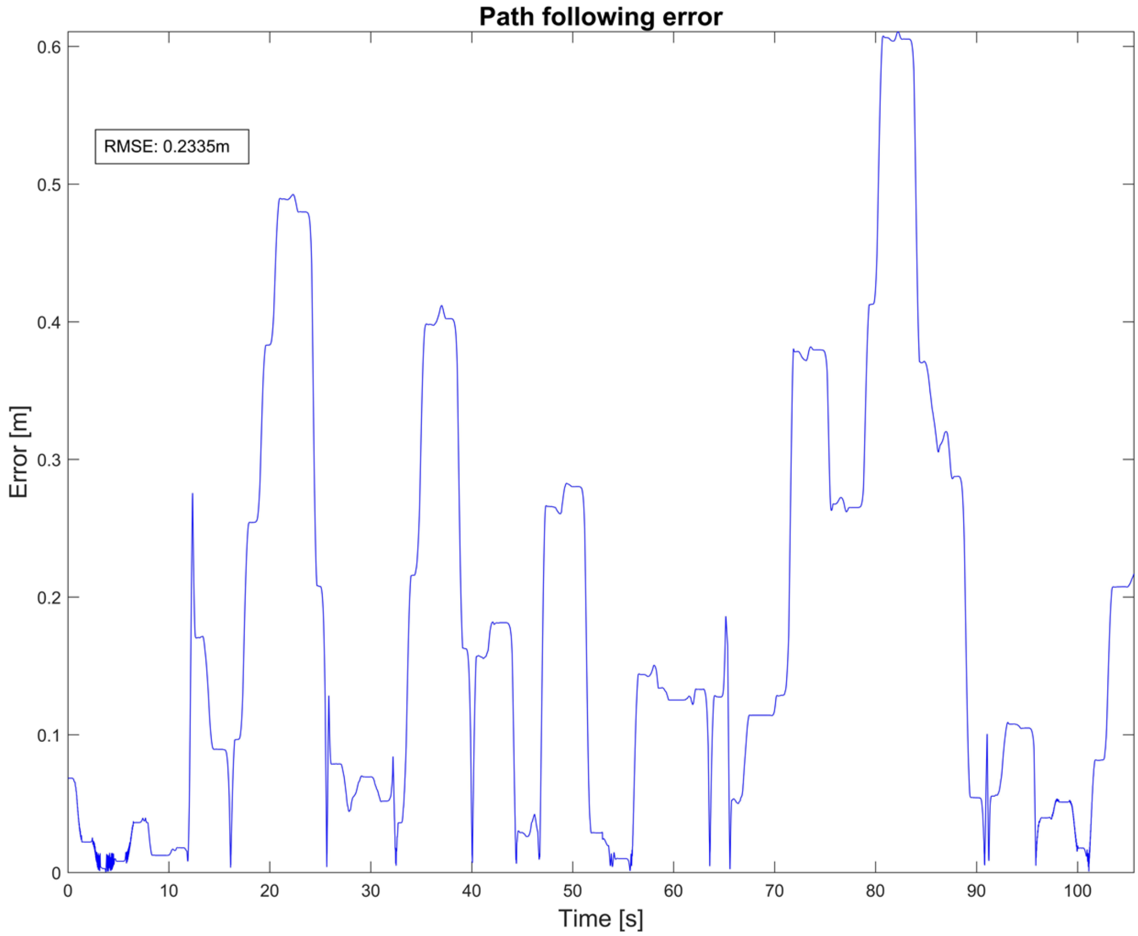

Fig. 44. Path following error from the real EPW using eye tracker.

Table 15. Path following error for real training using eye tracker.

Participant	RET RMSE [m] per trial during the training						VET RT [m]
	1	2	3	4	5	6	7
16	0,21	0,38	0,52	0,51	0,62	0,43	0,3621
17	0,34	0,68	0,57	0,66	0,69	0,47	0,3714
18	0,30	0,34	0,25	0,52	0,33	-	0,3259
19	0,25	0,42	0,52	0,37	0,37	0,41	0,4498
20	0,22	0,38	0,41	0,40	0,56	0,46	0,2496
Mean	**0,2642**	**0,4395**	**0,4544**	**0,4926**	**0,5147**	**0,4438**	**0,3518**
SD	**0,0506**	**0,1221**	**0,1151**	**0,1012**	**0,1401**	**0,0265**	**0,0651**

Table 16. Path following error statistical test for virtual and real training with eye tracker (Comparison 1).

