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BERTHIL BORGES LONGO

Development and Evaluation of Serious Games as Assistive Technology through Affordable Access Multi-Devices

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Doctoral thesis presented to the Biotechnology Postgraduate Program (RENORBIO), at the Federal University of Espírito Santo, as a requirement to obtain the Doctorate title.

Advisor: Prof. Dr. Teodiano Freire Bastos Filho.

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To my family and friends, especially to my parents Mario and Janice, my brother Bruno and my sister Priscila.

To Dr. Teodiano Freire Bastos Filho, for believing in my ideas, again.

To all my friends at NTA-UFES.

The true measure of a man is not his intelligence or how high he rises in this freak establishment. No, the true measure of a man is this: how quickly can he respond to the needs of others and how much of himself he can give.

Philip K. Dick

RESUMO

LONGO, B. B. **Development and Evaluation of Serious Games as Assistive Technology through Affordable Access Multi-Devices**. 2019. Exame de Qualificação (Doutorado Renorbio) – Programa de Pós-Graduação em Biotecnologia, UFES, Espírito Santo. Brasil.

O objetivo de um processo de reabilitação é restaurar uma pessoa para um estado de ótimo funcionamento. Uma ampla variedade de processos de reabilitação consiste em exercícios de repetição de tarefas. Assim, Jogos Sérios podem ser utilizados como tecnologia para ajudar neste processo, motivando os pacientes a executar os exercícios durante as sessões de reabilitação, usando uma variedade de artefatos, como por exemplo, metas ou pontos a serem alcançados durante as sessões. Contudo, os jogos utilizados nesses processos podem ser jogos comerciais, projetados com função principal o entretenimento, ou jogos criados especificamente para reabilitação. Esses últimos têm algumas vantagens sobre os primeiros, pois são projetados especificamente para esse propósito, envolvendo conhecimento específico na área de reabilitação no desenvolvimento dos jogos. Entretanto, existe uma discussão sobre a eficácia clínica e a aceitação por parte de usuários e profissionais de saúde envolvidos nessa nova abordagem, e como integrá-la dentro da reabilitação convencional.

De acordo com o Relatório Mundial sobre Deficiência produzido pela Organização Mundial de Saúde, pessoas com deficiência e suas famílias são mais propensas a sofrer desvantagens econômicas, educacionais e sociais do que as pessoas sem deficiência, o que também é realidade para a maioria da população brasileira. Assim, é importante que as novas abordagens desenvolvidas sejam acessíveis para todos, independentemente do seu nível social. O uso de dispositivos de baixo custo no desenvolvimento e produção de tal tecnologia reduz seu custo final, tornando-a mais acessível. Assim, este trabalho aborda o tema Jogos Serios aliados a dispositivos de baixo custo para melhorar sua acessibilidade, além de sua avaliação por parte de usuários, paciente e profissionais de saúde envolvidos em reabilitação. Para tal, jogos sérios foram criados em duas modalidades: uma delas voltada para ser usado por profissionais de saúde diretamente e pacientes que estão passando por reabilitação, e uma outra voltada para pesquisas em laboratório, ambas envolvendo o uso de dispositivos de baixo custo, sendo que todos são avaliados por questionários específicos para esse propósito.

Palavras-chave: Jogos Sérios, Tecnologia Assistiva, Reabilitação, Dispositivos de Custo Acessível.

ABSTRACT

LONGO, B. B. **Development and Evaluation of Serious Games as Assistive Technology through Affordable Access Multi-Devices**. 2018. Qualification Exam (Doctorate Renorbio) – Postgraduate Program in Biotechnology, UFES, Espírito Santo. Brazil.

The purpose of rehabilitation processes is to restore a person to a state of optimal functioning. A wide variety of rehabilitation processes consist of repetitive tasks. Thus, Serious Games can be used as a technology to assist in this process by motivating patients to perform the exercises during rehabilitation sessions using a variety of objectives, such as goals or scores to be achieved during the sessions. However, electronic games used in these processes can be commercial games designed with a main purpose of player entertainment, or games created specifically for rehabilitation, whose main purpose is patient rehabilitation. The latter has some advantages over the former because they are specifically designed for this purpose, involving specific rehabilitation knowledge applied in the game development. However, there is some discussion about clinical efficacy and acceptance by users and health professionals involved on this new approach, and how to integrate it into conventional rehabilitation.

According to the World Disability Report produced by the World Health Organization, people with disabilities and their families are more likely to suffer economic, educational and social disadvantages than people without disabilities, which is also a reality for most people in Brazil. It is therefore important that new approaches developed are accessible to all, regardless of their social level. The use of affordable access devices in the development and production of such technology reduces its final cost by making it more accessible. Thus, this work addresses the theme Serious Games combined with affordable access devices to spread their use, as well as their evaluation by users, patients and health professionals involved in rehabilitation. In order to do so, Serious Games were created in two modalities: one aimed at being used by health professionals directly with patients undergoing rehabilitation, and another one focused on laboratory research, both involving the use of affordable access devices, all of which are evaluated by specific queries for this purpose.

Keywords: Serious Games, Assistive Technology, Rehabilitation, Affordable Access Devices.

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LIST OF ACRONYMS

AR	Augmented Reality
CREFES	Centro de Reabilitação Física do Estado do Espírito Santo
CRPS	Complex Regional Pain Syndrome
CRPD	Convention on the Rights of Persons with Disabilities
EEG	Electroencephalography
EPW	Electric Powered Wheelchair
EMG	Electromyography
FF	Full Fist
GBS	Guillain Barré Syndrome
HCI	Human Machine Interfaces
HMD	Head-Mounted Display
IBGE	Instituto Brasileiro de Geografia e Estatística
INPI	Instituto Nacional da Propriedade Industrial
IPQ	Igroup Presence Questionnaire
LE	Leg Extension
NTA-UFES	Núcleo de Tecnologia Assistiva da Universidade Federal do Espírito Santo
VE	Virtual Environment
VR	Virtual Reality
sEMG	Surface EMG
SG	Serious Game
SSVEP	Steady State Visually Evoked Potential
STS	Sit to Stand
SUS	System Usability Scale
TBI	Traumatic brain injury
UI	User Interface
UN	United Nations
WHO	World Health Organization
WRD	World Report on Disability

SUMMARY

1 INTRODUCTION

According to the World Report on Disability (WRD) produced by the World Health Organization (WHO) and published in 2011, nearly 200 million people experience considerable difficulties in functioning of some kind. Almost every person on Earth will be, at some time on their life, temporarily or permanently impaired. Also, people who survive to old age will experience increasing difficulties in functioning (WHO, 2011).

In 2008, the treaty of Convention on the Rights of Persons with Disabilities (CRPD) came into force, organized by the United Nations (UN). This treaty reinforced our understanding of disability as a human right and development priority. It symbolized the determination of the international community to place the theme "People with Disabilities" on the global agenda from the perspective of human rights. Brazil ratified this Convention and incorporated it into its legal system, granting it constitutional power (BRASIL, 2009). Also, other important international documents can be cited regarding the disability as human rights issue, including the World Programme of Action Concerning Disabled People (1982), the Convention on the Rights of the Child (1989), and the Standard Rules on the Equalization of Opportunities for People with Disabilities (1993). The CRPD also calls on countries to organize, strengthen, and extend rehabilitation services and programmes, based on multidisciplinary assessment of individual needs, including the provision of assistive technologies devices (UN, 2006).

In the WRD, WHO relates disability and poverty, showing that persons with disabilities are at a disadvantage in educational attainment, labor market outcomes, as well as wealth. Also, households with disabled members spend relatively more on health care than households without disabled members, aggravating their economic situation (WHO, 2011). This highlights the importance of researching and producing cost-effective devices so that the access to state-of-the-art rehabilitation therapies are available for all social levels.

1.1 Biotechnology and Assistive Technologies

Assistive Technology (AT) is a multidisciplinary area of study that involves healthcare; rehabilitation; and psychosocial, educational, engineering and biotechnology specialties (BLAKE, BODINE, 2002). The latter involves, but is not limited to, the usage of biosignals to develop novel AT devices, which can be used in rehabilitation processes or as tools to improve daily living. The objective of AT devices is to contribute, provide or expand functional abilities of persons with disabilities or reduced mobility, trying to amplify their autonomy, independence, quality of life and social inclusion (BERSCH, 2008), (BRASIL, 2007B). It includes the development, creation or improvement of assistive, adaptive, and rehabilitative devices, services or software for people with disabilities. Disability can be defined as any physical or mental impairment, substantially limiting daily activities. It includes, but is not limited to learning disabilities, blindness or low vision, hearing loss, speech impairments, and mobility impairments (Robitaille, 2010).

The speed of the emergence of innovations developed for the health area in this early century is unparalleled with other moments in human history. According to the WHO, 50% of all therapeutic advances available today did not exist until the beginning of this century. It includes new equipment, drugs, biomedical and surgical procedures to prevent, diagnose and treat diseases (BRASIL, 2007A). In this context, AT has also benefited from technological advances. In 2006, a committee was established in Brazil, aiming to improve, give transparency and legitimacy to the development of AT (BRASIL, 2009). The number of people in Brazil with any kind of disability, in addition to persons with reduced mobility, permanent or temporary, is about 43.5% of the population (BRASIL, 2009). According to results of the 2010 census released by the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística - IBGE), the country has approximately 13.3 million people with some motor deficiency, of which 5 million are men and 8.3 million are women (BRAZIL, 2010).

Physical disabilities include a broad range of disabilities that affect motor skills, causing problems at the person's limbs, muscles or nerves. It may be acquired congenitally or during life, from physical injury or disease (ROBITAILLE, 2010). People affected by physical disability can make use of AT to restore fully or partially their movements by having rehabilitation sessions accompanied by a specialist when physical recovery is possible, or use it to improve daily living activities when the partial or full recovery is not possible. In both cases, Virtual Reality (VR) and Serious Games (SG) can be used as AT to help in the rehabilitation sessions or training. The creation, development and testing of these new tools are important to verify their role in the rehabilitation area; a role that grows along with technology growth.

1.2 Virtual Reality

Virtual Reality (VR) is a state-of-the-art technology, part of a computing field which has the objective of simulating a Virtual Environment (VE) where the user can experience the sensation of being inside it, interacting with this created world in real time, while using specific devices (BOAS, 2013; LI et al., 2011).

