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RESEARCH ARTICLE

Affect-Driven VR Environment for Increasing Muscle Activity in Assisted Gait Rehabilitation

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ABSTRACT In recent years, the focus on gait therapy research has intensified, driven by a desire to enhance session efficiency. Accelerating rehabilitation timelines is imperative to accommodate a larger patient population annually. For instance, the Centro de Rehabilitacion Infantil Teleton, a prominent rehabilitation center in Mexico, operates at total capacity, leading to patient rejections. The acceleration of rehabilitation relies on encouraging patients to engage in active muscle efforts. Significant strides have been made in this direction, leveraging motivational techniques like virtual reality. However, a crucial aspect that requires attention is the customization of the environment to adapt to the evolving motivational states of patients. This personalized approach is an essential dimension that remains to be fully explored. Our research addresses this gap by introducing a rehabilitation scenario with a patient in a walking machine while immersed in a virtual reality environment and having a brain-computer interface tracking his affective states encompassing engagement, boredom, meditation, frustration, and excitement. The virtual reality environment dynamically adjusts in real-time using affect to trigger motivational stimuli. A study involving 27 participants, with 13 in the control group and 14 in the experimental group, showed the potential of this approach. The results indicate a significant improvement in the active effort for subjects in the experimental group, yielding an efficiency increase of 54.25% with a p-value below 0.05.

INDEX TERMS Virtual reality, affective computing, unity3d, adaptive feedback system, rehabilitation, robot-assisted gait training, BCI, HCI.

I. INTRODUCTION

The integration of Virtual Reality (VR) and affective computing opens up a plethora of possibilities for different domains. As reviewed by Dawn [1], applications focus not only on healthcare but beyond medical training and education to encompass patient education, communication, rehabilitation, mental health interventions, physical rehabilitation, fitness programs, and management of addiction and phobias. These technologies offer interactive interfaces facilitating more engaging and effective collaboration among practitioners, patients, and other stakeholders. One notable application of VR in healthcare is enhancing training for medical professionals and students across various disciplines. Furthermore, the metaverse includes multiple challenges where the communication between humans requires processing text in natural language but can be improved by including emotion analysis as shown by Park et al. [2]. Their proposed model can improve the processing of emotions by an average of 1 to 2% compared to other models. Gervasi et al. [3] presents another example, since the collaboration between robots and humans has increased significantly in the last years but can be

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improved if the system gauges the mental state of the operator by using different sensors that allow emotion recognition, such as facial expressions, voice, and brain signals. Moreover, it is not only recognizing but also eliciting emotions as reviewed by Somarathna et al. [4], where researchers can use multiple mechanisms to induce a range of different emotions.

VR and affective computing are two cutting-edge technologies that have the potential to revolutionize the way we create dynamic feedback systems. VR immerses users in a simulated environment, allowing them to interact and engage with virtual scenarios. These virtual scenarios are up to the imagination and can be as immersive as possible when combining compelling graphics, audio, and interaction. On the other hand, affective computing focuses on recognizing, interpreting, and responding to human emotions and affective states. Affective Computing, coined by Dr. Rosalind Picard [5] in 1995, is a computer science branch focused on designing systems that recognize, interpret, and respond to human emotions. It integrates computer science, psychology, cognitive science, neuroscience, and artificial intelligence insights. Affective computing aims to develop empathetic, human-like systems for more intuitive and responsive human interaction. There are multiple ways for obtaining data to interpret into affective states; the most common are experts assessing situations in person or a video, facial gesture recognition, and physiological markers like brain waves and galvanic skin response. By combining these two technologies, researchers and developers can create innovative feedback systems that adapt and respond to users' emotional and cognitive states. In fields such as education, healthcare, gaming, and training, these systems can provide personalized and adaptive feedback that considers users' emotional and cognitive responses. For example, in rehabilitation settings, VR can create immersive training environments where the user can be entertained during therapy. Affective computing can enhance these experiences by monitoring physiological signals and tailoring the feedback based on the patient's response to the system's adjusted settings to re-engage the user and aid the therapy session to be more consistent.

In Mexico in 2020, the Instituto Nacional de Estadística y Geografía (INEGI) [6] reported that from the total population of approximately 126 million people, 16.53% have an impairment, roughly 20.8 million have at least one of the seven most reported impairments which are related to the following activities: walking or climbing stairs using their legs; seeing even with glasses; learning, remembering or concentrating; listening even with a hearing aid; showering, getting dressed or eating; talking or communicating; emotional or mental problems. Moreover, according to the report from 2014 [7], 64.1% of people with an impairment are specifically related to walking or climbing stairs using their legs. Moreover, 68.3% are children and young adults, in other words, people between 0 and 29 years. Jalisco is the state with the most significant percentage of reports at 71%, and in the country, the main triggers for this impairment are illness at 41.3% and aging at 33.1%. Consequently, the main triggers in children are birth at 47.5% and illness at 26.7%. Meanwhile, young adults reported birth at 44.5% and illness at 39%.

The medical field has highly benefited from the advancements in engineering, particularly those related to mechanical devices, computer software, and sensors. One of the rehabilitation therapies available in Mexico is robot-assisted gait training (RAGT), but unfortunately, the process requires consistency and physical and mental effort. We believe that by using affective computing, gamification, virtual reality, and sensors, we can improve the user experience and increase the effectiveness of each session, which could translate into patients recovering in fewer sessions than average, more attendance, and a higher amount of patients rehabilitated each year. VR provides an immersive interaction that can help avoid boredom, mitigate pain [8], and enhance the user experience. Multimodal interfaces allow the patient to interact with the system and gather information to detect the affective state. For example, the patient could use his gaze to focus on things while using voice commands. Finally, gamification introduces the tools to engage in interaction; for instance, the use of power-ups and rewards provide purpose and gratification to keep interacting. Furthermore, the limitation of using headsets for displaying images and capturing affective states due to the high cost of overall equipment has been significantly reduced because current-gen entry devices can work standalone and range in the 300 to 500 USD price. And since both devices are intuitive and easy to use, combining both during the sessions is feasible. In the following sections, we present the related work, then the materials and methods used for this research, where we thoroughly explain the environment, devices, setup, and experiment. Afterward, we show the results and the discussion. Finally, we present the conclusions based on the results found.

II. RELATED WORK

Gait problems have been addressed with therapies, many of which are performed by a therapist, but others are done by exoskeletons, as shown by the review done by Lefmann et al. [9]. They searched six databases for clinical trials using RAGT from 1980 to 2016 and found three randomized controlled trials. These reported some positive benefits when using RAGT in minors with cerebral palsy; unfortunately, during the review, the findings could not be confirmed with a meta-analysis due to inconsistent evidence. Gait therapy is a type of physical therapy that focuses on improving a person's ability to walk. It is commonly used to rehabilitate individuals who have experienced injuries or neurological conditions that affect their mobility. The therapy aims to increase the strength and flexibility of the muscles involved in walking and improve coordination and balance. General Electric [10] created the first exoskeleton between the 1950s and 1960s, and it was named Hardiman; the primary purpose of this device was to help people carry heavy objects. Since then, multiple new objectives have been set, and at the beginning of the XXI century, the first commercial exoskeleton devoted

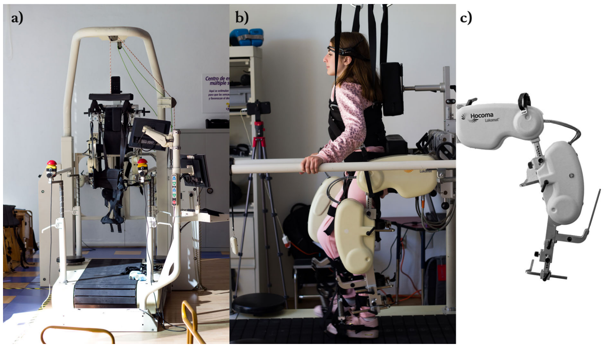

FIGURE 1. a) Front view of the Lokomat. b) Side view of the Lokomat while a patient is in therapy. c) Close up of the leg orthosis used by the Lokomat.

to assisting in gait therapy was created. RAGT can involve a range of exercises and techniques, including treadmill training, strength training, and balance exercises.