Trial	**1**	**2**	**3**	**4**	**5**	**6**
RET-VET [m]	-0,087	-0,002	0,175	0,106	0,285	0,095
	0,133	0,426	0,235	0,383	0,370	0,144
	-0,071	-0,007	-0,208	0,020	-0,107	-
	0,014	0,179	0,350	0,113	0,104	0,089
	-0,146	-0,004	0,135	0,104	-	-
SW	0,940	0,768	0,890	0,776	0,956	0,826
Critical Wα	0,806	0,762	0,806	0,762	0,806	0,806
p-value	**0,665**	**0,043**	**0,356**	**0,051**	**0,753**	**0,179**
F	1,707	3,936	1,454	1,279	4,534	1,773
Critical F	6,388	6,388	6,388	6,388	9,117	9,277
N df	4	4	4	4	4	3
D df	4	4	4	4	3	3
p-value	**0,309**	**0,107**	**0,363**	**0,409**	**0,122**	**0,325**
t	0,756	1,730	1,837	2,148	2,030	5,491
Critical t	2,306	2,306	2,306	2,306	2,365	2,447
df	8	8	8	8	7	6
p-value	**0,472**	**0,122**	**0,103**	**0,064**	**0,082**	**0,002**

Table 17. T-test of path following errors. Comparison 2, 3, 4 and 5 from the VE and RE using eye tracker.

Comparison #	**Between**	**Mean [m]**	**Variance [m²]**	**t-test type**	**t**	**Critical t**	**df**	**p-value**
2	VET T6	0,339	0,001	Paired one-tailed	2,205	2,353	3	0,057
	VET T1	0,279	0,005					
3	RET VT	0,380	0,012	Paired two-tailed	0,887	3,182	3	0,440
	VET T6	0,339	0,001					
4	RET VT	0,350	0,013	Paired one-tailed	0,989	2,132	4	0,189
	VET T1	0,296	0,005					
5	RET VT	0,350	0,013	Unpaired one-tailed equal variances	1,517	1,860	8	0,084
	RET T1	0,264	0,003					
2	RET T6	0,444	0,001	Paired one-tailed	7,164	2,353	3	0,003
	RET T1	0,254	0,004					
3	RET T6	0,444	0,001	Paired two-tailed	1,624	3,182	3	0,203
	VET RT	0,358	0,007					
4	VET RT	0,352	0,005	Paired one-tailed	2,385	2,132	4	0,038
	RET T1	0,264	0,003					
5	VET RT	0,352	0,005	Unpaired one-tailed equal variances	1,207	1,860	8	0,131
	VET T1	0,296	0,005					

Appendix D. Commands in virtual and real training using a joystick.

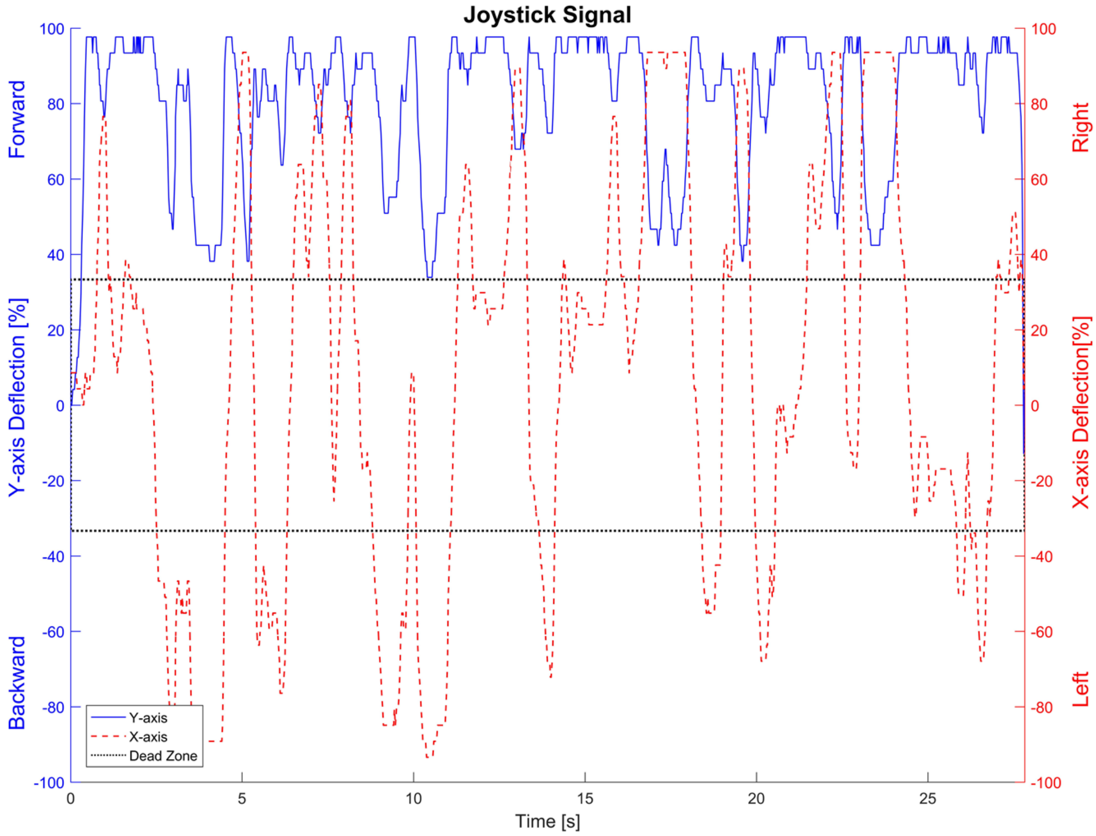

Fig. 45. Joystick's X and Y-axes signals while driving the virtual EPW.