The more the user feels inside this simulated environment, the less he/she feels present in the real environment, the more effective is the VR. VR uses a set of technologies and methods that allows achieving these sensations of presence inside the created world while feeling disconnected from the real world. To do so, a broad range of devices can be used to simulate human sensations, which include, but are not limited to, high-end visualization and audio devices, verbal control and communication, eye gaze control, tactile and haptic sensing. A multi-functional (multi-device) VR system amalgamates various types of these technologies to enhance the sense of presence, sending and receiving information about what is happening around the user, and providing feedback, in order to make the experience as real as possible (HORVÁTH et al., 2009). These technologies have a wide field of use, for example in military training, in the health area, virtual classrooms or flight and driving simulators, among others (KILNER e TORI, 2004).

VR has its design roots on the 50s, with the first prototype launched in 1962 (Figure 1A). It was a cabinet with movie projection, and audio, haptic, olfactory stimuli, and even wind to provide an immersive experience, but the user could not send information to the system to control it (BOAS, 2013). The first Head-Mounted Display (HMD) was developed by Philco in 1961 (Figure 1B), and the first Glove-based input devices were developed in 1977 (STURMAN, ZELTZER, 1994). In the early decades of VR, the technology was not cheap enough to become commercial products for the general public. Thus, its development was mainly found in the military, and academic research until the technologies became more cost-effective (BOAS, 2013). In 2012 The Oculus Rift company launched its first prototype (Figure 1C), which was the first affordable access VR headset available on the market (BONNECHÈRE, 2018), popularizing VR and one of its medical strands, the virtual rehabilitation.

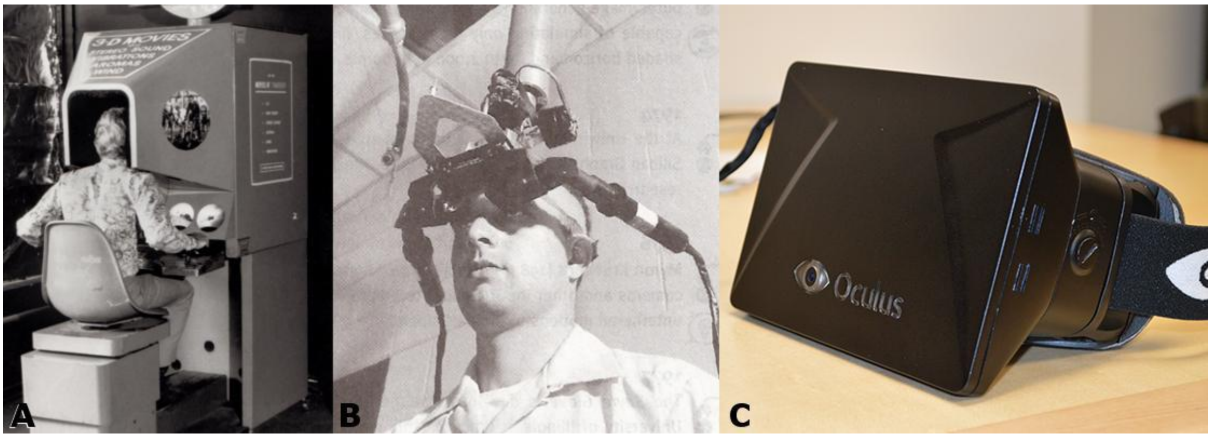

Figure 1. VR devices. A) First VR prototype B) First HMD prototype C) Oculus rift DK1. Source: TECHRADAR, 2016; IGYAAN, 2014; OCULUS, 2012.

The health area has been one of the greatest beneficiaries and inspirers for the development of VR advances and applications. VR can provide resources for the computational needs related to simulations, and training and therapies for various health specialties. The exploitation of this technology has many advantages compared to conventional therapies:

- Provides the possibility to practice procedures safely, which can later be applied in the real world;
- Can be designed to be used by people with physical or mental disabilities, supplying individual needs;
- Can provide an interface that generates a high level of interest from the user, also increasing the attention and persistence of the user in the task, increasing his/her engagement;
- Facilitates, for the health professionals, to study of the characteristics and motor and cognitive capacities of the patients;
- Provides entertainment and fun for users.

The main feature that distinguishes other media, such as video or television from VR is interaction. VR allows the user to interact, not only with the environment, but also with virtual objects, using a pointer operated by a mouse or joystick, or depending on the input source, a representation of the user's hand (or other body part) can be used, allowing a more natural interaction with objects (SVEISTRUP, 2004). This characteristic allows a broad range of options for VR usage in motor rehabilitation. VR can also be divided into two different definitions, immersive VR and non-immersive VR, as defined by KOZHEVNIKOV and GURLITT (2013):

- Immersive VR: The environment is rendered in a 3D simulation and the user is in the center, surrounded by it, in an egocentric navigation. The hardware usually used are HMDs (Figure 2A) or room projections with special glasses (Figure 2B).
- Non-immersive VR: The environment is rendered in a 3D or a 2D simulation and the user is outside, looking at it, which is usually displayed on a screen (Figure 2C).

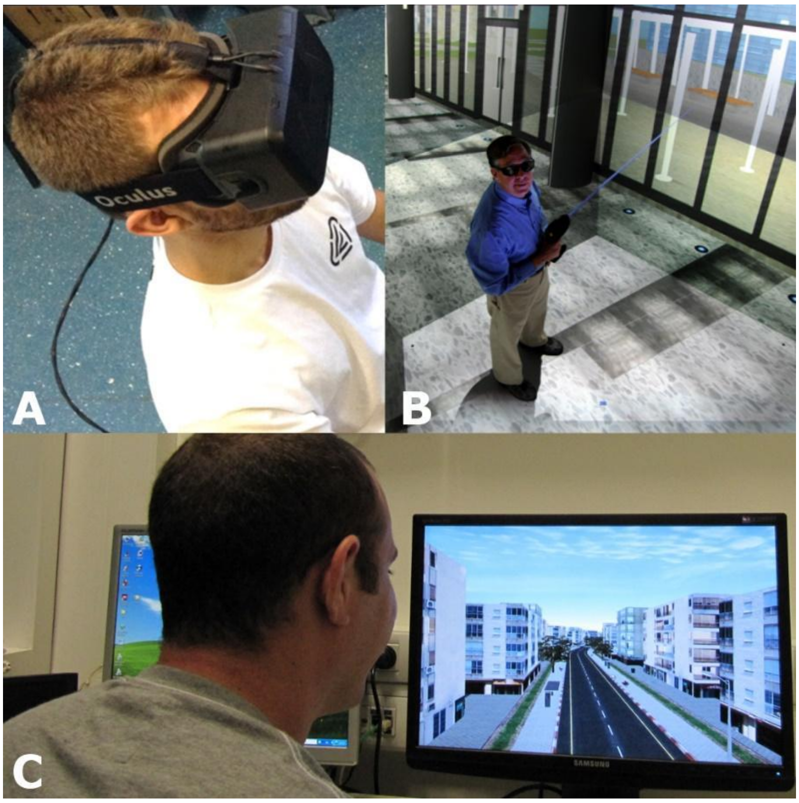

Figure 2. Immersive and non-immersive VR. A) Head-Mounted Display. B) The CAVE. C) VR on monitor. Source: LONGO, 2015; DEFANTI et al.,2009; ORON-GILAD, 2012.

Along with the VR technology, also following the growth of the computational power, the number of video games were created and improved. The growth of processing power over the years allowed the development of visual graphic applications, which was essential for the development of video games (BONNECHÈRE, 2018).

VR can cause a side-effect know as cybersickness, also called VR sickness, and it is a common affliction caused by the use of virtual environments. It can result in nausea, headaches, and dizziness, similar symptoms to motion sickness. The biological causes of cybersickness have not been firmly established, but the factor most accepted as the main responsible is sensory mismatch, which is the motion perceived from the visual, vestibular system, and somatosensory senses is mismatched (NG, CHAN, LAU, 2018; REBENITSCH, OWEN, 2016).

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1.3 Games and Serious Games

Games have always been part of human culture and history, and the first traces of games (a board game) date from 3000 BC (BONNECHÈRE, 2018). As defined by Salen and Zimmerman (2004), a game is the engagement of players in an artificial conflict, regulated by rules, that results in a quantifiable outcome. Basically, a game is composed of goals, rules, challenges, and interaction, and depending on its complexity, it can involve mental and physical stimulation.

A video game is a game that is played on a video screen. Some benefits of the use of video games may include the development and increase of social skills, memory improvement, visual attention, problem solving and others (DUCHENEAUT, MOORE. 2005; COLZATO et al.2013; GREEN, BAVELIER. 2003; ADACHI, WILLOUGHBY. 2013). It is mostly used for pure amusement, but it might have another primary intention, such as healthcare, rehabilitation, education, training, prevention of injuries and others (BONNECHÈRE, 2018). When a game is designed to intentionally stimulate these last cited characteristics on the player rather than pure amusement as first objective, it is classified as a SG. Despite the word “serious” on the definition name, entertainment is one of the objectives of SGs, stimulating the user to accomplish a task that might be considered, by most people, boring or tiresome. DJAOUTI and colleagues (2011), searching the origin of the term, reported that it was first used in 1970, with a meaning close to its current use, to describe a computer game developed to be used by military officers to study the Cold War.

Thanks to the different potential of video games and their positive aspects, the medical and rehabilitation field has been using these positive effects and became interested in the gamification of some interventions (RITTERFELD, CODY, VORDERER. 2009).

Also, the popularization of video games in the last decades helped to increase SG usage acceptance and development.

1.3.1 Serious Games for Rehabilitation

MEYER and colleagues (2014) describe rehabilitation by its aim, i.e. to restore an impaired person to a state of optimal functioning. A broad variety of rehabilitation processes consist of task repetition exercises (DELISA, GANS, WALSH. 2005), which can be adapted to the condition of each patient (MONTEIRO, 2011). Rehabilitation therapy should begin as early as possible, but many patients may experience trauma, since in many cases, the sequelae can result in paralysis on limbs, speaking problems and difficulties to realize simple tasks. It is common for stroke survivors to experience depression, and it may be difficult for patients to engage in the therapy programme. Even though rehabilitation plans attempt to stimulate patients with a variety of rehabilitation exercises, it is a common complaint that traditional rehabilitation tasks can boring due to their repetitiveness (BURKE et al., 2009). Thus, SGs can be used in this process, assisting both patients and clinicians, motivating patients to execute exercise movements during the rehabilitation sessions, using a variety of features, for example, goals or scores to reach during the gameplay. DECI and RYAN (2000) describe, based on contemporary theories, motivation as the initiation and persistence of people in certain behavior that will lead to a desired outcome or goal.