The Lokomat [11] and the ReoAmbulator are commercial products controlled by a computer that can regulate and monitor gait parameters in a particular gait pattern [9]. The Lokomat is a robotic exoskeleton that supports the legs and provides assistance with walking movements, as shown in Figure 1. It can be programmed to provide customized gait training based on the individual's specific needs and real-time feedback on gait performance. Multiple studies have shown that robot-assisted gait therapy can help improve walking ability in individuals with neurological conditions such as stroke, neurological disorders, multiple sclerosis, or spinal cord injury while also highlighting the need for well-designed randomized controlled trials. Like the work of Beer et al [12]. They ran a randomized, controlled clinical trial that evaluated the feasibility and efficacy of RAGT in multiple sclerosis (MS) patients with severe walking disabilities. Thirty-five stable MS patients participated in either RAGT or conventional walking training during a three-week inpatient rehabilitation stay, followed by a six-month follow-up. While the RAGT group showed moderate to large effect sizes favoring improvements in walking velocity and knee-extensor strength, the results were not statistically significant. Nevertheless, RAGT demonstrated high acceptance and convenience among patients. Another example is the research done by Swinnen et al. [13], their study evaluated the effectiveness of RAGT in spinal cord injury patients' walking ability and performance. Two researchers independently assessed methodological quality, analyzing two randomized controlled trials and four pre-experimental trials involving 43 patients. Although some improvements were noted in body functions and activities, limitations in sample size and methodological flaws hinder firm conclusions. In the case of strokes, the review done by Morone et al. [14], outlined the significance of robot-mediated gait training for stroke patients, highlighting its role as a burgeoning field in rehabilitation. However, they found its efficacy relies on adherence to well-defined neuroscientific principles. Another review by Schwartz and Meiner [15], about the crucial role of regaining walking ability for neurological patients, yet challenging due to motor weakness and balance issues. RAGT, employing end-effector and exoskeleton devices, shows beneficial effects in sub-acute stroke and spinal cord injury patients. However, optimal RAGT protocols remain uncertain. Technical limitations, such as fixed trajectory control and limited degrees of freedom, warrant further refinement. Direct comparisons between device types are lacking. Moreover, accessibility and cost constraints hinder widespread adoption. Finally, Khan et al. [16] present a novel telerehabilitation framework utilizing PTC ThingWorx IIoT platform and augmented reality (AR) interfaces to deliver upper-limb exercises remotely. Operators can teleoperate with rehabilitation robots like the xArm 5, SREx exoskeleton, and DMRbot via an AR-based graphic user interface, enabling therapy sessions. Validation shows effectiveness in 2D and 3D exercises. The system integrates cutting-edge technologies for robust remote therapy and leverages digital twin structures for real-time visualization. Future research involves clinical trials and comparison with traditional therapy and exploring mixed reality and machine-learning integration for enhanced outcomes. Robotic devices like the Lokomat have also led to new insights into the underlying mechanisms of gait recovery, which could help develop even more effective therapies. During a regular session in a Lokomat, the patient puts a harness around the waist, and the exoskeleton is adjusted to the pelvis and legs. The therapist configures the parameters for the session, and the treadmill starts to move. Moreover, the patient needs to make a physical and mental effort to create muscle memory and correct the walking pattern as much as possible until the end of the session.

One of the approaches to improve the process of rehabilitation via RAGT is the modification of the gait pattern. In other words, they personalize the gait trajectory to suit every patient better. The work of Semwal et al. [17], [18], [19], [20] focuses on learning the unique pattern of human joints when doing different styles of walking (brisk, normal, very slow, medium, and fast) and jogging. They measure the gait joint angles delta with various methods, such as learning-based techniques. Afterward, they can generate the personalized gait trajectory for different gait speeds based on the hip, knee, and ankle joints. Meanwhile, a recurrent approach to gait therapy is using a RAGT or a treadmill and sometimes combining it with some form of VR. For instance, the work of Fung et al. [21] focuses on a VR-based locomotor training system for gait rehabilitation. It had two stroke patients and one healthy for control. Patients can effectively increase their gait speed and adapt to changes in physical terrain. Another example is the VR training that addresses gait and cognitive deficits associated with fall risk in Parkinson's disease (PD). Results showed significant improvements in gait speed, gait variability, and cognitive function [22]. Likewise, Perez et al. [23] aimed to develop a VR-based system for gait therapy and research in Parkinson's disease patients, utilizing a digital camera to measure gait parameters. Show that these kinds of systems have potential for clinical and research applications. A common conclusion is that VR-assisted therapy is most effective in initiating active participation in all participants, as shown in the work of Brütsch et al. [24]; in their study, they aimed to evaluate the effect of different forms of training interventions, with and without VR, on active participation during RAGT. In addition, the paper from Labruyère et al. [25] examined whether children with neurological gait disorders could adjust their participation level in a rehabilitation game while using a driven gait orthosis. Results showed that cognitive function and motor impairment influenced game performance. The improvements are not limited to using sight; Park and Chung's [26] work investigates the effects of RAGT using VR and auditory stimulation on balance and gait abilities in stroke patients. Results showed significantly improved balance and gait abilities compared to general physical therapy and effectively enhanced functional activity.

In general, multiple studies show increased motivation due to using virtual elements, such as the research of Hamzeheinejad et al. [27], where they present a VR therapy system for gait rehabilitation after neurological impairments, targeting increased motivation through stimulating virtual exercise environments, using motion sensors and HMD. Usability and user experience were evaluated through a user-centered design process. Also, Manuli et al. [28] worked on evaluating the effects of robotic neurorehabilitation with and without VR on cognitive functioning and psychological well-being in stroke patients. Results showed significant improvements in global cognitive functioning, mood, and executive functions, as well as in activities of daily living. Even considering the possible downsides of using VR, such as cybersickness, as demonstrated by Morizio et al. [29] when they conducted a study to validate a fully immersive VR application RAGT and assess the onset of cybersickness in healthy participants. Results showed high usability, sense of presence, and low occurrence of cybersickness. Meanwhile, Panzeri et al. [30] delved into personalized rehabilitation, employing visual biofeedback within a VR environment to assist hemiparetic children and teenagers. Their findings suggested the effectiveness of this approach in reshaping motor control, enhancing gait patterns, extending walking endurance, and bolstering gross motor functions, offering promising prospects for tailored rehabilitation strategies.

Likewise, Salameh et al. [31] introduced a novel protocol that combined brain stimulation with focused stance phase training in the context of chronic stroke survivors. This comprehensive regimen included elements of virtual reality-assisted treadmill and overground practice, resulting in clinically meaningful improvements in gait function. Their study underscored the potential of VR-enhanced rehabilitation techniques for individuals with chronic neurological conditions. Furthermore, Galperin et al. [32] explored the benefits of a multi-modal VR training program for individuals with Multiple Sclerosis (MS). Their research revealed that this comprehensive approach, merging motor and cognitive elements within a VR environment, positively influenced cognitive function, mental well-being, and both usual and dual-task gait. The study shed light on the promising role of VR in enhancing the holistic rehabilitation of MS patients. These results show great promise with children, young adults, and even adults; for instance, in a specific case study presented by Kim and Kim [33], the focus was on a 58-year-old man with right hemiplegia stemming from a brain injury. Following an eight-week regimen of VR-based physical therapy, the individual exhibited marked improvements in gait and lower limb motor function. This case exemplified the potential of VR-based interventions to facilitate substantial gains in functional outcomes for individuals with neurological impairments.