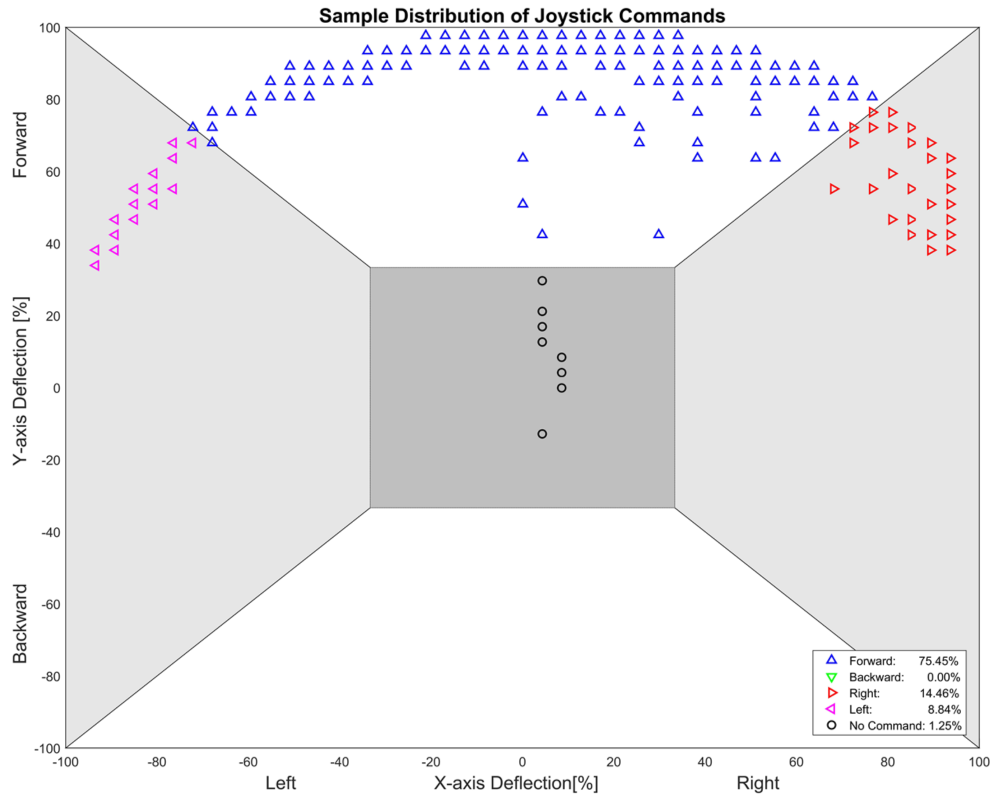

Fig. 46. Samples from joystick signals generated while driving the virtual EPW, distributed in commands.