Bonnechère (2018) cites, in his work, three different approaches that complement each other to explain why SGs are, or could be, efficient in virtual rehabilitation:

- The possibility of adjustment on the balance between challenges and skills. Besides, the level must be adapted separately for each patient, and this can be more easily achieved when the game is built specially to be used in rehabilitation.
- The delivery of real-time feedback of the activity. The combination of the rehabilitation exercise with the real-time feedback can increase the motor performance. The motor gain must be used in activities of daily living.

- If patients, while using SGs in rehabilitation, experience improvement in the targeted movements in real life, they will be motivated by the game usage.

A key to increase motivation in people performing rehabilitation with SGs is the delivery of positive reinforcement to the player when they correctly execute the desired exercises (LEVIN, WEISS, KESHNER. 2015). This positive feedback can be a simple sentence or symbol temporarily displayed on screen or the earned score highlighted, or it can be delivered as audio or tactile feedback, or even the sum of more than one of the feedback devices (SUBRAMANIAN et al., 2013). DECI (1971) showed in a psychology experiment that verbal reinforcement and positive feedback can motivate and enhance the executed activity.

It is extremely important that the game played during rehabilitation has a repetition and movement complexity that matches the skill level of the patient in order to prevent frustration, boredom, and fatigue. Also, to keep attention and motivation, the task difficulty should be increased as the patient improves (LEVIN, WEISS, KESHNER. 2015).

The type or category of the game played is defined as game genre (YUSOFF et al., 2009), which are related to similar gameplay characteristics. Game developers usually chose the game genre before the production of a game depending on the target audience. Game genres are not usually defined by their visual or narrative content, as occurs on movies and books, but by their gameplay interaction (ADAMS, E. 2014, APPERLEY, H. 2006). For example, on Action games, physical challenges that require eye coordination and motor skill are required to advance and this defines this genre. Action games are more suitable to be used as SGs for physical rehabilitation, which requires patient movement. On the other hand, simulation games are designed to imitate aspects of a real or fictional reality, with a small or no background story and many degrees of freedom, and are more suitable as SGs designed for training. Thus, it is important to know what genre is best for the tool being developed, and this depends on the objective for the SG. Table 1 shows a super-category classification of game genres and its characteristics, followed by each of the most common subcategories (ROGERS, S. 2014, APPERLEY, H. 2006). It is important to highlight that a video game's genre is open to personal interpretation. Moreover, each individual game may belong to several game genres at once (APPERLEY, H. 2006).

Table 1. Game genres classification, characteristics and common subcategories. Source: (ROGERS, S. 2014, APPERLEY, H. 2006, HARTEVELD, C., 2011).

Genre	Characteristics	Common Subcategories	Best Suitable for
Simulation	Simulates aspects of a real or fictional reality	Management, Life and Vehicle simulations	Training
Strategy	Top-Down view of the actions taking place. Requires careful and skillful thinking and planning	Real-Time Strategy, Turn-Based Strategy, Tower Defense	Cognitive
Action	Requires eye coordination and motor skills. The game is centered around the player, usually an avatar, who is in control of most of the actions	Platformer, First-Person Shooters, Third Person Shooter, Fighting	Physical Rehabilitation
Role-playing	Sets the player in the role of an avatar who is specialized in specific skills while progressing through the storyline	Action RPG, Massively Multiplayer Online RPG	Cognitive and Social
Adventure and Puzzle	Puzzle solving by interacting with the environment or characters. Gameplay without reflex challenges or intense action	Text Adventures, Graphic Adventures, Interactive Movie	Cognitive

In rehabilitation, SGs used can come from two different sources:

- Commercial games - These games are designed to the general public, having entertainment as primary objective. When used as a SG for rehabilitation the health professional or team responsible for their usage needs to keep in mind that commercial games were not built for people with impairments, and cannot be modified to adapt to rehabilitation needs, as their code is closed for commercial release and only the developers of the game have access to it.
- Games built specifically for rehabilitation - These games are more suitable for rehabilitation since they are designed and built specifically for this purpose. The game developers are usually from the project team or hired specifically to build SGs, meaning that specific knowledge in the rehabilitation area can be used when designing the game. As the designer knows the target users and their limitations, all the structure of the project is designed to meet their needs.

Furthermore, the team can modify and make required changes at any stage of the project, which cannot be done in a commercial game (Figure 3).

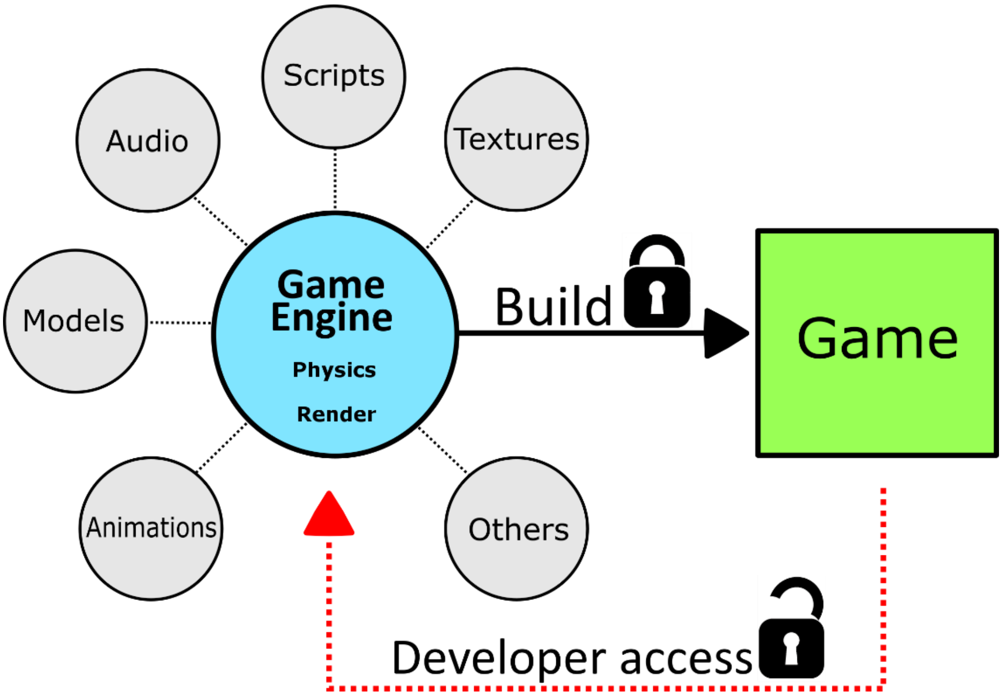


Figure 3. Game development scheme. Source: produced by the author, 2018

The use of SGs in rehabilitation followed a different path if compared with the commonly used regarding the integration of new medical devices and methods. Usually, there is a demand from clinics, and the research team works on a prototype, and then a series of tests takes it to the final product. The use of SGs in rehabilitation started totally different: the games already existed and were created for the general public and designed for fun and entertainment. The clinics saw an opportunity, and started using these games with their patients in the rehabilitation process. Later on, researchers and game developers started developing games specifically for rehabilitation (LEVIN, WEISS, KESHNER. 2015). The drawback of using off-the-shelf gaming systems is that they were designed to be used by individuals who do not have motor or cognitive impairments, making their use less specific and thus, not reaching their full potential. The SGs designed specifically for rehabilitation can be built focusing on the patient group, and can be designed in such a way to fulfil individual needs and include challenges, with progressive difficulties in order to maintain the desired level of effort.

1.3.2 Serious Games Development

The design and development of engaging video games for a wide number of users requires a high level of expertise and creativity. When designers have also to deal with the special needs of users with disabilities the difficulty increases substantially, with extra implementation challenges. Dealing with accessibility usually requires integrating, or even developing complex technologies, and sometimes it may even require producing special hardware (TORRENTE et al. 2014). Game Accessibility is defined by International Game Developers Association as (BIERRE et al., 2004):

“The ability to play a game even when functioning under limiting conditions. Limiting conditions can be functional limitations, or disabilities - such as blindness, deafness, or mobility limitations.”

Thus, during the SGs development process, the designer must make some decisions to deliver the most suitable product according to the SG objective. According to Harteveld (2011), it can follow the approach of Triadic Game Design, which is a balance of reality, meaning, and play (Figure 4). This balance guides the development to a first raw stage of design. It requires them to pass through a process of prototyping, testing, evaluating, and redesigning until it reaches the desired product (RÜPPEL, U., SCHATZ, K. 2011). When designing a SG, it is also essential to think about what game genre is most adequate for the task (Table 1), which hardware the SG will use, and if the users will have physical, cognitive or any other impairments.

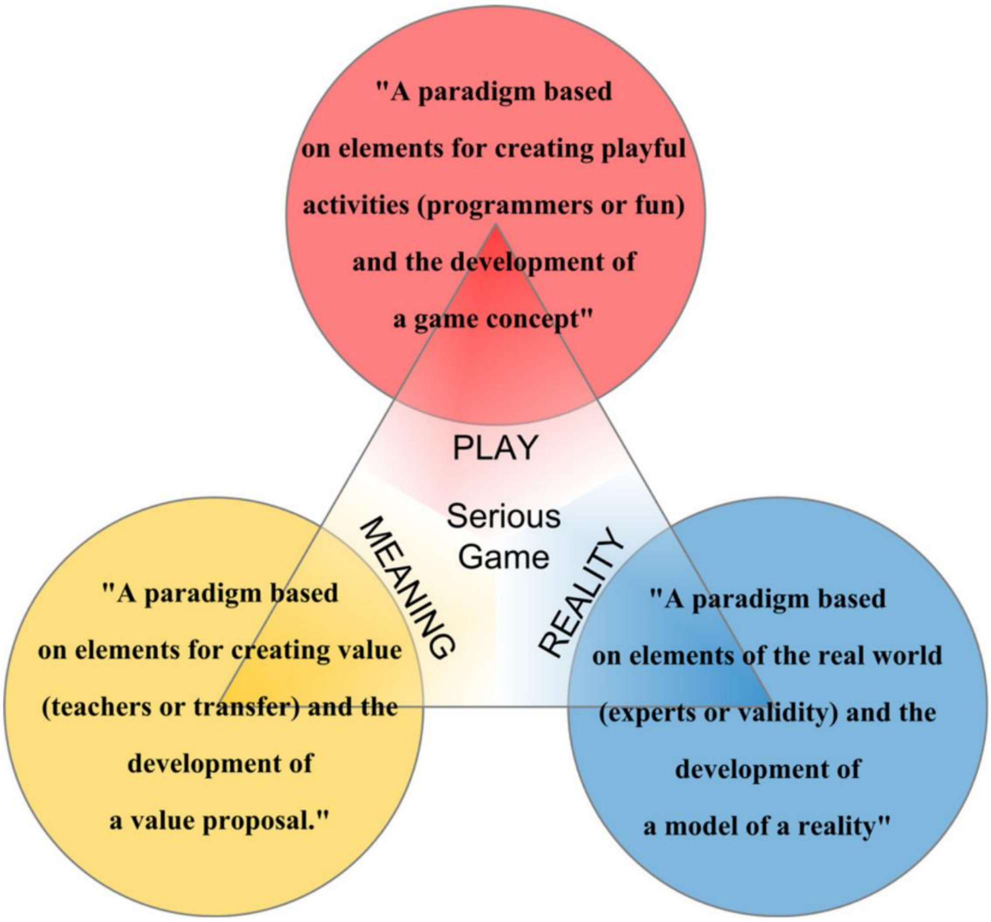


Figure 4. Triadic game design according to Hartveld. Source: RÜPPEL, U., SCHATZ, K. 2011