The combination of affective states and virtual reality for rehabilitation has evolved at a rapid pace in the last 8 years [34], [35], [36]; unfortunately, it is still an emerging field despite its great potential. One of the most significant challenges lies in the measurement of the affective states, where there are multiple software available like Affectiva [37], Emotiv SDK [38] and the Affect-Driven Self-Adaptive System (ADAS) [39]. Many of these systems are based on the work of Tomkins [40]; he proposed that nine innate affects or ''affects tones'' are present at birth and related to facial expressions. Later, Mehrabian and Russell [41] introduced the Self-Assessment Manikin (SAM), which is a widely used tool to assess affective and cognitive states (ACS) and affective states (AS) in response to various stimuli such as products, advertisements, and websites. The SAM is a non-verbal, pictorial rating scale that consists of three separate dimensions: valence (pleasure), arousal (excitement), and dominance (control), usually referred to as PAD [42]. The valence dimension ranges from unpleasant to pleasant, the arousal dimension ranges from calm to excited, and the dominance dimension ranges from submissive to dominant. Participants are asked to rate their affective state by indicating the level that best describes their emotional response to the stimulus on each dimension. Hence, each software analyzes the brainwaves and, based on a proprietary model, determines the affective states and their values. ADAS is a framework that provides affect recognition and adaptive functionalities to keep track of user affective states and target system status. The framework supports Tobii eye-tracking devices, Emotiv headsets, and some skin conductance and pressure sensors created at MIT. One of the main advantages is that it is designed to be easily modified to incorporate more devices. The only requirement is to obtain the data from the device and then transform it into PAD. In Table 1, we have the affective states and how they are composed based on the pleasure, arousal, and dominance values. For example, Bekele et al. [43] worked with both technologies to create a VR-based platform that controls an avatar's facial expressions and to infer the affective states of a schizophrenic patient. Hence allowing physicians to understand their patients better and be

TABLE 1. Composition of affective states based on PAD.

State	Pleasure	Arousal	Dominance
Engagement	+	+	+
Boredom	-	-	-
Excitement	+	+	-
Frustration	-	+	-
Meditation	+	-	+

able to interact in a controlled environment safely. And then the combination of RAGT, VR, and Electroencephalogram (EEG) is the cornerstone that multiple researchers like Koenig et al. [44], Moghimi et al. [45] and Salminen et al. [46] have used. Koenig et al. [44] presented a VR task and a neural network classifier to induce different psychological states in nondisabled subjects and patients with neurological disorders during RAGT. The mental engagement was classified in real time using heart rate, skin conductance, and temperature. Meanwhile, in a clinical trial, Calabro et al. [47] studied the neurophysiological basis of motor function recovery induced by RAGT in the Lokomat and VR in stroke patients. Results showed improved gait, balance, and larger cortical activations in the affected hemisphere. Kern et al. [48] also created an immersive VR rehabilitation system with procedural content generation, evaluating the motivation and affect compared to traditional treadmill-based training. Results showed significantly greater enjoyment, competence, decision freedom, and meaningfulness, with lower physical demand, simulator sickness, and anxiety. Afterward, the next big challenge arises, determining what to do with the resulting states. Furthermore, it is paramount to identify which parameters should be selected to be dynamically adjusted by the algorithm.

III. APPARATUS

Following on our previous work of a preliminary study where patients in a RAGT were monitored using the ADAS system and then used a static VR scenario showing that it is possible to obtain the affective state of subjects that suffer from neurological disorders and even impact it by using a virtual scenario [49]. As mentioned before, the ADAS system provides the following states: engagement, boredom, excitement, frustration, and meditation. Therefore, considering that the patients require enhanced motivation to increase the time they actively move their legs, we selected engagement, frustration, and excitement. The following subsections will explain why we selected these parameters and how they are adjusted.

A. VR ENVIRONMENT

The selection of environment can significantly impact the user's immersion and how they perceive the system. Based on the findings from other experiments [31], [48], [49], [50], we decided to update the scenario to look more realistic and the terrain to allow us to hide objects so the user can have a purpose. We selected the Moon because it is an environment that most people have never experienced; hence, there is no point in comparison. Furthermore, it does not require buildings and other objects to feel realistic, making it lightweight, and it is a vast area where the user can walk for long periods. We used the Sci-Fi Moon Base by [51], then we redesigned a more diverse terrain with hills and craters, as shown in Figure 2. The new terrain covers a 1,000m^2 which would take approximately 1 hour and 10 minutes to travel between opposite corners since the walking speed was set at 1.2km/h. Also, the scenario includes a lab that measures 29.5m x 60m x 26m (width, length, and height, respectively), where users can travel between stairs and try to find more items to collect. In order to provide a purpose to the interaction and keep the user entertained, the story is that the user is a space explorer and is now stranded on the Moon and needs to collect as many batteries as possible to power the lab and survive. Hence, we randomly placed 200 batteries throughout the scenario. Then we ran an algorithm to validate the average distance between each battery to the next one, which resulted in 37.11m $\pm$ 20.03m meaning that the user approximately has to walk around to find the next battery for a maximum of 3 minutes.

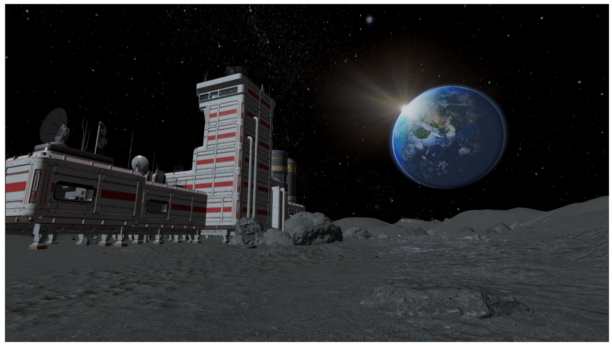

FIGURE 2. Screenshot of the modified environment from the VR camera.

FIGURE 3. Image of the battery glowing with an outline that goes from 4% to 68% of alpha.

Since the batteries are the main task during the interaction and the user needs to locate them relatively quickly, we created a shader to create a glowing orange outline. The fragment shader follows $lerp(oci, ocf, abs(sin(t))) * om$ where oci stands for the outline's initial color, ocf for the outline's final color, t for time, and om for the outline multiplier which is the parameter to be modified based on the EEG data. Furthermore, we also included a vertex shader to help the user identify the object either by the change of color or the change of size. This shader used the equation $lerp(oci, ocf, abs(sin(t)))$ with the same variables explained

TABLE 2. Feedback affective mapping.

State	Environment's parameter	Default	Range	Proportionality
Engagement	Music volume	0.5	[0.1, 0.8]	$a \propto 1/b$
Frustration	Battery's visual aid	0.5	[0.2, 1.0]	$a \propto b$
Excitement	Environment's illumination	0.5	[0.3, 1.0]	$a \propto 1/b$

before. In Figure 3, we present the different stages of the outline as time passes.

We opted for background music and an indicative sound every time the user grabbed a battery. We combined the Deep Space song by Audionautix [52] with Growing Space by Astron [53] by adjusting the latter with -9.462dB, resulting in a song of 7 minutes and 51 seconds. Also, we used the Ratchet Wrench Slow sound from YouTube [54] sound effect library for when the subjects collect a battery. Integrating all these aspects enhances the users' experience, quickly immerses them into a different scenario, and detaches them from the actual activity they are doing in the physical world.