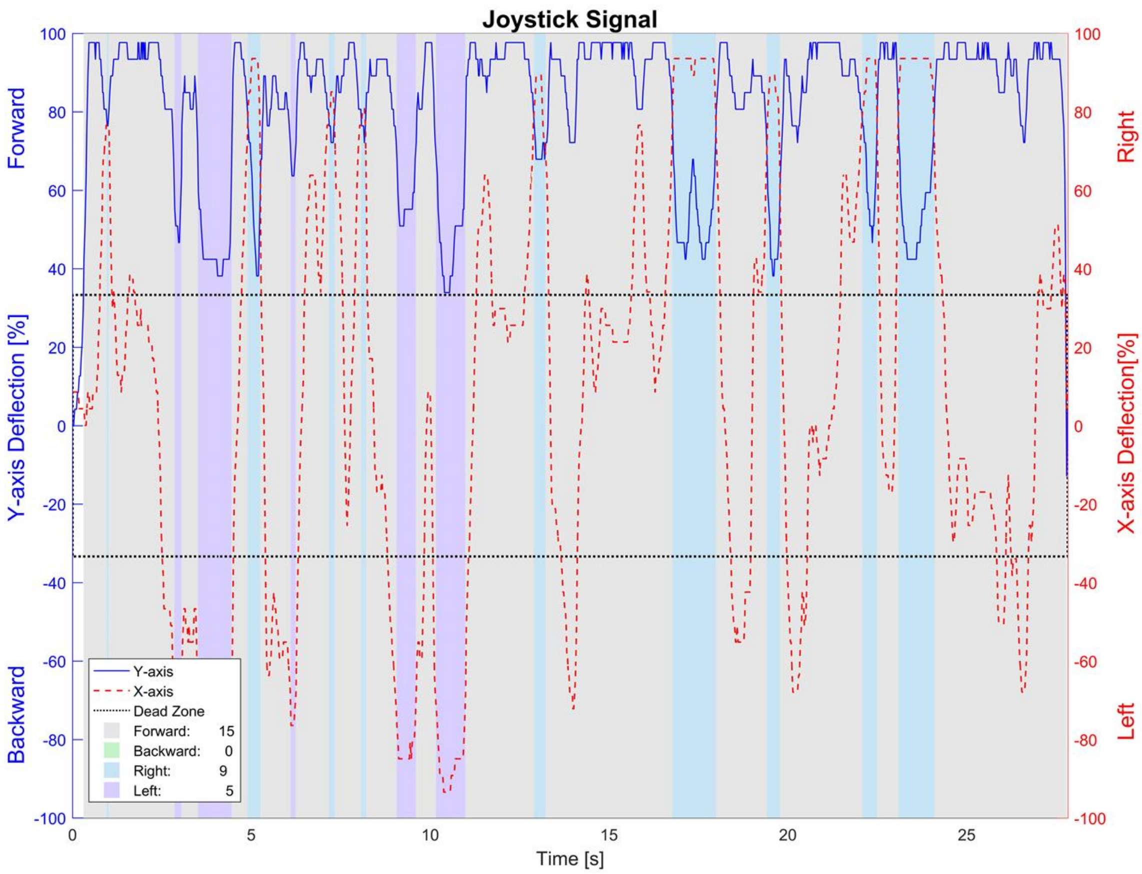

Fig. 47. Classification of commands from Joystick's signals while driving the virtual EPW.

Table 18. Total number of commands made in virtual training using a joystick.

Trial	Participants from the VJ group					Mean	SD
	1	2	3	4	5		
VJ T1	36	37	42	35	55	**41,00**	7,40
VJ T2	31	37	28	32	46	**34,80**	6,31
VJ T3	33	43	34	34	49	**38,60**	6,34
VJ T4	46	45	18	41	46	**39,20**	10,76
VJ T5	37	26	29	35	35	**32,40**	4,18
VJ T6	35	37	35	38	42	**37,40**	2,58
RJ VT	26	33	49	41	42	**38,20**	7,93

Table 19. Total number of commands made in real training using a joystick.

Trial	Participants from the RJ group					Mean	SD
	6	7	8	9	10		
RJ T1	15	27	31	46	34	**30,60**	10,05
RJ T2	11	33	31	28	22	**25,00**	7,92
RJ T3	11	13	25	38	20	**21,40**	9,69
RJ T4	13	11	31	31	20	**21,20**	8,54
RJ T5	11	-	24	25	13	**18,25**	6,30
RJ T6	13	-	23	23	11	**17,50**	5,55
VJ RT	31	32	73	35	47	**43,60**	15,77

Table 20. Statistical test for the number of commands made in virtual and real training with a joystick (Comparison 1).

Trial	1	2	3	4	5	6
RJ-VJ [commands]	-21	-20	-22	-33	-26	-22
	-10	-4	-30	-34	-	-
	-11	3	-9	13	-5	-12
	11	-4	4	-10	-10	-15
	-21	-24	-29	-26	-22	-31
SW	0,838	0,886	0,892	0,862	0,922	0,945
Critical Wα	0,806	0,806	0,806	0,806	0,806	0,806
p-value	**0,159**	**0,337**	**0,369**	**0,236**	**0,548**	**0,686**
F	1,844	1,579	2,332	1,587	2,427	4,940
Critical F	6,388	6,388	6,388	6,388	6,591	6,591
N df	4	4	4	4	3	3
D df	4	4	4	4	4	4
p-value	**0,284**	**0,334**	**0,216**	**0,333**	**0,206**	**0,078**
t	1,666	1,935	2,971	2,621	3,559	6,280
Critical t	2,306	2,306	2,306	2,306	2,365	2,365
df	8	8	8	8	7	7
p-value	**0,1342**	**0,0890**	**0,0178**	**0,0306**	**0,0092**	**0,0004**

Table 21. T-test of total number of commands made. Comparison 2, 3, 4 and 5 from the VE and RE using a joystick.

comparison #	Between	Mean [commands]	Variance [commands²]	t-test type	t	Critical t	df	p-value
2	VJ T1	41,0	68,5	Paired one-tailed	1,260	2,13	4	0,138
	VJ T6	37,4	8,3					
3	RJ VT	38,2	78,7	Paired two-tailed	0,207	2,78	4	0,846
	VJ T6	37,4	8,3					
4	VJ T1	41,0	68,5	Paired one-tailed	0,688	2,13	4	0,265
	RJ VT	38,2	78,7					
5	RJ VT	38,2	78,7	Unpaired one-tailed unequal variances	1,187	1,86	8	0,135
	RJ T1	30,6	126,3					
2	RJ T1	34,5	67,0	Paired one-tailed	4,627	2,35	3	0,010
	RJ T6	17,5	41,0					
3	VJ RT	46,5	358,3	Paired two-tailed	3,349	3,18	3	0,044
	RJ T6	17,5	41,0					
4	VJ RT	43,6	310,8	Paired one-tailed	1,506	2,13	4	0,103
	RJ T1	30,6	126,3					
5	VJ RT	43,6	310,8	Unpaired one-tailed equal variances	0,299	1,86	8	0,386
	VJ T1	41,0	68,5					

Appendix E. Commands in virtual and real training using eye tracker.