1.3.3 Devices

The devices used in SGs are the connections between the user and the machines. As the machines running the SGs are computers, these devices can be called Human Machine Interfaces (HCI), in which people use their actions to interact with and send/receive commands to/from computers. This is done using input devices (for example, keyboard, mouse, microphone) and output devices (for example, monitor, printer, speakers). With the development of video games and computers, specific devices were developed to be used with games. They are designed and built to try to achieve the best possible experience for players, sometimes changing the traditional passive gameplay, as with joysticks, to an active gameplay where the players are required to move in order to interact with the games. This extended the possibilities of the usage of games in the rehabilitation process. Some of the most used devices in rehabilitation with SGs are described below:

Commercial Devices:

- Nintendo Wii Controller (Figure 5A) – The Nintendo Wii Controller is the main control of the Nintendo Wii. It connects to the console via Bluetooth and uses accelerometers in three axes as well as an infrared sensor to recognize user gestures. It also has a vibration system and a small speaker (HALTON, 2008).
- Nintendo Wii Balance Board (Figure 5B) – The Wii Balance Board is shaped like household body scale. The board uses Bluetooth technology and contains four force sensors that are used to measure the user's center of balance (ANDERSON, ANNETT, BISCHOF. 2010).
- PlayStation Move (Figure 5C) – This device uses inertial sensors to detect motion while the hand´s position is tracked using a PlayStation Eye or PlayStation Camera. It connects with the console using a Bluetooth connection (TANAKA et al., 2012).
- Microsoft Kinect (Figure 5D) – Kinect is an input device with a RGB camera for video capture and microphones for audio capture. Also, an infrared emitter and a depth sensor are used to measure the distance between objects and the sensor. This allows it to track the human body, including distance and build, using its software, a simplified skeleton of the human body so it can use its movements as inputs (ANDERSEN et al., 2012). There are two Kinect versions, namely Kinect V1 (also known as Xbox Kinect) and Kinect V2, being the V2 version an improvement of the V1. The V2 version is recommend over V1 version due to its 3D reconstruction, visual odometer and higher accuracy (WASENMÜLLER, O., STRICKER, D., 2016). Kinect has been compared with other more expensive motion capture devices used for rehabilitation, and, despite the fact that the Kinect is less precise compared with these devices, it has several advantages: it has a lower price, better portability and it does not need markers on the user’s body to determine its position. They also pointed out that Kinect can be a very useful technology for rehabilitation therapies (SCHÖNAUER et al. 2014; FERN'NDEZ-BAENA et al., 2012).
- Oculus Rift (Figure 5E) – Rift is a HMD with accelerometer, gyroscope, magnetometer, constellation tracking camera (external positioning sensor) and integrated headphones. The kit also comes with motion tracked controllers (BORREGO et al., 2018).

- HTC VIVE (Figure 5F) – VIVE is an HMD with accelerometer, gyroscope, Lighthouse laser tracking system (two base stations emitting pulsed IR lasers to track the user), and a front-facing camera (BORREGO et al., 2018).

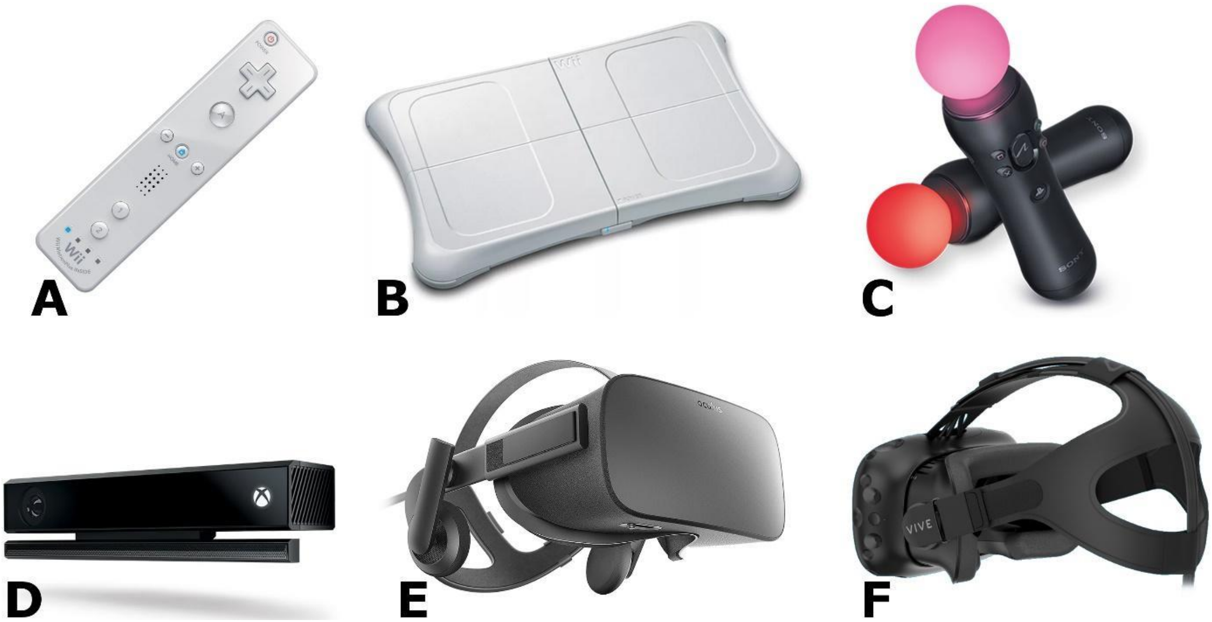


Figure 5. Commercial Devices. A) Nintendo Wii Controller. B) Nintendo Wii Balance Board. C) PlayStation Move V2. D) Kinect V2. E) Oculus Rift HMD. F) HTC VIVE. Source: GREENWALD, 2010; TSAO, 2008; SONY, 2018; MICROSOFT, 2018B; OCULUS, 2018; HTC CORPORATION, 2018.

Commercial Biological Signals Devices:

- Myo Armband (Figure 6A) – This device is worn on the forearm and uses a set of eight surface electromyography (sEMG) sensors to capture electrical activity in the forearm muscles to recognize hand gestures. It has a wireless connection with the computer and built-in gyroscope, accelerometer and magnetometer (MASSON et al., 2016; GANIEV, SHIN, LEE. 2016).
- Emotiv EPOC (Figure 6B) – This device is a headset that records 14-channel Electroencephalography (EEG) and has a 2-axis gyroscope, transmitting the collected data wirelessly to the computer (LONGO et al., 2014).
- Eye-Trackers (Figure 6C) – Eye trackers are devices which use infrared oculography to locate the user's eye and identify his/her eye positions and eye movements. It can be used to control a cursor on a screen and send commands to the computer (LONGO et al., 2016). Several affordable access

eye-tracker devices are available for purchase, making this technology more accessible (EYETRIBE, 2016).

Figure 6. Commercial Biological Signals Devices. A) Myo Armband B) Emotiv EPOC C) Eye tracker from The Eye Tribe. Source: THALMIC, 2016; EMOTIV, 2017; IPPINKA, 2018.

Medical Devices:

- BrainNet-36 (Figure 7A) – BrainNet-36 equipment is used to capture EEG and Electromyography (EMG) signals developed by the Brazilian company Lynx Tecnologia Ltd. It is compatible with touch proof connector electrodes (TELLO, MÜLLER, BASTOS, 2015).
- Minibike (Figure 7B) – Minibike is an electrical device for pedaling exercise, where the pedals turn automatically at a variable speed, to therapeutically encourage gentle leg movement, stimulating the muscles and generating better circulation (PARADIGM HEALTH & WELLNESS INC, 2017).

Figure 7. Medical Devices. A) BrainNet-36 B) Minibike. Source: EMSA, 2017; PARADIGM HEALTH & WELLNESS INC, 2017.

1.3.2.2 Affordable Access Devices

According to the World Report on Disability produced by WHO, people with disabilities and their families are more likely to experience economic, educational and social disadvantage than those without disability (WHO, 2011). Thus, it is important that the new developed approaches are accessible for everyone, independent of its wealth. Using affordable access devices in the development and production of such technology reduces its final cost, thus, making it accessible for all classes, achieving better health equity. WHO highlights the importance of investing in research and developing accessible, appropriate, affordable and available medical technologies, especially in countries considered developing economies (WHO, 2017).

1.3.3 Game Engines

Game engines are complex software used in the creation and development of video games (EBERLY, 2006). Modern game engines have features such as scripting, rendering, animation, physics, artificial intelligence, human-computer interface module, audio and networking (MESSAOUDI et al.,2017; COWAN, KAPRALOS, 2017). All these parts are compiled by the game engine in the finishing process and becomes part of a single final product. Most of the game engines nowadays can be used to create games for a broad variety of devices and platforms.

Despite the growth of SGs usage, there are no standard development tools specifically designed for SG development. However, game engines for commercial entertainment games can be used on its development. The design and development of SGs is a difficult and time-consuming process, and the choice of which game engine to use for this task can influence drastically in the final results. Cowan and Kapralos (2017) published a survey showing, by the frequency of mention in academic writing, the game engines most used by SGs developers, highlighting and describing them, in descending order, the most used ones, namely: Unity 3D, Adobe Flash, eAdventure, Unreal, Torque, Ogre, Cocos, XNA and RPG Maker.

1.3.4 Hardware and Software Influence

Although the first video game creations are from the middle of the last century, only in recent years the usage of video games in rehabilitation had a prominent growth in the number of research projects due to advances in hardware and software. This allowed the creation of realistic environments that increased user's immersion, as well as reducing their cost and popularizing the used technology.