B. FEEDBACK SYSTEM AND MATHEMATICAL MODEL

The purpose of feedback is to reduce the distance between the goal and the current value by changing a variable. For our feedback system, we selected engagement, frustration, and excitement because each one is unique. Meanwhile, boredom is the opposite of engagement and the meditation of frustration, as shown in Table 1. These parameters come from ADAS by interpreting the patient's brain waves; these values range from zero to one, in other words, intensity. In Table 2, we present the selected mapping between the affective states and their environment's parameter to be affected; also, it includes the default value when the system is neutral, the possible range of the parameter and the proportionality.

The ranges were adapted based on a small study done with 50 participants, 50% female and 50% male, with 22.3 ± 1.89 years of age. We presented the scenario starting with a volume of 0% and increased it every 5 seconds until reaching 100%; the same procedure was followed for the battery's visual aid and the environment's illumination. During the test, the subjects had to indicate when they started noticing a change when they could not differentiate any more changes, or if the effect was in excess. In the particular case of sound, the users reported that a volume greater than 80% was deafening, produced discomfort, and wanted to remove the headset. In Figure 5 we have a diagram on how each system is connected and the sequence followed by the adaptive feedback system when activated.

The proposed scenario includes multiple challenges, such as reading the affective state from an EEG, displaying a virtual environment in real-time at around 90 FPS, and adjusting parameters as quickly as possible, we depend on the polling rate of each device, the wireless connection speed and interference, and the processing power of the VR headset and the main computer. Therefore, we preferred a difference

FIGURE 4. 1) Meta Quest 2 VR Headset 2) Emotiv Insight EEG 3) Treadmill 4) Emotiv Insight USB Wireless Receiver 5) Camera 6) Glute Band 7) Computer

system that can swiftly be calculated and still provide a mechanism to reach the goal. A simple first-order linear difference equation (FOLDE) could follow the form $y[n] = \alpha_1 y[n-1]$ and then we solved by inspection as Equation 1 shows and it became a closed form definition resulting in $y[n] = y[0]\alpha_1^n$.

$$\begin{aligned} y[n] &= \alpha_1 y[n-1] \\ &= \alpha_1(\alpha_1 y[n-2]) \\ &= \alpha_1(\alpha_1(\alpha_1 y[n-3])) \\ &= \alpha_1(\alpha_1(\alpha_1(\alpha_1 y[n-4]))) \\ &= \alpha_1(\alpha_1(\alpha_1(\alpha_1 \ldots y[0]))) \\ &= y[0]\alpha_1^n \end{aligned} \tag{1}$$

After careful analysis, we noticed that the best approach was a discreet mechanism instead of directly adjusting the values and risking causing discomfort and rejection. We registered every time the system detected that the selected parameter was below the recorded average baseline for that specific user, as shown in Equation 2.

$$R_x = \begin{cases} +1 & \text{if } current_x < \mu_x \\ -1 & \text{otherwise} \end{cases} \tag{2}$$

It is important to mention that the report count increases when the value is still below the average which increases the effect of the adjustment. We decided to limit the number of reports from 0 to 10, first to have a quick response and secondly to have a smooth transition where zero has no adjustment and then we have ten levels of adjustment to gradually alter the environment. Furthermore, the impact of the adjustments was set from 0% to 50%, these range sum with the default value gave us a range of [0.5,1.0]. Therefore, our FOLDE became $y[n] = 1.47875765^{y[n-1]}$ where $y[0] = \frac{1}{100}$ and which means that $y[1] = \frac{1.47875765^1}{100} \approx 0.01478$ and $y[10] = \frac{1.47875765^1}{100} \approx 0.5$. In other words, we get a range of (1.5%,50%) and when there are no reports no adjustment is done.

Also, the report count decreases every time the value is above the average; in other words, we did not want the subject to get accustomed to the adjustment because it would gradually stop working, and the system would

TABLE 3. Comparison between Oculus Go and Meta Quest 2.

Spec	Oculus Go	Meta Quest 2
Device type	Standalone	Standalone and tethered
IPD	Fixed 63.5mm	Flexible 58-68mm
Passthrough	No	Yes
Resolution per eye	1280x1440	1832x1920
Refresh rate	60Hz	120Hz
Visible FoV Horizontal	89°	97°
Visible FoV Vertical	90°	93°
Weight	468g	503g
Tracking	3 DoF in position	6 DoF in an area
Cast to other device	Yes	Yes

become unstable. Hence, when the adaptive feedback system successfully reduces the delta between the desired and current value, we gradually removed the stimulus until it was required again.

C. DEVICES

In Rodriguez, Del-Valle-Soto and Gonzalez-Sanchez [49] the Emotiv Insight and Oculus Go were used and thoroughly explained the reasoning behind the selection focusing on the importance of weight. Based on that, for the next part of the study, we analyzed all the different devices in the market as well. After careful consideration, we noticed that the Meta Quest 2 provided more tools to introduce a higher level of immersion, comfort, and interaction. In Table 3 shows the main differences in specs between devices where the refresh rate and resolution per eye are tremendous differentiators. As mentioned, the refresh rate can produce dizziness, and resolution can create immersion, making the Quest 2 a step forward to a much better experience. Furthermore, the Quest 2 allows the developer to either create a standalone experience where no other device is required or tethered environments that can push the limits of computer graphics by using the full power of a computer. Finally, there is a slight increase in weight, but the rest of the pros can counter them.

Moreover, for our experiments, we used a Dell Precision 7550 with an Intel Core i7-10750H, 32GB of RAM, and a Quadro RTX 3000. This laptop was wirelessly connected to both the VR and EEG headsets. The following section will explain the software used and device interaction.

D. SOFTWARE AND SETUP

Our solution uses the ADAS 2.0, Emotiv Xavier Controlpanel 3.5.1 and Emotive SDK 3.5, built on Unity3D version 2021.3.5f1. The development was done in C# with the Meta XR All-in-One SDK. Since we created an experience where the subject has to walk and collect items on the moon, we decided to name our software the VR MoonWalker (VRMW), which includes the entire VR headset application and the computer's Command Center (CC). The VRMW CC software is the central system responsible of connecting the EEG, feedback system, and VRMW's app. Designed as a vertical application that uses a 297×856 resolution to work on a monitor with 1920×1080 resolution along with Emotiv's Xavier Control Panel and the ADAS software, as shown

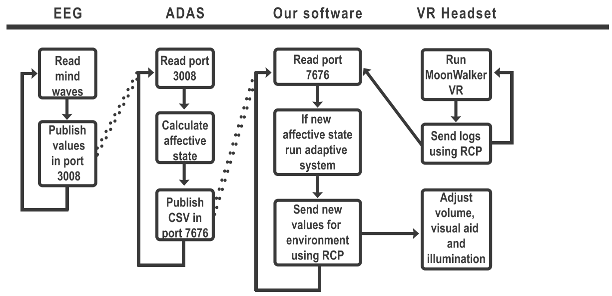

FIGURE 5. Process diagram of the interaction of the multiple systems including adaptive feedback.