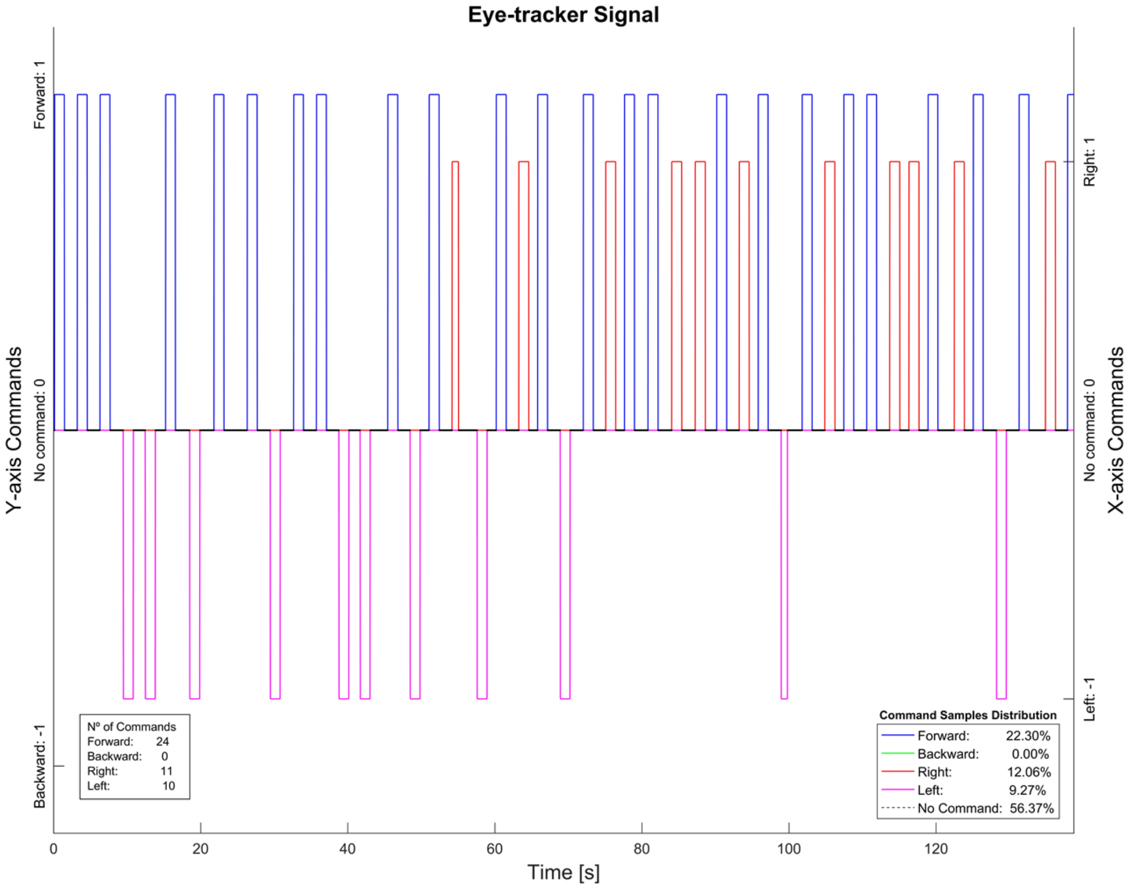

Fig. 48. Classification of commands from the eye-tracker interface while driving the virtual EPW.

Table 22. Total number of commands made in virtual training using eye tracker.

Trial	VET Participant					Mean	SD
	11	12	13	14	15		
VET T1	57	45	69	50	48	**53,80**	8,57
VET T2	58	50	54	51	43	**51,20**	4,96
VET T3	50	45	69	43	40	**49,40**	10,33
VET T4	57	44	60	41	38	**48,00**	8,83
VET T5	45	44	78	42	-	**52,25**	14,91
VET T6	44	44	57	44	-	**47,25**	5,63
RET VT	64	53	66	48	56	**57,40**	6,74

Table 23. Total number of commands made in real training using eye tracker.

Trial	RET Participant 16	17	18	19	20	Mean	SD
RET T1	89	53	52	52	81	**65,40**	16,21
RET T2	78	48	60	57	55	**59,60**	10,01
RET T3	73	48	43	54	66	**56,80**	11,16
RET T4	62	51	60	60	60	**58,60**	3,88
RET T5	72	54	52	54	57	**57,80**	7,28
RET T6	56	57	-	63	71	**61,75**	5,97
VET RT	41	50	37	45	42	**43,60**	15,77

Table 24. Statistical test for the number of commands made in virtual and real training with eye tracker (Comparison 1).