The human eye is the sensory organ that picks up most information in most people (ZWERN, 1995). Some SGs can make use of realistic graphics to deliver an experience as close as possible to the real world. Thus, the basic requirement to simulate reality is a computer powerful enough to generate this kind of graphics, processing images, whose scenes can be formed by millions of textured polygons, and at the same time maintain an acceptable frame rate delivery, which is generally above 30 per second (CLAYPOOL, CLAYPOOL, DAMAA, 2006; MARSS, 2017). Thus, the designer of SGs must know the hardware and software which will be used to execute it, thus promoting a balance between quality and performance. Other factors such as lighting, texture quality and frame size, for example, also influence the visual quality and final performance of the SGs. Figure 8 shows images of three versions of the same model, with low, medium and high numbers of polygons, and an image showing the final result using textures and lighting. The numbers of polygons influence directly the model quality and performance, as well as textures and lighting.

In addition to graphical processing, which, depending on the SG type, can be the most expensive task in processing cost, there are other process demanding tasks which run simultaneously, like audio rendering, physics calculations, input/output devices management and others. Also, HMD usage is computationally expensive due to the fact that it needs to render everything double, once per-eye.

A good balance between all demanding tasks is important to deliver the best user experience.

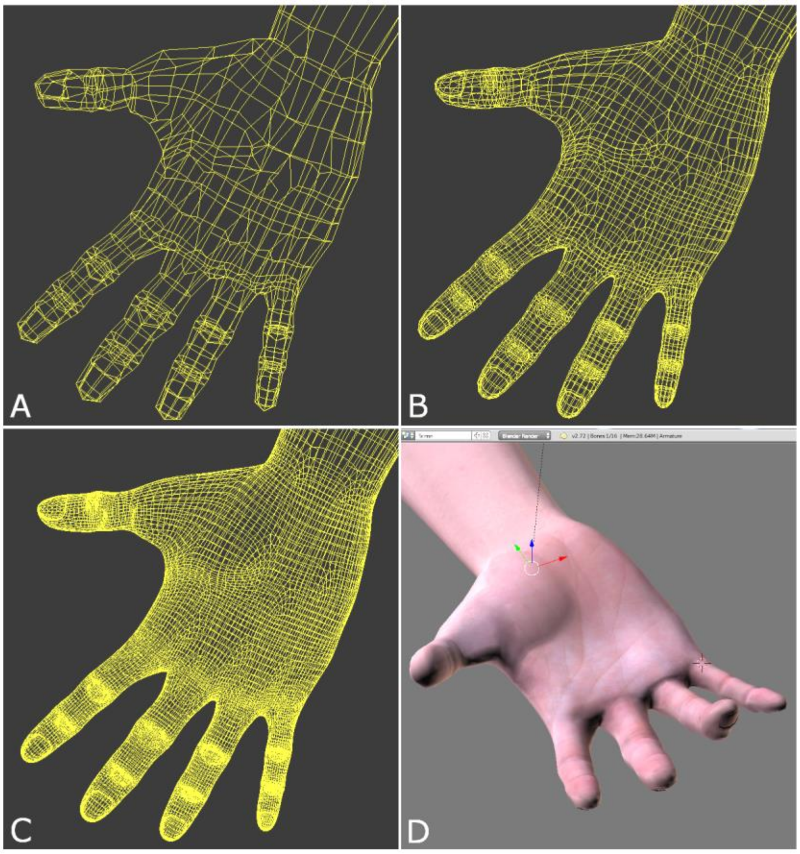


Figure 8. Three versions of the same model, with low, medium and high numbers of polygons, and an image showing the final result using textures and lighting. All images were rendered using Blender 3D. A) 1019 faces, with processing time of 1.17 seconds. B) 4069 faces, with processing time of 3.25 seconds. C) 16276 faces, with processing time of 8.57 seconds. D) Final result using 4069 faces, texture and illumination. Source: LONGO, 2015.

1.4 Evaluative Methods

The right evaluation method depends on what kind of information the researcher is trying to obtain. Health technology assessment involves evaluation of the effects, risks, and costs of methods (SBU, 2016). Evaluation is a process characterized by the interpretation of collected data (KISNER, COLBY, 2012). The collection of data about a new intervention or changes in an already used one makes significant contribution to obtain the best final results. The information collected provides the knowledge necessary to plan appropriate changes, when necessary. The evaluation may involve functional and/or laboratory tests depending on the evaluated target, the availability of equipment and technical expertise. Questionnaires can also provide an indication of the individual's perception of the rehabilitation process. Input from patients can be acquired about this process as their expectations and experiences during rehabilitation (CARR, SHEPHERD, 2003). The following evaluative methods are commonly used to evaluate new practices or tools:

- Intrinsic Motivation Inventory (IMI) – The IMI is an instrument for evaluating the intensity of individuals' intrinsic motivation for a target activity. This scale consists of statements that have to be scored on a 7-point Likert scale. It can be divided in 6 subscales: interest/enjoyment, perceived competence, effort, value/usefulness, felt pressure, tension, perceived choice. The way in which the items are formulated allows researchers, in order to make the questionnaire more specific to the context studied, to replace generic terms with more specific terms about the practiced activity (FONSECA, BRITO, 2001; FITZGERALD ET AL., 2010).
- System Usability Scale (SUS) – SUS is a ten-item, five-point Likert scale, to assess the usability of a wide variety of products and services, including hardware, software and applications. It takes into account three different aspects: effectiveness (the ability of the user to complete the task, and the quality of the output), efficiency (how much effort and resources were needed), satisfaction (contentment regarding system usage) (FINSTAD, 2006). SUS is used right after the respondent has used the system being evaluated, and before any debriefing or discussion about it. Respondents should record their immediate response to each item, rather than thinking about items for a long time (BROOKE, 1996, 2013). It is a good tool to evaluate a system for its ease of use and the need for professional assistance in order to use it (SAURO, 2011).
- Simulation Sickness Questionnaire (SSQ) – SSQ is an evaluation method widely used in cybersickness investigations, i.e., symptoms caused by exposure to a VR. It is composed of three specific factors (Oculomotor,

Disorientation and Nausea) and a total score of severity (KENNEDY et al., 1993; DE CARVALHO et al.,2011).

- Igroup Presence Questionnaire (IPQ) – IPQ is a scale for measuring the sense of presence experienced in a virtual environment. It has three subscales (Spatial Presence, Involvement, Experienced Realism) and one additional general item ("sense of being there") (IGROUP, 2016).
- Free questionnaires – questionnaires filled by the user, patients or health professional responsible for the patient's group, can also be used to obtain feedback about a tool.

1.5 Objectives

The objective of this work is to create and assess the usage of SGs as Assistive Technologies for rehabilitation and training purpose using affordable access multi-devices equipment as input/output devices. This research was structured in two branches of the main purpose, both contributing to the development of the SGs. One of the branches uses SGs developed to be used by rehabilitation health professionals along with their patients in rehabilitation treatment. These games are part of a SGs project (Virtual-R) designed during the development of this work to unify the created SGs of this branch in a single platform. The other branch is composed of SGs developed to be used in Assistive Technologies projects of NTA-UFES (Núcleo de Tecnologia Assistiva - Universidade Federal do Espírito Santo). To do so, a series of evaluation methods are applied for each investigation. The specific objectives are:

- Design and build a SG for rehabilitation using the Kinect as the input device, to be used with physically impaired patients, focusing on lower limb exercises, specifically, Leg Extension (LE) movements.
- Design and build a SG for rehabilitation using the Kinect as the input device, to be used with physically impaired patients, focusing on lower limb exercises, specifically, Sit to Stand (STS) movements.
- Design and build a SG for rehabilitation using the Myo Armband as the input device, to be used by tendon/nerve injuries, or forearm/wrist fractures patients, focusing on hand exercises, specifically, Full Fist (FF) position exercise.

- Design and build a SG for rehabilitation using the HTC VIVE as the input/output device, to be used by tendon/nerve injuries, or forearm/wrist/shoulder fractures patients, focusing on upper limbs exercises.
- Group all the SGs cited above in a platform with patient data entry to save session scores. Also, an exercise level menu for each game, to allow the possibility of choosing the number of repetitions for each session.
- Design and build a SG for training using the HTC VIVE as input/output device, to be used in an Electric Powered Wheelchair (EPW) training.
- Design and build a SG for training using an eye-tracker as input device, to be used in an intelligent environment training.
- Design and build a SG for rehabilitation using the HTC VIVE as input/output device, to be used in a Mini-bike exerciser device.
- Analyze the usability of each SG developed and compare it with each other.
- Analyze the intrinsic motivation of each SG developed and compare it with each other.
- Analyze cybersickness results for one of the SG which used a Head Mounted Display (HMD) and compare it with each other.

2 REVIEW

2.1 Serious Games Built Specifically for Rehabilitation using Affordable Access Devices

There are several academic studies on the use of SGs for rehabilitation and training. SGs for rehabilitation are highly dependent on software and hardware. Bonnechère (2018) relates the increase of SGs studies and publications to the commercial release of the Wii and Kinect sensors developed for commercial games, both with wide availability and affordable prices.l This review covers papers published from 2010, the year of the Kinect commercial release (MAMGAIN e DESAI, 2010), the oldest of all devices used in this study, until February 2018, using the following terms on the Google Scholar database: Kinect serious game, Myo Armband serious game, HMD serious game. This review describes relevant works found in the literature about SGs specifically built for rehabilitation, which was carried out focusing on the SG used and affordable access input/output devices. All the selected papers in this review used SGs built specifically for AT, designed by the research group or by a hired game developer team.

2.1.1 Kinect

SCHÖNAUER et al. (2014) describe the creation and usage of three SGs, used in lower back and chronic neck pain rehabilitation. These specifically built SGs were created using the Unity game engine and used the Kinect sensor as the input device, along with a biosignal sensor to acquire sEMG signals. There is a common storyline for all the three SGs; to provide motivation, the player score is shown during the gameplay. These SGs have three different objectives: increase reaching ability by extending the user's arms upwards to climb a mountain during the gameplay; increase walking speed by walking in a treadmill to control an avatar running in an ancient temple to collect items; increase cervical ROM by imitating head movements made by a character on the screen (Figure 9). Six volunteers used the system during four weeks with 2 sessions per week and 45 minutes per session (15 minutes preparation / 30 minutes gaming). During the first session the authors used questionnaires to determine pain intensity, level of disabilities and expectations. Also, after the last session the authors again used the same questionnaires to evaluate pain intensity, level of disabilities and expectations. In addition, usability, user experience and physical fitness were assessed. The authors also compared Kinect to Iotracker (IOTRACKER, 2014), another infrared motion tracking system, but a more expensive device compared to the Kinect. The authors concluded that volunteers were positive and enjoyed training with the developed SGs. Also, on clinical change, there was a positive trend of decreasing pain intensity and disability scores, and an increase on walking distance. They also concluded that the Iotracker is too expensive for home use and too difficult to be operated by a patient, and the Kinect can be used as an affordable access / easy to use input device.