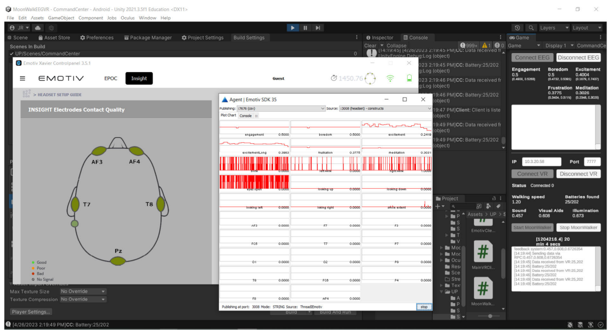

FIGURE 6. Screenshot of the computer's full screen where Emotiv's Control Panel, ADAS and VRMW Command Center are running.

in Figure 6. Everything is controlled with a keyboard and mouse, and it records an independent log along with Unity's log.

The VR application was designed as an Android app that runs standalone on the device; meanwhile, the CC application is for PC or Mac. The VRMW takes advantage of the 2560×1440 resolution, and to avoid reducing the level of immersion, there is no visible GUI. This means that the subject has no idea how many items have successfully been collected and can focus on obtaining the maximum amount. The idea behind this concept is to avoid having the users know the record of other participants and then settling down for a number that could be reached mid-session and having the rest of the time falling back into the bad habit of not making a physical effort. However, there is a displaying GUI, as shown in Figure 7 on the right side, where the administrator can fill in the information of IP Address and Port of the device and then fire up the server. During initial testing to decide which device should be the server and which one the client, we found that multiple computers face more obstacles working as servers due to firewalls and antiviral software.

To simplify the usage of the VRMW's mobile app, we mapped all the required actions into the controllers as demonstrated in Figure 8. The person in charge of the study is the only one who needs to use the controllers at the beginning of the session. The small line indicates which UI element is selected and will be affected. The next UI button goes to the next element on the right or the following line if it is already in the most right position. The previous UI button does the opposite; both go around the interface infinitely. The up and down arrows work on the text fields showing

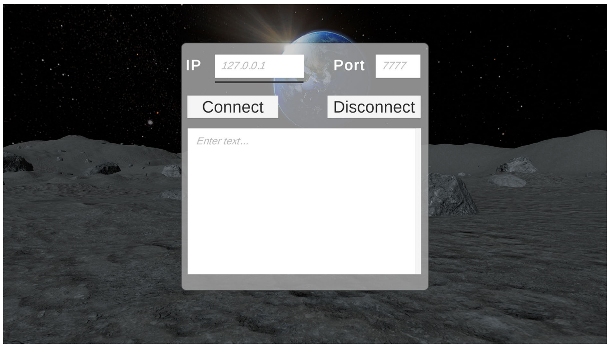

FIGURE 7. Screenshot of the GUI for connecting the VR Headset with the computer. It is a hidden menu that can be switch on and off.

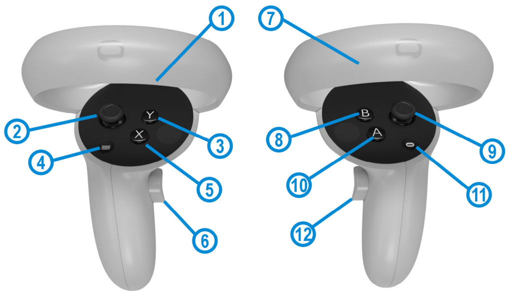

FIGURE 8. 1) Scroll up the Log 2) Show/Hide Menu 3) Next UI 4) Action 5) Previous UI 6) Scroll down the Log 7) Next character position 8) Up arrow 9) Delete last character 10) Down arrow 11) Meta menu and view re-center 12) Previous character position

the next or previous value in the list, which is constituted by "empty", 0,1,2,3,4,5,6,7,8,9,".". Also, the next character position button moves the cursor to the right to add more characters to the string, and the delete last character does the opposite. The log is controlled by the scroll up and down buttons, and all apps include the Meta menu and view re-center button to return to the main screen or adjust where the user is looking. As a precaution, the action button can also send the command to start the MoonWalker when outside the button area and the left joystick to move the user around the environment. Also, the headset records the last IP and port used and loads them automatically to reduce the setup time and obtain the values.

When MoonWalker has started the user defines the direction to walk by using the rotation of their heads. This presents an issue since the user should not rotate for than 90° to either side because to keep rotating the subject rotates the hip causing them to stop walking forward and increasing the chances of falling on the treadmill. Furthermore, this is not an option a patient has during a RAGT therapy. Therefore, the range from [0°, 25°] and [335°, 360°] the rotation is directly translated into the virtual world, then from (25°, 45°) and (310°, 335°) an extra ±0.2° is used for the rotation and finally if the angles is between [45°, 90°) or (270°, 310°] an extra ±1.2°.

In the work of Rodriguez and Del-Valle-Soto [55] they thoroughly explained the tremendous challenge of having multiple wireless devices close to the subject while trying to reduce the amount of data loss due to interference. Figure 4 includes the usage of the Emotiv Insight which uses a proprietary 2.4GHz connection with a dongle and Bluetooth Low Energy (BLE), the Meta Quest 2 includes 5GHz and 2.4GHz Wi-Fi and BLE 5.0 connections, and the computer has 5GHz and 2.4GHz Wi-Fi along with Bluetooth 5.0. Furthermore, the proposed scheme requires multiple processes between the EEG headset, VR headset and the computer that functions as command center, to be synced carefully.

In Figure 5, the EEG and VR headset communicate to the CC that is responsible for logging all data, receiving and processing the signals, and then adjusting the parameters for the virtual environment. When we started to analyze how to make this possible using Unity, we decided that Netcode for GameObjects (NGO) was the best option since it allows multiple Operating Systems (OS) to communicate via Wi-Fi and in a timely fashion. Other options would be managing everything as web services; unfortunately, this could require more time to set up, and communication can be slower. Moreover, NGO includes the usage of Remote Procedure Calls (RPC) that allow GameObjects to communicate with each other and change the value of variables. Hence, this is the approach we preferred and that we coded into both the CC and the VR MoonWalker software. Our system waits every 2 seconds to read information from the EEG, and then the feedback algorithm determines if a parameter should change; if that is the case, an RPC call is sent to the VR MoonWalker. Meanwhile, the VR MoonWalker sends every ≈ 3 seconds the current environment values that are in that moment used, and then the CC records this info to the log for manual validation later.

It is important to highlight that a certain order has to be follow so all devices and systems run correctly and can be synchronized, in the following list we have the step-by-step that has to be followed to start a session with a subject:

1) Initiate Emotiv software
2) Initiate ADAS software
3) Select Agent Emotiv 3.5, publishing to ":7676 (csv)" and source to ":3008 (headset) - constructs"
4) Start reading data using ADAS by hitting the "run" button
5) Initiate the Command Center software
6) Connect to the EEG by hitting the "Connect EEG" button
7) Obtain the IP address of the VR Headset
8) Initiate the VR MoonWalker software on the VR Headset
9) Open the menu by hitting the "Show/Hide Menu" button
10) Validate the IP address on the first field
11) Validate the port on the second field
12) Once everything is ready, select the Connect button and hit the "Action" button
13) On the CC input the IP and port of the VR Headset and hit the button "Connect VR"

14) Validate on the CC that status is now connected
15) Start the treadmill at the desired speed
16) On the CC start the moon walk by hitting the "Start MoonWalker" button

E. PROCEDURE

We recruited participants for the research experiment by emailing all students at the University, where we introduced the study, outlined its objectives, and provided a clear explanation that their participation was completely voluntary. A link to an online form was included in the email where they could accept being part of the experiment. Also, information about the study's procedures, potential risks, and benefits was explained while insisting on the whole process's confidentiality and anonymity. We collected basic information from the participants, including their full name, date of birth, gender, weight, and height. Furthermore, we inquired about their current engagement in organized sports or physical activities, the frequency of their participation, the duration, and the specific types of physical activities they undertook. Furthermore, we included questions regarding their smoking and alcohol consumption habits, such as if they currently smoke, the number of cigarettes consumed, and the frequency of their alcohol intake. We addressed specific medical conditions related to cardiovascular and respiratory health by asking participants if they had ever been diagnosed with any cardiovascular or respiratory conditions and if there was a familial history of such conditions. Our research focused on physical capabilities, so we paid particular attention to lower limb conditions that could impact mobility. We inquired whether participants had been diagnosed with lower limb conditions, such as arthritis, osteoarthritis, or peripheral neuropathy. Additionally, we explored how much their mobility was affected and whether they experienced any pain or discomfort while using their legs. We needed to gauge their current therapeutic interventions and determine whether they required any assistance for walking or mobility.