Trial	**1**	**2**	**3**	**4**	**5**	**6**
RET-VET [commands]	32	20	23	5	27	12
	8	-2	3	7	10	13
	-17	6	-26	0	-26	-
	2	6	11	19	12	19
	33	12	26	22	-	-
SW	0,911	0,967	0,893	0,907	0,891	0,855
Critical Wα	0,806	0,806	0,806	0,806	0,806	0,806
p-value	**0,476**	**0,852**	**0,373**	**0,451**	**0,387**	**0,253**
F	3,580	4,081	1,168	5,186	4,475	1,126
Critical F	6,388	6,388	6,388	6,388	6,591	9,277
Num df	4	4	4	4	3	3
Den df	4	4	4	4	4	3
p-value	**0,122**	**0,101**	**0,442**	**0,070**	**0,091**	**0,462**
t	1,266	1,504	0,973	2,198	0,644	3,060
Critical t	2,306	2,306	2,306	2,306	2,365	2,447
df	8	8	8	8	7	6
p-value	**0,241**	**0,171**	**0,359**	**0,059**	**0,540**	**0,022**

Table 25. T-test of total number of commands made. Comparison 2, 3, 4 and 5 from the VE and RE using eye tracker.

Comparison #	Between	Mean [commands]	Variance [commands²]	t-test type	t	Critical t	df	p-value
2	VET T1	55,3	108,3	Paired one-tailed	2,858	2,35	3	0,032
	VET T6	47,3	42,3					
3	RET VT	57,8	74,9	Paired two-tailed	3,108	3,18	3	0,053
	VET T6	47,3	42,3					
4	VET T1	53,8	91,7	Paired one-tailed	- 1,439	2,13	4	0,112
	RET VT	57,4	56,8					
5	RET T1	65,4	328,3	Unpaired one-tailed unequal variances	0,912	1,86	8	0,194
	RET VT	57,4	56,8					
2	RET T6	61,8	47,6	Paired one-tailed	0,509	2,35	3	0,323
	RET T1	59,5	205,7					
3	RET T6	61,8	47,6	Paired two-tailed	3,789	3,18	3	0,032
	VET RT	44,5	16,3					
4	RET T1	65,4	328,3	Paired one-tailed	2,505	2,13	4	0,033
	VET RT	43,0	23,5					
5	VET T1	53,8	91,7	Unpaired one-tailed equal variances	2,250	1,86	8	0,027
	VET RT	43,0	23,5					

Appendix F. Distribution of samples from effective commands in virtual and real training using a joystick.

VJ	Trial	Distribution of samples from effective commands [%]			
		Forward	**Backward**	**Right**	**Left**
1	1	52,78	0	25,00	22,22
	2	54,84	0	25,81	19,35
	3	51,52	0	24,24	24,24
	4	52,17	0	26,09	21,74
	5	51,35	0	27,03	21,62
	6	51,43	0	28,57	20,00
2	1	45,95	0	35,14	18,92
	2	48,65	0	35,14	16,22
	3	51,16	0	27,91	20,93
	4	51,11	0	31,11	17,78
	5	53,85	0	38,46	7,69
	6	51,35	0	29,73	18,92
3	1	54,76	0	26,19	19,05
	2	53,57	0	32,14	14,29
	3	50,00	0	23,53	26,47
	4	50,00	0	33,33	16,67
	5	51,72	0	31,03	17,24
	6	51,43	0	28,57	20,00
4	1	51,43	0	34,29	14,29
	2	50,00	0	28,13	21,88
	3	50,00	0	26,47	23,53
	4	48,78	0	31,71	19,51
	5	51,43	0	31,43	17,14
	6	50,00	0	26,32	23,68
5	1	47,27	0	29,09	23,64
	2	50,00	0	30,43	19,57
	3	42,86	0	32,65	24,49
	4	43,48	0	28,26	28,26
	5	45,71	0	28,57	25,71
	6	47,62	0	30,95	21,43
Mean	1	50,44	0	29,94	19,62
	2	51,41	0	30,33	18,26
	3	49,11	0	26,96	23,93
	4	49,11	0	30,10	20,79
	5	50,81	0	31,30	17,88
	6	50,37	0	28,83	20,81
SD	1	3,33	0	4,12	3,23
	2	2,37	0	3,22	2,68
	3	3,18	0	3,25	1,79
	4	3,03	0	2,59	4,11
	5	2,71	0	3,93	6,00
	6	1,48	0	1,53	1,65

RJ	Trial	Distribution of samples from effective commands [%]			
		Forward	**Backward**	**Right**	**Left**
6	1	53,33	0	33,33	13,33
	2	54,55	0	27,27	18,18
	3	54,55	0	27,27	18,18
	4	53,85	0	30,77	15,38
	5	54,55	0	27,27	18,18
	6	53,85	0	23,08	23,08
7	1	51,85	0	33,33	14,81
	2	45,45	0	27,27	27,27
	3	53,85	0	30,77	15,38
	4	54,55	0	18,18	27,27
	5	-	-	-	-
	6	-	-	-	-
8	1	48,39	0	35,48	16,13
	2	54,84	0	29,03	16,13
	3	56,00	0	28,00	16,00
	4	48,39	0	29,03	22,58
	5	54,17	0	29,17	16,67
	6	52,17	0	21,74	26,09
9	1	60,87	0	19,57	19,57
	2	53,57	0	28,57	17,86
	3	52,63	0	26,32	21,05
	4	54,84	0	32,26	12,90
	5	52,00	0	28,00	20,00
	6	52,17	0	30,43	17,39
10	1	44,12	0	32,35	23,53
	2	54,55	0	31,82	13,64
	3	55,00	0	30,00	15,00
	4	55,00	0	35,00	10,00
	5	53,85	0	30,77	15,38
	6	54,55	0	27,27	18,18
Mean	1	51,71	0	30,81	17,47
	2	52,59	0	28,79	18,62
	3	54,40	0	28,47	17,12
	4	53,32	0	29,05	17,63
	5	53,64	0	28,80	17,56
	6	53,18	0	25,63	21,18
SD	1	5,57	0	5,72	3,66
	2	3,59	0	1,67	4,62
	3	1,13	0	1,67	2,25
	4	2,50	0	5,78	6,37
	5	0,98	0	1,32	1,72
	6	1,04	0	3,44	3,57