Figure 9. User’s arm and head movements. Source: SCHÖNAUER et al. (2014).

JUNIOR and colleges (2013) describe the development and implementation of their SG called MoVER, for upper limb rehabilitation using the Kinect sensor and developed using the XNA game engine. The user uses their hands to reach objects passing through the screen, with its trajectory defined by a physiotherapist. The game consists of an image of the player on the screen which interacts with the objects. When the player reaches an object, a sound is emitted and the score, which shows on the screen, increments by the object´s value. A traffic light icon is displayed on the screen to correct the user´s posture. It has a red light when his/her posture is incorrect, and green when it is correct. Three adapted table tennis athletes with physical impairments tested the system, and the mean time to reach the objects was used to evaluate their usage. The authors did not use questionnaires to evaluate it and concluded that this SG allowed the patients to execute the physiotherapy exercises with the joy of a game. They also highlighted that the SG they created needs improvements in the graphics and more study needs to be done in the field of SGs for rehabilitation.

DUARTE, POSTOLACHE and SCHARCANSKI (2014) developed a SG for upper limb physiotherapy using the Unity game engine and the Kinect sensor. The game simulates harvesting apples with apple trees forming columns in both sides of the player. The apples fall from the trees and the user must execute movements with their arms to catch them and acquire points. The developers used two different colors, red and green, to differentiate the values of the apples. Two male participants played this SG for two minutes. The authors used eighty-seven seconds to collect data from the Kinect sensor to evaluate the performance of the system based on the range and velocity of the patient's hands. The difficulty of the game can be adjusted by the therapist responsible for the patient, and a comparison of each user during the different sessions was used to evaluate the tool. The authors did not use questionnaires to evaluate it.

2.1.2 Myo Armband

A group of researchers proposed a forearm rehabilitation system based on a SG in Augmented Reality (AR). AR enables the usage of the physical environment interacting with digital information, allowing users to manipulate objects in virtual space using real, thus tangible, objects. In this SG, tangible markers become objects inside the game, which can be visualized by the user. The user uses a real cube, rotating it to rotate a virtual cube and thus, redirect a bouncing ball to another cube, which is the target (Figure 10A). The game has two different levels, which are related to the ball speed, one slow and one fast. The Myo Armband was used to record sEMG signals in order to evaluate the applied force. The data was analyzed in order to find a relationship between the applied force and the difficulty of the game. The authors tested the SG with 5 healthy persons and found that the applied force is proportional to the sphere speed. Thus, they propose a SG in which the health professional responsible for the patient could set the game level ideal to the patient’s physical conditions and also monitor the rehabilitation process. They also claim that the usage of an affordable access portable device could reduce equipment and national healthcare system costs, by allowing it to be used in home rehabilitation (BEVILACQUA et al., 2015).

Lipovský and Ferreira (2015) developed a SG for stroke patients using the Unity engine. The Myo Armband was used as the input/output affordable access device, along with an Arduino based robotic glove developed by them. It was designed for hand rehabilitation and training, in which the user must grab, hold, transport and drop a cube, thus executing the exercises. The glove fitted on the impaired hand uses two stepper motors for hand opening/closing and also has touch buttons and detects a fully opened/closed hand. On the other hand, the Myo Armband was used on the healthy forearm (Figure 10B). The user executes the required movements, which are translated into movement of the virtual hand/arm in the SG. These movements are also translated to the robotic glove so the user executes them with the help of the robotic glove. The authors tested the system with healthy subjects and are planning to test it with stroke patients.

Lupu, Ungureanu and Stan (2016) developed a SG to be used for upper limb stroke rehabilitation. They built a scenario where a virtual therapist using pre-established exercise animations, coordinates the exercises which the patient must execute (Figure 10C). The application provides visual feedback for the patient when he/she executes it correctly, playing a sound, indicating when it was done correctly. It uses the Myo armband and the DataGlove to capture the patient's arm position and analyse the exercise. They also use the Oculus Rift HMD for better immersion. The authors separated the rehabilitation process in two different stages. The first one for patients who, immediately after the stroke, are unable to control their affected limb and it is associated with mirror box therapy. In this stage the user uses the Myo Armband and the DataGlove on their strong arm. They see both limbs in the VE, and moving the strong limb moves both limbs of the patient's avatar and the patient has the illusion of controlling their weakened limb. The second stage is for patients who already have enough movement on the affected limb. The Myo Armband and the DataGlove are placed on the impaired upper limb and the patient can see only the movements of this limb y while repeating the virtual therapist movements. The authors declared that preliminary tests suggest user's acceptance of the technology and a real potential for beneficial effects, and future tests with patients will be performed in a next study.

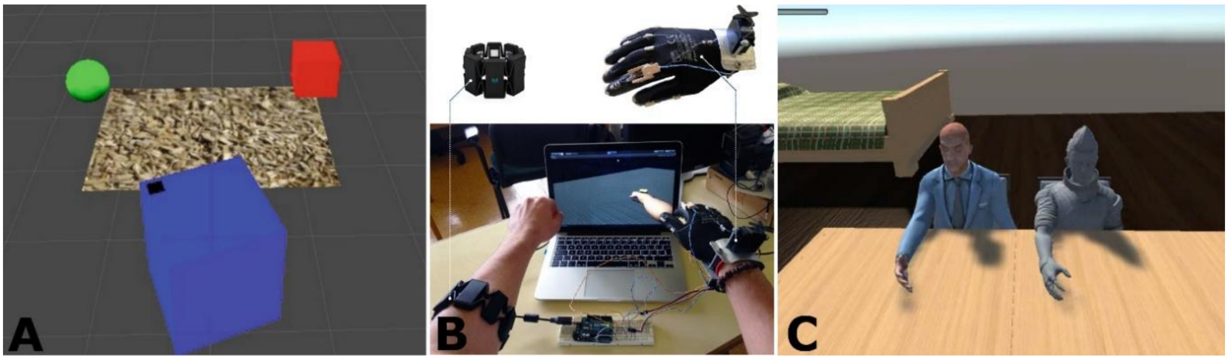


Figure 10. Myo Armband SGs. A) Cube rotation SG. B) Myo Armband and robotic glove. C) SG scenario with virtual therapist. Source: SCHÖNAUER et al., 2014, BEVILACQUA et al., 2015, LUPU, UNGUREANU, STAN, 2016.

2.1.3 Head Mounted Display devices

A group of researchers developed, using the Unity engine, a simulation SG using real-world imagery and a recumbent trike for peddling exercises which could be used for lower limb rehabilitation exercises. It uses an HMD device (HTC VIVE or Oculus Rift) to make immersive VR using Google Street View images. Data from trike speed sensor is passed to Unity, so the user moves through the streets peddling the trike. They developed two pedaling games for health and psychological assessment to test their tool, testing the user engagement and motivation. In the first game the players used the recumbent trike to safely cycle in different cities with a guided tour that describes each location. In the second game the players start in an unfamiliar city and need to navigate to landmarks to recognize those places. When the city is recognized, the player can choose between 3 guesses shown in the User Interface (UI) (Figure 11A). A successful guess will lead players to the next level. They evaluated their tool with young students and older adults. The results showed that both of the developed SG were engaging ways to do exercise for different age groups. The employment of real-world imagery in VR engaged participants to keep pedaling to explore new places, and most of the players were willing to register for future sessions. (WANG, IJAZ, CALVO, 2017).

A study has been conducted aiming the usage of new technology in order to assist traditional therapy and motivate patients to execute their rehabilitation program. A serious game for post-stroke patients was developed using the Unity game engine. It uses a Kinect V2, an HMD and a Smart TV as input/output devices. The developed SG can be used in six activities: flexion, abduction, shoulder adduction, horizontal shoulder adduction and abduction, elbow extension, wrist extension, knee flexion, and hip flexion and abduction (Figure 11B). The game consists of an on-screen character representing the player, which executes the same movements made by the player in front of the Kinect. The UI shows score, remaining time and level. The authors tested one of the game levels with 10 healthy participants aged between 61 and 75 years old, using two different visualization devices, a Smart TV and an HMD. Each session consisted of 30 seconds to perform a task and a two-minute rest interval between the use of each equipment. A usability evaluation protocol for 3D UI for older adults questionnaire was used to collect the user preference data. All the participants classified the developed tool as interesting, showing good acceptance. The authors concluded that the game could be used as a useful tool to motivate the patients during rehabilitation sessions (TROMBETTA et al., 2017).

Another study using an HMD device was conducted in order to analyze neuro-rehabilitation of children with movement disorders. It uses a robotic haptic device to sense touching of the virtual objects, in dual finger configuration (index and thumb). The developed system includes two training games intended to practice motor and cognitive abilities of children between 5 and 15 years old, with movement disorders and developmental delays. One of the SGs focuses on grasp and reaching tasks. The player is asked to grasp a golden coin and to insert it in a floating coin bank which rotates clockwise or counterclockwise during the game. The other game focuses on single joint movement (pointing) with the combination of shoulder abduction and adduction. This game is a labyrinth where a sliding token has to be driven through the maze by dragging it with the fingertip (Figure 11C). The authors conducted an experimental rehabilitation session consisting of playing the two serious games with a predefined set of parameters and repetitions: 15 grasping and reaching movements for the moneybox SG and four different planar paths for the labyrinth SG. The child had to repeat each level five and three times for the two games, respectively. In order to evaluate usability of the proposed rehabilitation system, the authors measured and compared between groups the following metrics: Missed Contacts, Completion Time, and Velocity. All the subjects and patients completed the rehabilitation session. The patients, who were familiar with conventional rehabilitation treatments, verbally reported they enjoyed the gaming experience. The authors concluded that the tool might be effective at motivating physical activity since its gameplay encourages exercise. They also highlight that the results are encouraging for application of the tool in a prolonged experimental treatment (BORTONE et al., 2017).

Figure 11 – HMD SGs. A) Trike pedaling exercises. B) User executing one of the rehabilitation movements. C) User dragging a token with the fingertip. Source: WANG, IJAZ, CALVO, 2017; TROMBETTA et al., 2017; BORTONE et al., 2017.

3 RESULTS AND DISCUSSION

This chapter will show the objectives obtained during the doctorate period, including software (registry), articles and hardware (patents). All the objectives obtained are a result of research based on a main aspect, which is the development of SG for rehabilitation and training. For organizational purposes, the work here is subdivided into two categories: SGs developed to be used by rehabilitation health professionals and SGs to be used in AT projects.