After applying the inclusion and exclusion criteria, we sent an email with a link to register for their three sessions in a period of 2 weeks. All subjects were measured with a measuring tape and a weighing machine during the initial session. Also, all the previously provided info was verified. Afterward, we explained how the experiment would be conducted step by step, starting with using a fast glute band between the legs to limit their ability to walk and get an approximation of how the patients would have to make an active effort. Then, they stepped up on the treadmill, and the EEG was placed on their head, followed by the VR headset and the calibration to ensure they were looking straight forward to avoid rotating or misalignment with the treadmill. We specifically requested to grab the side bars to reduce the possibility of falling down and dizziness. After validating that everything was set, we launched the ADAS and the VR environment and started the treadmill. When each session ended, we requested the subjects to fill out a post-session questionnaire to evaluate their satisfaction with the interaction. We used a Likert scale of 1 to 5, and the SAM evaluated pleasure, arousal, and dominance with a Likert scale of 1 to 9.

These were the questions asked:

1) How satisfied are you with the time it took to gather each item?
2) How satisfied are you with the total time the activity took?
3) Did you experience any unexpected behavior of the system?
4) How severe were the errors you encountered while using the system?
5) Were you able to successfully complete the exercise session?
6) How satisfied are you in general with the system during the session?
7) How comfortable it was to use both headsets during the session?
8) Did you feel that the system affected your physical performance during the session?
9) How easy it was to interact with the system?
10) How did you feel during the first half of the session (10 minutes)? (SAM)
11) How did you feel during the second half of the session (10 min to 20 min)? (SAM)
12) During the activity, did you notice a change in the volume of the background music?
13) During the activity, did you notice a change in the visibility of the environment?
14) During the activity, did you notice the system highlighting an item?

After the first session, each subject's data were analyzed, and based on their average and standard deviation value recorded on each of the five parameters from ADAS, the baseline was created. The input file for the system was updated so the environment could use these values if the subject was in the experimental group. Therefore, the subsequent two sessions followed the same procedure as the first one. In other words, to be clearer and more concise, a user in the control group has three sessions with the system, only detecting the baseline without activating the dynamic system. Meanwhile, a user in the experimental group had a first session to create a baseline without the dynamic system, and the subsequent two sessions with the system activated and personalized with their baseline from the first session.

In resume the steps followed in each session were:

1) Ask the subject to place the Glute Band between their legs above their knee level
2) Turn on the EEG and help the user place
3) Swiftly move the EEG until the Emotiv software shows a good connection
4) Start the ADAS software and run it
5) Start the VRMW CC and connect to the EEG via ADAS
6) Start and setup the VRMW app in the VR headset
7) Start the VRMW app server's connection

8) Place the VR Headset and adjust the straps
9) Connect to the VR Headset from the VRMW CC
10) Start the treadmill
11) Start the MoonWalker
12) Wait for the experiment's time to finish
13) Stop the MoonWalker and EEG
14) Ask the user to remove the VR Headset
15) Ask the user to remove the EEG
16) Ask the user to remove the Glute Band
17) Ask the user to answer the Post session questionnaire

FIGURE 9. Comparison of the strides when making a physical effort. Left shows a minimal effort, center shows an active effort and right shows maximum effort.

IV. MATERIALS AND METHODS

The study was divided into three main sections, recruitment, selection of candidates, and the experiment. Considering the previous experiments done, we decided that it was best to test the dynamic system with subjects that are healthy, can provide feedback, identify possible issues while using the system, and communicate them instantly. Also, engagement allowed us to identify if the user was responding and actively participating in the rehabilitation session. Frustration works as an alarm that signals when the patient is most likely to abort the use of the system environment and finish the therapy session without making any physical effort. The study focused on validating the hypothesis by adjusting the volume of the background music based on engagement, the brightness of the targets based on frustration, and the general illumination of the scenario based on excitement. The experiment consisted of three sessions of approximately 15 to 20 minutes, walking at a 1.2 km/h speed while collecting space batteries in a VR moon setting. The first session was to create a baseline of all subjects' 5 parameters ADAS measures. An experimental and a group control were randomly created, and during the subsequent two sessions, the experimental group used the dynamic feedback environment; meanwhile, the control group repeated the settings of the first session. The initial session helped to validate all the previously provided information and to explain with great detail the step-by-step of the experiment.

A. PARTICIPANTS

Twenty-seven students from 18 to 24 years old, eleven female and sixteen male, participated and completed the study. Eight male were on the control group and eight male on the experimental group, meanwhile five and six female respectively. The mean age, weight, height, and BMI of the participants were 21.2 ± 1.69 years, 73.28 ± 16.93 kg, 174.56 ± 6.92 cm, and 23.88 ± 4.34, respectively. Then, the inclusion criteria were students between 17 to 25 years that currently do not have any pain or discomfort in their legs or feet, do not receive any physical therapy or rehabilitation for a lower limb condition, and do not use any assistive devices such as a cane or walker to help with mobility. Moreover, the exclusion criteria were subjects that exercised more than 4 days a week, smoked or drank alcohol more than 2 times per week, or were ever diagnosed with any specific cardiovascular conditions, such as coronary artery disease, heart failure, or arrhythmia, or diagnosed with a respiratory condition such as asthma, chronic obstructive pulmonary disease (COPD), or lung cancer also, if they had any difficulty walking or climbing stairs or been diagnosed with a lower limb condition such as arthritis, osteoarthritis, or peripheral neuropathy.

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of Universidad Panamericana Campus Guadalajara (20230209). It was fully explained to each student the complete procedure, the study's purpose, and how the data collected are handled and protected. Furthermore, full permission was requested to record videos, take photographs, and use them for research purposes. Once the subjects agreed to participate, they signed the informed consent form and participated in the study.

V. DATA ANALYSIS

To determine the amount of time a user is actively making an effort, the Lokomat records this data and provides a summary at the end of the session. Meanwhile, all the sessions were recorded in video for our experiment, and we analyzed them. The glute band forces the users to make a small effort to be able to walk, but it is easy to spot when a user is making more than a minimal effort by watching their stride and how much the band is stretched, as demonstrated in Figure 9. Consequently, when the user stretches the band more than the minimum, it is flagged as time making an active effort; otherwise, it is recorded as a negative. This is how we can compare active muscular effort between RAGT users versus the treadmill users. Over 40 hours of recorded video were analyzed, and the experimentation took over 54 hours over two weeks.