Appendix G. Distribution of samples from effective commands in virtual and real training using eye tracker.

VET	Trial	Distribution of samples from effective commands [%]			
		Forward	**Backward**	**Right**	**Left**
11	1	43,86	0	28,07	28,07
	2	46,55	0	25,86	27,59
	3	52,00	0	24,00	24,00
	4	45,61	0	28,07	26,32
	5	55,56	0	22,22	22,22
	6	56,82	0	22,73	20,45
12	1	53,33	0	24,44	22,22
	2	50,00	0	26,00	24,00
	3	57,78	0	22,22	20,00
	4	61,36	0	20,45	18,18
	5	61,36	0	20,45	18,18
	6	59,09	0	20,45	20,45
13	1	36,23	0	30,43	33,33
	2	48,15	0	24,07	27,78
	3	42,03	4,35	31,88	21,74
	4	50,00	1,67	23,33	25,00
	5	39,74	7,69	24,36	28,21
	6	50,88	8,77	19,30	21,05
14	1	50,00	0	26,00	24,00
	2	50,98	0	25,49	23,53
	3	55,81	0	23,26	20,93
	4	58,54	0	21,95	19,51
	5	57,14	0	21,43	21,43
	6	56,82	0	22,73	20,45
15	1	52,08	0	25,00	22,92
	2	60,47	0	20,93	18,60
	3	62,50	0	20,00	17,50
	4	65,79	0	18,42	15,79
	5	-	-	-	-
	6	-	-	-	-
Mean	1	47,10	0	26,79	26,11
	2	51,23	0	24,47	24,30
	3	54,02	0,87	24,27	20,83
	4	56,26	0,33	22,45	20,96
	5	53,45	1,92	22,12	22,51
	6	55,90	2,19	21,30	20,60
SD	1	6,34	0	2,20	4,14
	2	4,86	0	1,90	3,35
	3	6,89	1,74	4,04	2,13
	4	7,41	0,67	3,25	4,04
	5	8,19	3,33	1,44	3,62
	6	3,05	3,80	1,48	0,26

RET	Trial	Distribution of samples from effective commands [%]			
		Forward	Backward	Right	Left
16	1	51,69	0	22,47	25,84
	2	64,10	0	15,38	20,51
	3	68,49	1,37	15,07	15,07
	4	72,58	0	12,90	14,52
	5	69,44	0	13,89	16,67
	6	80,36	0	8,93	10,71
17	1	54,72	0	18,87	26,42
	2	62,50	2,08	16,67	18,75
	3	64,58	0	16,67	18,75
	4	62,75	0	17,65	19,61
	5	64,81	1,85	14,81	18,52
	6	56,14	3,51	17,54	22,81
18	1	71,15	0	13,46	15,38
	2	65,00	3,33	13,33	18,33
	3	79,07	0	9,30	11,63
	4	68,33	0	15,00	16,67
	5	75,00	0	11,54	13,46
	6	-	-	-	-
19	1	73,08	1,92	11,54	13,46
	2	71,93	0	12,28	15,79
	3	75,93	0	11,11	12,96
	4	71,67	0	11,67	16,67
	5	77,78	0	9,26	12,96
	6	69,84	0	12,70	17,46
20	1	45,68	3,70	24,69	25,93
	2	63,64	0	16,36	20,00
	3	59,09	1,52	18,18	21,21
	4	68,33	0	13,33	18,33
	5	70,18	0	14,04	15,79
	6	60,56	4,23	16,90	18,31
Mean	1	59,26	1,13	18,21	21,41
	2	65,43	1,08	14,81	18,68
	3	69,43	0,58	14,07	15,92
	4	68,73	0	14,11	17,16
	5	71,44	0,37	12,71	15,48
	6	66,73	1,93	14,02	17,32
SD	1	10,91	1,49	5,05	5,74
	2	3,35	1,38	1,72	1,65
	3	7,30	0,71	3,35	3,58
	4	3,45	0	2,07	1,72
	5	4,52	0,74	2,04	2,06
	6	9,29	1,95	3,48	4,32

Appendix H. Sense of presence questionnaire results from all participants.