3.1 Serious Games for Rehabilitation Professionals

The first group of SGs were developed as products to be used by health professionals involved in physical rehabilitation. These games use movements commonly used in a rehabilitation session in order to play. A partnership was established with rehabilitation professionals from CREFES (Centro de Reabilitação Física do Estado do Espírito Santo, Brazil) and professors from the Department of Occupational Therapy UFES, to guide the development of these SG developments using their knowledge of rehabilitation needs.

Significant changes were made from the initial concept of the SGs to improve user experience and the final product, thus achieving better results. The most significant was the removal of BrainNet36, used in the early stages of the project (LYRA et al., 2016d). This change was done to maintain one of the main proposals of this research, which is the use of affordable access input/output devices, since BrainNet36 is an expensive medical device. Another significant factor for its removal was to improve the user experience, once the Kinect SGs are now fully free of cables connected to the patient, facilitating its usage, and greatly reducing its set up time. It is important to emphasize these previously cited factors because “difficulty of usage” and “high cost” are significant factors of AT abandonment (DA COSTA et al., 2015).

The input/output devices used in this category are commercial devices (Kinect sensor, Myo Armband and HTC VIVE), so they are already validated and commercialized. This helps make the developed software closer to a final and marketable product.

The term “Electronic Games” was used in the software title to replace “Serious Games”, since the former is more commonly used in a commercial context, and the latter is more commonly used in an academic context.

3.1.1 Production 1 – Computer Software Registration

Process nº: BR 51 2018 000826-7 (Attachment 1)

Description in English:

VIRTUAL-R: Electronic Games for Motor Rehabilitation

The computer program of this application (**Virtual-R: Electronic Games for Rehabilitation**) was developed to be used in processes of physical rehabilitation and neurorehabilitation, that use treatments with repetitive movements and cognitive tasks. In conventional rehabilitation sessions, patients perform repetitive pre-established movements over a period of time. The repetitiveness makes the rehabilitation process monotonous and discouraging. Using the software developed in this patent application, the patient undergoing the rehabilitation process can perform the pre-established tasks, performing the same movements used in the conventional sessions, but interacting with electronic games, which were developed specifically for this purpose. Another advantage over conventional therapies is that, while the patient performs the sessions, the health professional follows his/her and can evaluate their progress over time, comparing the data of each session, such as the number of sessions performed, the score obtained in each session and the number of repetitions established for each session. These electronic games play a fundamental role in the motivation of the patients, since it presents a playful interface that captures the attention of the users, as well as different and gradual levels of difficulty. These features encourage users to seek better scores for each session. The health professional who accompanies them can, when they deem it necessary, increase the level of difficulty to follow their progress, maintaining the level of challenge that is conducive to each individual.

This program was developed using Unity3D game engine version 2017.1.1.f1 Personal Edition, and C # programming language. Unity3D Personal Edition is free to download, and developers who use it can market their games on it without paying royalties if the total revenue from each game is less than $ 100,000 a year. If the profit generated with the commercialization is higher than this value, the developer needs to buy a Pro version. The objects presented in the electronic games were built using Blender 3D, a free 3D modeling and texturing program. Some of the images used were treated in GIMP, a free image processing program.

This program can run on computers with a video card with support for DX9 or higher, Microsoft Windows XP SP2+ or higher and does not require installation, running directly from the folder through the Virtual-R.exe file. It is presented to the user in the form of a platform with 4 games that can be used in 3 different commercial devices (HTC VIVE, Myo Armband and Microsoft Kinect 2). These devices are displayed in the main menu and the user can select which device to use by clicking on their respective image (Figure 1), which leads to a submenu with options for the selected device. If the user is using the program for the first time, he can register with his name so that his data is stored. If the user is already registered, he can select his name from a list of registered users to continue saving the number of repetitions used in each session and the scores obtained. This score is presented to the patient at the beginning of each match, so that he/she is aware of the points obtained in the previous match (Figure 2). This presentation is important to encourage the patient to achieve better results.

Figure 1. Device Menu.

Figure 2. Table with score obtained in previous matches.

The commercial devices used to control the developed games work as input device (Microsoft Kinect 2) or input/output devices (Myo Armband and HTC VIVE).

For the Kinect 2 device, 2 games with winter sports theme were developed, where the user controls a skier or a snowboarder. Kinect features a depth (Infrared) sensor that records user movements and detects movements that can be used to trigger actions in games and applications. For these two games, two different movements commonly used in rehabilitation processes with repetitive movements were programmed, using Kinect SDK software. In the ski game, the user controls the athlete to jump obstacles and collect coins that increase their score, which is constantly informed on the screen

(Figure 3). The number of repetitions of the rehabilitation exercise is determined by the health professional and assigned at the beginning of each match. This number represents the number of obstacles to be jumped and determines the position of the finish line. As soon as the avatar passes through the finish line, the game ends and his/her points are counted. To perform the jump the patient, who sits during the game, should stand up. This movement is captured by the Kinect, and it triggers the skier's jump. The snowboarding game works like the ski game regarding the number of repetitions and positioning of the finish line. However, what triggers the jump is an extension movement of the patient's right or left leg (selected during repetition selection), which remains seated throughout the course. In this game the snowboarder must jump using ramps of the course, and the punctuation is given by the maneuver executed by the athlete, which are 3 different maneuvers. What determines the maneuver executed is the positioning of the athlete in the ramp, which worth different scores, being the lower position of the ramp with a lower value, the median with an average value and the upper position of the ramp with a higher value. These positions are highlighted with colored flags in the side of each ramp, being the lower position highlighted with a yellow flag, the median with a green flag and the upper one with a blue flag (Figure 4). After each jump the obtained score is immediately informed to the user, and the score is added to the total score, which is constantly displayed on the corner of the screen. In addition to the jump score, the player also obtains points collecting coins (Figure 5). This score is also added to the total score.

Figure 3. Skier jumping obstacle and collecting coins.

Figure 4. Colored flags indicating the position of each jump.

Figure 5. Snowboarder performing stunt and collecting coins.

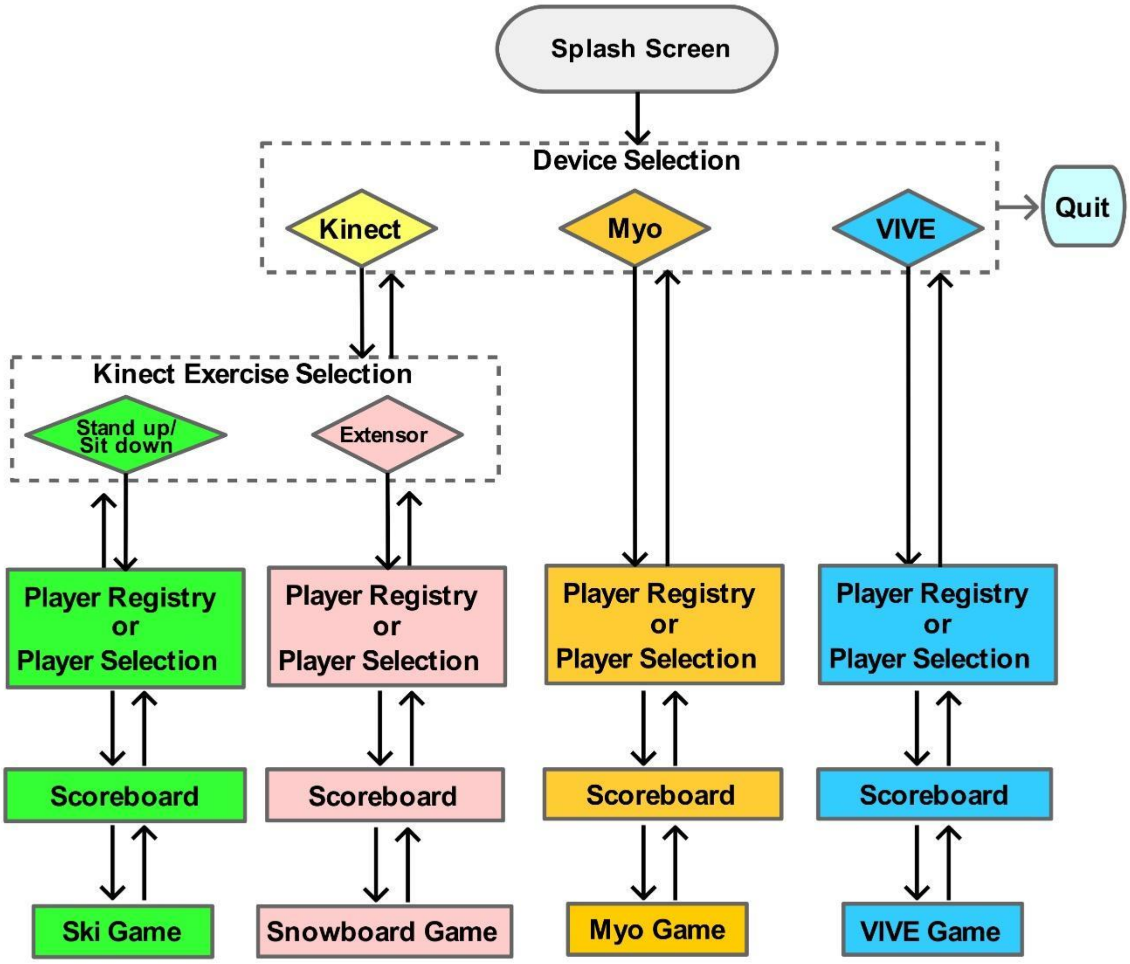
For the input and output device, Myo Armband, a target shooting game was created. This device features positioning and direction sensors (gyroscope, accelerometer, magnetometer) which the user uses to control the gun and aim at targets. To capture the muscle signals from the user's forearm, Myo Armband uses sEMG electrodes. Executing a closed fist movement, the gun fires a projectile that, if it hit the target, generates an impact that removes the target from the shelf, and immediately informs the player the obtained points (Figure 6). The score for each hit is added to the total score of the play, which is constantly displayed in the corner of the screen. The number of repetitions, which is chosen before each match, is converted into ammunition of the weapon, it is, the user can perform the rehabilitation move and fire the weapon as many times as the number of bullets he/she has, which is the same number of repetitions chosen before the start of the match.

Figure 6. Target being hit and score added.

For the virtual reality device (HTC VIVE), a virtual supermarket scenario was created in which the player must collect products from the shelves and place it in a shopping cart, which is placed in the aisle, obtaining points for each item added. This score is displayed in a panel just ahead of the shopping cart (Figure 7). Before each match, the health professional determines how many objects will be collected by the patient by selecting the number of repetitions. The number of repetitions and the score obtained are displayed in a table before and after each game. The health professional determines which objects should be collected. The complexity of the exercise is linked to the range of motion that the patient will perform, where objects higher up or down the shelf require greater amplitude and greater effort. Objects that require the use of both hands also require more of the patient. In addition to the physical part the cognitive is worked because the user must look for specific items on a shelf with a large variety of objects, which requires attention.