The post-questionnaire included six questions to be answered using the Likert scale, two using SAM, and three yes or no questions. The questions using Likert and SAM are presented as a waffle diagram to facilitate the reading of the results and see as a cluster the subject's answers. Finally, to validate if engagement, boredom, excitement, frustration, and meditation parameters were statistically different, we performed a Two-Sample T-Test between the

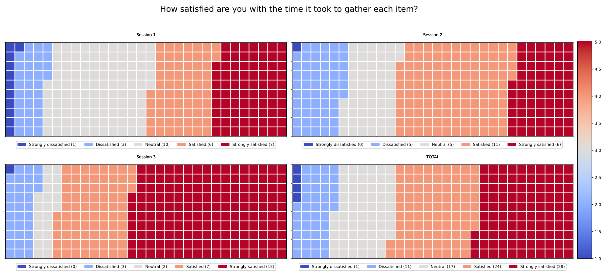

FIGURE 10. Results of the first question on the post session questionnaire.

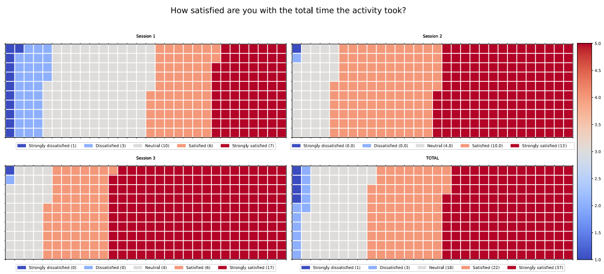

FIGURE 11. Results of the second question on the post session questionnaire.

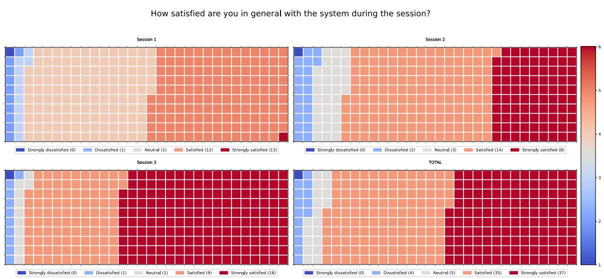

FIGURE 12. Results of the third question on the post session questionnaire.

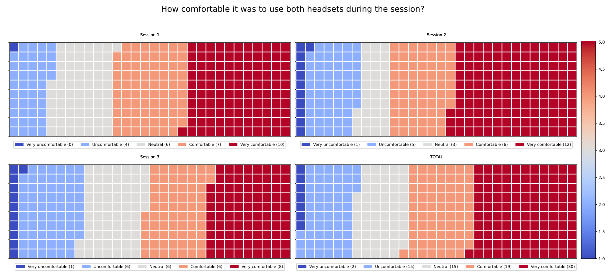

FIGURE 13. Results of the fourth question on the post session questionnaire.

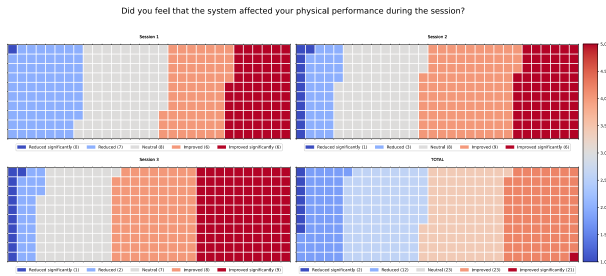

FIGURE 14. Results of the fifth question on the post session questionnaire.

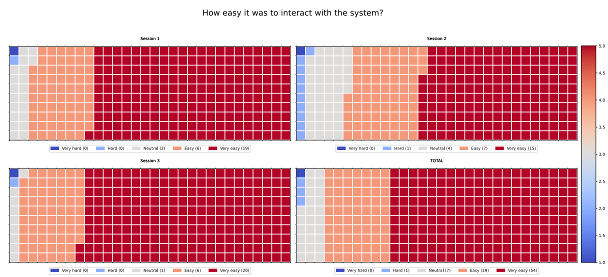

FIGURE 15. Results of the sixth question on the post session questionnaire.

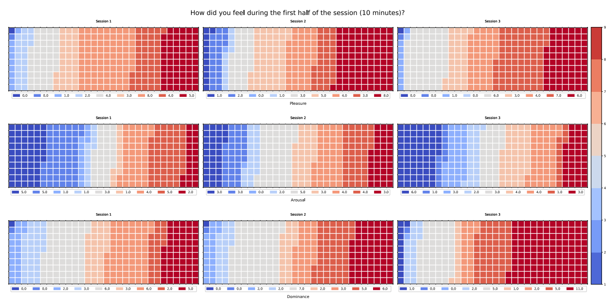

FIGURE 16. Results of pleasure, arousal and dominance on the first half of each session from the post session questionnaire.

control and experimental groups by obtaining the mean of each value during the second and third sessions.

VI. RESULTS

The results describe a positive experience through all the sessions. As the sessions passed the level of satisfaction increased meanwhile comfort of using both headsets increased and then decreased to a value lower in the third session than in the first. Also, users' awareness of improvement in physical performance due to the adaptive feedback system increased, and became easier to use the system. SAM for the first half of the sessions shows an increase in pleasure and arousal from the first to the second session but then a slight decline for the third session; meanwhile, dominance increases in both. On the other side, the SAM for the second half of the sessions on the three parameters shows an increment from session to session. The diagrams show an approximate on blocks, and even though some values registered 0 items, they are displayed as a single block. Also, some blocks include a gradient between two values for a better representation.

Furthermore, VRMW software ran on the headset with an average of 99 frames per second (FPS), showing a drop to 86 FPS inside the lab. This is due to the large amount of polygons in some of the rooms, including devices, furniture, and more. Meanwhile, VRMW CC ran on the laptop with an average of 916 FPS.

The efficiency of active physical effort is the amount of time during the therapy where the subject is making an effort versus just letting the device move their legs. The efficiency of the control group was 42.97%; meanwhile, the

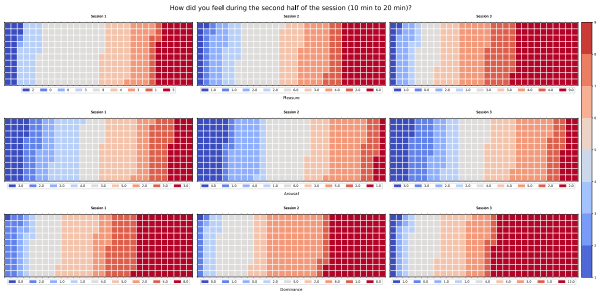

FIGURE 17. Results of pleasure, arousal and dominance on the second half of each session from the post session questionnaire.

TABLE 4. During the activity did you notice a change in the volume of the background music?.

Response	Session 1	Session 2	Session 3	Total
Control group				
Yes	6	5	7	18
No	7	8	6	21
Experimental group				
Yes	8	5	7	20
No	6	9	7	22
Total				
Yes	14	10	14	38
No	13	17	13	43

TABLE 5. During the activity did you notice a change in the visibility of the environment?.

Response	Session 1	Session 2	Session 3	Total
Control group				
Yes	8	8	5	21
No	5	5	8	18
Experimental group				
Yes	9	5	7	21
No	5	9	7	21
Total				
Yes	17	13	12	42
No	10	14	15	39

TABLE 6. During the activity did you notice the system highlighting an item?.

Response	Session 1	Session 2	Session 3	Total
Control group				
Yes	11	12	11	34
No	2	1	2	5
Experimental group				
Yes	12	13	13	38
No	2	1	1	4
Total				
Yes	23	25	24	72
No	4	2	3	9

TABLE 7. Two-Sample T-Test results.