Table 26. Results for each IPQ item after driving the virtual EPW using an HMD and a joystick.

IPQ item #	name	VJ 1	VJ 2	VJ 3	VJ 4	VJ 5	RJ 6	RJ 7	RJ 8	RJ 9	RJ 10	Mean	SD
1	G1	5	6	5	4	6	5	5	6	6	6	5,40	0,66
2	SP1	6	6	4	6	6	6	5	6	5	5	5,50	0,67
3	SP2*	6	6	5	6	5	5	4	6	4	5	5,20	0,75
4	SP3	5	3	3	6	6	5	5	6	5	6	5,00	1,10
5	SP4	5	6	5	6	6	6	4	6	6	6	5,60	0,66
6	SP5	5	6	5	6	6	5	4	6	5	6	5,40	0,66
7	INV1	5	6	6	5	2	3	4	6	4	6	4,70	1,35
8	INV2	5	6	6	5	4	3	4	6	4	6	4,90	1,04
9	INV3*	5	6	5	1	2	3	2	2	3	6	3,50	1,75
10	INV4	5	6	4	6	5	3	5	6	4	6	5,00	1,00
11	REAL1*	3	3	4	5	5	5	5	3	5	6	4,40	1,02
12	REAL2	5	2	2	6	6	5	5	3	5	6	4,50	1,50
13	REAL3	3	3	3	6	5	5	5	4	5	6	4,50	1,12
14	REAL4	0	1	0	3	3	2	3	0	2	2	1,60	1,20

Table 27. Mean and standard deviation of each IPQ factor after driving the virtual EPW using an HMD and a joystick.

IPQ item name	Mean	SD pooled
G1	5,40	0,66
SP	5,34	0,60
INV	4,53	1,02
REAL	3,75	1,35

Table 28. Results for each IPQ item after driving the virtual EPW using a projector and eye tracker.

IPQ item #	name	VET 1	VET 2	VET 3	VET 4	VET 5	RET 6	RET 7	RET 8	RET 9	RET 10	Mean	SD
1	G1	3	5	2	5	5	3	4	3	5	5	4,00	1,10
2	SP1	4	5	1	3	5	3	3	5	5	5	3,90	1,30
3	SP2*	1	5	3	2	2	3	5	6	6	5	3,80	1,72
4	SP3	4	5	2	1	4	4	5	6	5	5	4,10	1,45
5	SP4	4	5	4	2	4	4	5	3	5	5	4,10	0,94
6	SP5	3	5	3	3	5	5	5	6	5	5	4,50	1,02
7	INV1	4	3	1	6	3	2	2	6	4	5	3,60	1,62
8	INV2	5	3	1	5	2	1	2	6	4	5	3,40	1,74
9	INV3*	4	1	2	4	1	1	4	6	5	5	3,30	1,79
10	INV4	3	5	0	5	4	1	4	6	5	5	3,80	1,83
11	REAL1*	4	5	3	2	5	2	5	4	5	5	4,00	1,18
12	REAL2	5	4	4	2	5	4	4	5	6	5	4,40	1,02
13	REAL3	4	5	4	2	5	4	3	5	5	5	4,20	0,98
14	REAL4	3	3	0	0	2	0	0	1	1	1	1,10	1,14

Table 29. Mean and standard deviation of each IPQ factor after driving the virtual EPW using a projector and eye tracker.

IPQ item name	Mean	SD pooled
G1	4,00	1,10
SP	4,08	0,83
INV	3,53	0,79
REAL	3,43	1,48

Appendix I. User experience questionnaire results from all participants.

Table 30. Results of participants' agreement-disagreement level for each user experience question for the groups that used a joystick in the VE and RE.

Participant		Scores for the Questions									
Group	**#**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
VJ	1	4	5	4	1	1	5	-	3	-	2
	2	4	5	5	1	1	3	-	5	-	4
	3	3	4	4	2	1	5	-	3	-	5
	4	4	4	5	1	1	5	-	1	-	5
	5	4	4	5	1	1	4	-	5	-	5
RJ	6	4	4	4	1	1	-	5	4	-	3
	7	4	4	4	3	3	-	4	2	-	2
	8	5	3	5	1	1	-	5	3	-	1
	9	4	5	5	1	1	-	5	3	-	2
	10	5	1	4	4	2	-	2	2	-	1

Table 31. Results of participants' agreement-disagreement level for each user experience question for the groups that used eye tracker in the VE and RE.

Participant		Scores for the Questions									
Group	**#**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
VET	11	4	4	1	1	4	-	5	-	2	5
	12	4	4	3	1	3	-	5	-	2	5
	13	4	5	4	1	3	-	5	-	4	5
	14	5	4	4	1	2	-	5	-	5	5
	15	5	5	4	1	3	-	5	-	4	5
RET	16	5	5	4	1	1	5	-	-	4	5
	17	4	4	4	2	3	4	-	-	4	1
	18	1	4	3	2	4	5	-	-	5	5
	19	-	2	2	4	4	5	-	-	1	5
	20	4	5	4	2	3	5	-	-	2	5