	Engagement	Excitement	Frustration	Effort time
t(df)	0.595	-1.132	0.989	-4.406
p	0.554	0.262	0.327	5.287e-05
Control group				
Median	0.498	0.376	0.377	560.192s
StdDev	0.007	0.132	0.004	81.371s
Experimental group				
Median	0.496	0.447	0.375	700.464s
StdDev	0.017	0.123	0.009	142.079s

experimental group had 54.25%, which is an increase of 26.25%. Also, four two-sample t-tests were performed to compare engagement, excitement, frustration, and subject's effort time in a control and experimental group during the second and third sessions. For engagement, there was not a significant difference between the control group and the experimental group; in contrast, there was a significant difference for excitement, frustration, and effort time, as shown in Table 7.

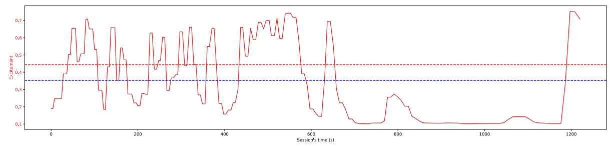

FIGURE 18. Excitement values from the EEG on Session 3 of subject 11.

VII. DISCUSSION

The active feedback system has demonstrated that it improves the subject's active effort time, as shown in Table 7 with a p-value of less than 0.05, and rejects the null hypothesis. Compared to the experiment from Rodriguez et al. [49] where a static VR environment increased the active effort time by 16%, the active feedback system achieved a 26.25% improvement. However, engagement is the only parameter that has shown no statistical significance. Table 4 reflects that 53.1% of the users did not detect a change in the volume. When placing the VR headset on the different sessions, the system detected a slight increase in engagement, but it quickly wore off on the university participants and CRIT's patients. However, it is crucial to notice that, in general, the patients have an approximately average lower engagement than the subjects of the previous study, which could mean that the system could have a more significant effect. Meanwhile, excitement and frustration have a statistical difference. However, the opinion is divided on whether the users noticed a change in the visibility of the environment, while users did notice the system highlighting items. Therefore, the system can motivate excitement through the illumination of the environment without being apparent to the user and reduce frustration by highlighting items of interest even though the user clearly notices the manipulation.

The difference done by the active feedback system can be appreciated in Figure 18, where a subject from the control group uses the VR environment. This was the last session, and the dotted red line is the baseline calculated from the first session; meanwhile, the dotted blue line is the average from the last session. There were 194 events registered, and on 125 occasions, the excitement recorded was below the baseline, meaning 64.43%. A little over ten minutes into the session, the user's excitement drops drastically, stays below the baseline, and rises until they are informed they have reached the end of the session.

Meanwhile, in Figure 19 from the last session of a subject from the experimental group, we can appreciate the excitement data along with the number of reports from the feedback system. The baseline was 0.331259, and the session's average was 0.3854985, which is a 16.37% increase; also, it is noticeable how the excitement value rises

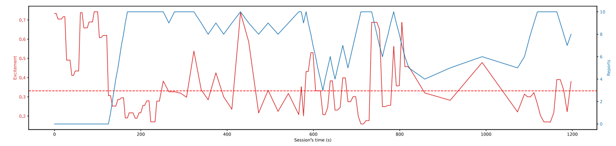

FIGURE 19. Excitement values from the EEG and number of reports from the feedback system on Session 3 of subject 17.

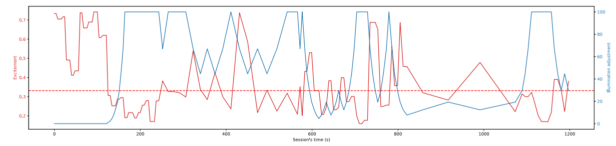

FIGURE 20. Excitement values from the EEG and illumination's adjustment percentage from the feedback system on Session 3 of subject 17.

once the report number rises as well. The active feedback system decreases the number of reports when the excitement parameter is above the baseline to avoid getting the user accustomed to the added stimulus. Also, in Figure 20, we have the adjustment values normalized. In plain sight, we can identify that the report's line and adjustment's line look similar, but the effect is more prominent on the latter. This is because our mathematical model is not linear but still allows a smooth transition for the user. In this case, we had 137 events where 72 registered a value inferior to the baseline, which is 52.55%.

Moreover, analyzing the results from the post questionnaire, the user experience, in general, improved from the first to the last session, particularly considering that at the end of each session, when the users removed the headset, they had marked the forehead and areas where the headsets incurred more pressure. During the first session, all the users were very cautious and conscious about their movements and followed all indications, including always having both hands on the side rails. However, in the second session, 81.5% of the subjects were more daring, exploring more complicated areas like the lab, and their movements were more relaxed, even by walking without grabbing the rails for some moments. For the third session, 92.6% of users wanted to explore even further, rotating to the limit and a couple of times stumbling, such as one of the subjects with a fast and sudden move accidentally sent both headsets airborne.

During the experimentation, we found again that the shape of the head is an essential factor in getting a successful reading from the EEG, and even then, some subjects have more difficulty achieving a good connection. This particular problem reduces the amount of accurate data retrieved by the ADAS system; in other words, the most accessible parameter to detect is excitement, and the most difficult is engagement. Therefore, other systems must take this into account to create redundancies that allow the active feedback system to achieve the goal depending on which parameters are being detected accurately. The proposed active feedback system is an improvement but also reinforces the idea that the baseline should be measured on the first session and in the first minutes of every session. Because the system highly depends on the user's mood and could register a baseline on a fantastic day full of excitement or on a terrible day after a traumatic event.

VIII. CONCLUSION

In Mexico, over 8 million people have reported being unable to walk or climb stairs using their legs [6]. Multiple therapies are available; one is RAGT, which CRIT offers nationwide in many of its 24 locations [56]. Unfortunately, the availability of this therapy is low because these centers cannot allocate more time slots for patients. The main issue comes from having patients diagnosed initially for several sessions. Still, that number increases to twice or even more due to low active muscular efficiency, which is required to rehabilitate. We have identified an average of 28% efficiency for these sessions, meaning that patients can potentially need 3.5x sessions from anticipated initially. We created a VR environment that is easy to navigate, designed a purpose for the interaction based on collecting an item, in this case, batteries, and created an adaptive feedback system. The core of the system is based on the difference equation $y[n] = 1.47875765^{y[n-1]}$ where $y[0] = \frac{1}{100}$ which allows a range of [0, 0.5]. An experiment with 27 subjects demonstrated that the active feedback system improves the subject's active effort time with a p-value of less than 0.05 and rejects the null hypothesis. The experimental group achieved an efficiency of 54.25%, which is an improvement of 26.25% versus the original non-VR environment. However, engagement is the only parameter that has shown no statistical significance. During the first session, all the users were very cautious and conscious about their movements and followed all indications, including always having both hands on the side rails. However, in the second session, 81.5% of the subjects were more daring, exploring more complicated areas like the lab, and their movements were more relaxed, even by walking without grabbing the rails for some moments. For the third session, 92.6% of users wanted to explore even further, rotating to the limit and a couple of times stumbling, such as one of the subjects with a fast and sudden move accidentally sent both headsets airborne. The most accessible parameter to detect is excitement, and the most difficult is engagement. The proposed active feedback system is an improvement but also reinforces the idea that the baseline should be measured on the first session and in the first minutes of every session. The system is easily customizable, which allows adapting, so in addition to its application in rehabilitation and physical therapy, an adaptive feedback system holds immense potential for various other domains where increasing the efficiency of active physical effort is paramount. One such domain is sports performance enhancement, where athletes and coaches can benefit from real-time feedback tailored to their specific needs. By providing personalized guidance and corrective measures during training sessions or competitive events based on their affective state, athletes can optimize their performance. Moreover, in occupational settings involving physical labor or repetitive tasks, such as manufacturing or construction, an adaptive feedback system can promote ergonomic practices, identify low excitement levels, and apply corrective measures.

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