Figure 7. Virtual supermarket.

Fluxogram:



Especificações em português:

Virtual-R: Jogos Eletrônicos para Reabilitação

O programa de computador deste pedido de registro (**Virtual-R: Jogos Eletrônicos para Reabilitação**) foi desenvolvido para ser utilizado em processos de reabilitação física e neuroreabilitação, que utilizam tratamentos com movimentos repetitivos e tarefas cognitivas.

Em sessões de reabilitação convencionais os pacientes realizam movimentos preestabelecidos repetitivos durante um período de tempo. A repetitividade acaba tornando o processo de reabilitação monótono e desestimulante. Utilizando o software desenvolvido neste pedido de patente, o paciente que passa pelo processo de reabilitação pode realizar as tarefas preestabelecidas, realizando os mesmos movimentos utilizados nas sessões convencionais, mas interagindo com jogos eletrônicos, os quais foram desenvolvidos especificamente para esse propósito. Outra vantagem sobre os tratamentos convencionais é que, enquanto o paciente realiza as sessões, o profissional de saúde o acompanha e pode avaliar seu progresso ao longo do tempo, comparando os dados de cada sessão, como por exemplo o número de sessões realizadas, pontuação obtida em cada sessão e o número de repetições estabelecido para cada sessão. Os jogos eletrônicos desenvolvidos neste programa de computador têm papel fundamental na motivação dos pacientes, uma vez que apresenta uma interface lúdica que prende a atenção dos usuários, além de pontuações e níveis de dificuldade diferentes e graduais. Essas características incentivam os usuários a buscar melhores pontuações a cada sessão realizada. O profissional de saúde que os acompanha pode, quando julgar necessário, aumentar o nível de dificuldade para acompanhar seu progresso, mantendo o nível de desafio propício para cada indivíduo.

Este programa foi desenvolvido utilizando o motor de jogos Unity3D versão 2017.1.1.f1 Personal Edition, e linguagem de programação C#. O Unity3D Personal Edition é gratuito para download, e os desenvolvedores que o utilizam podem comercializar seus jogos nele desenvolvidos sem pagar royalites se o total arrecadado com as vendas de cada jogo for menor que 100.000 dolares estadunidenses anuais. Caso o lucro gerado com a comercialização seja superior a esse valor, o desenvolvedor precisa comprar uma versão Pro. Os objetos apresentados nos jogos eletrônicos foram construídos utilizando o Blender 3D, um programa gratuito de modelagem e texturização 3D. Algumas das imagens utilizadas foram tratadas no GIMP, um programa de tratamento de imagens gratuito.

Este programa pode ser executado em computadores com placa de vídeo com suporte a DX9 ou superior, e Microsoft Windows XP SP2+ ou superior e não requer instalação, sendo executado diretamente da pasta pelo arquivo Virtual-R.exe. Ele é apresentado ao usuário em forma de uma plataforma com 4 jogos que podem ser utilizados em 3 dispositivos comerciais diferentes (HTC VIVE, Myo Armband e Microsoft Kinect 2). Esses dispositivos são apresentados no menu principal e o usuário pode selecionar qual dispositivo vai utilizar clicando sobre sua respectiva imagem (Figura 1), o que o leva a um submenu com opções para o dispositivo selecionado. Se o usuário está utilizando o programa pela primeira vez, ele pode realizar um cadastro com seu nome, para que seus dados sejam armazenados. Se o usuário já está cadastrado, ele pode selecionar seu nome em uma lista de usuários cadastrados para continuar salvando o número de repetições utilizadas em cada sessão e as pontuações obtidas. Essa pontuação é apresentada para o paciente no inicio de cada partida, para que ele tenha ciência dos pontos obtidos nas partidas anteriores (Figura 2). Essa apresentação é importante para incentivar o paciente a obter melhores resultados.

Os dispositivos comerciais que podem ser utilizados para controlar os jogos funcionam como equipamentos de entrada (Microsoft Kinect 2) ou de entrada e saída (Myo Armband e HTC Vive).

Para o dispositivo Kinect 2 foram desenvolvidos 2 jogos com tema de jogos de inverno, onde o usuário controla um esquiador ou um *snowboarder.* O Kinect apresenta um sensor de profundidade (Infravermelho) que registra os movimentos do usuário e detecta movimentos que podem ser usados para disparar ações nos jogos e aplicativos. Para os jogos utilizados neste projeto foram programados, com o Kinect SDK, dois movimentos que são utilizados em processos de reabilitação com repetição de movimentos. No jogo de ski o usuário controla o atleta para saltar obstáculos e coletar moedas que aumentam sua pontuação, que é constantemente informada na tela (Figura 3). O número de repetições do exercício de reabilitação é determinado pelo profissional de saúde e atribuído no início de cada partida. Esse número representa a quantidade de obstáculos a serem saltados e determina a posição da chegada no percurso. Assim que o avatar passa pela chegada a partida termina e seus pontos são computados. Para realizar o salto o paciente, que fica sentado durante o jogo, deve se levantar. Esse movimento é captado pelo Kinect que dispara o salto do esquiador. O jogo de snowboard, funciona como o jogo de ski quanto ao número de repetições e posicionamento da chegada. Porém o que dispara o salto é um movimento de extensão da perna direita ou esquerda do paciente (selecionada durante a seleção de repetições), que permanece sentado durante todo o percurso. Neste jogo o *snowboarder* deve saltar usando rampas do percurso e a pontuação é dada pela manobra executada pelo atleta, que são 3 manobras diferentes. O que determina a manobra executada é o posicionamento do atleta na rampa, que valem pontuações diferentes, sendo a posição inferior da rampa com menor valor, a mediana com valor médio e a posição superior da rampa com maior valor. Essas posições são destacadas com bandeirinhas coloridas, sendo a posição inferior destacada com uma bandeirinha amarela, a mediana com uma bandeirinha verde e a superior com uma bandeirinha azul (Figura 4). Ao saltar a pontuação é informada imediatamente ao usuário e o valor é adicionado ao total de pontos da jogada sendo este apresentado constantemente canto da tela. Além da pontuação do salto, o jogador também obtém pontos coletando moedas (Figura 5). Essa pontuação é somada à pontuação total.

Para o dispositivo de entrada e saída Myo Armband foi desenvolvido um jogo do tipo tiro ao alvo. Este dispositivo apresenta sensores de posicionamento e direção (giroscópio, acelerômetro, magnetômetro) os quais o usuário utiliza para controlar a arma e mirar nos alvos. Para capturam os sinais musculares do antebraço do usuário, o Myo Armband utiliza eletrodos sEMG, e com movimento de cerrar o punho o usuário acionar a arma e disparar um projétil que, ao atingir os alvos, gera um impacto que retira o alvo atingido da estante de alvos, e imediatamente informa ao jogador os pontos obtidos (Figura 6). Essa pontuação de cada alvo atingido é adicionada ao total de pontos da jogada que fica constantemente sendo apresentado no canto da tela. O número de repetições, que é escolhido antes de cada partida, é convertido em munição da arma, ou seja, o usuário pode executar o movimento de reabilitação e disparar a arma tantas vezes quanto o número de balas que ele tem, que é o mesmo número de repetições escolhido antes do início da partida.

Para o dispositivo de realidade virtual HTC VIVE foi criado um cenário de um supermercado virtual onde o jogador deve coletar produtos das prateleiras para colocar em um carrinho de compras que está posicionado a sua frente, obtendo pontos para cada item adicionado. Essa pontuação é exibida em um painel logo à frente do carrinho de compras (Figura 7). Antes de cada partida o profissional de saúde determina quantos objetos serão coletados pelo paciente selecionando o número de repetições. O número de repetições e a pontuação obtida são expostos em uma tabela antes e depois de cada partida. O profissional de saúde determina quais objetos devem ser coletados. A complexidade do exercício está ligada à amplitude do movimento que o paciente vai realizar, onde os objetos mais acima ou mais abaixo na prateleira exigem maior amplitude e maior esforço. Objetos que exigem a utilização de ambas as mãos também exigem mais do paciente. Além da parte física o cognitivo é trabalhado pois o usuário deve procurar itens específicos em uma prateleira com uma variedade grande de objetos, o que exige atenção.

3.1.2 Production 2 – Submitted article

Games for Health Journal (attachment 2)

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Development and Evaluation of a Multi-Device Serious Games Platform for Rehabilitation Purposes

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Development and Evaluation of a Multi-Device Serious Games Platform for Rehabilitation Purposes

Objective: Compare levels of intrinsic motivation, cybersickness, and usability of a Serious Games Platform built specifically for rehabilitation purposes, which use commercial and affordable access devices.

Materials and Methods: Four Serious Games were tested and evaluated by volunteers, therapists, and patients with disabilities using the System Usability Scale (SUS), Intrinsic Motivation Inventory (IMI), and Simulation Sickness Questionnaire (SSQ).

Results: Results indicate high motivation and usability scores for people with impairments using the proposed rehabilitation platform, as well as acceptable levels of cybersickness symptoms.

Conclusion: High intrinsic motivation levels were registered during the rehabilitation sessions with the Serious Games presented in this research. Low Value/Usefulness results from users without impairment were obtained as expected according to internalization studies, in which the value and usefulness of an activity influences the intention of performing it.

Keywords: serious games; physical rehabilitation; intrinsic motivation; system usability, simulation sickness.

Introduction

The World Health Organization (WHO) estimates that more than a billion people live with some form of disability, and almost everyone will be, at some point of their life, temporarily or permanently impaired. Also, rates of disability are increasing due to population aging (WHO 2011). Disability can be defined as any physical or mental impairment, substantially limiting daily activities. It includes, but is not limited to learning disabilities, blindness or low vision, hearing loss, speech impairments, and mobility impairments. Mobility disabilities include a broad range of disabilities that affect motor skills, causing problems to people's limbs, muscles or nerves, including limitations caused by pain, which can affect dexterity and motor skills. It may be acquired congenitally or during life, from physical injury or disease (Robitaille 2010). The WHO also relates disability and poverty, showing that people with disabilities are at a disadvantage in educational attainment, labor market outcomes, as well as wealth (WHO 2011). This highlights the importance of researching and developing affordable access treatments and making them available for all social levels.

Rehabilitation is to use a set of measures to restore or return a person, who is experiencing disability, to a state of optimal functioning in their environment (Meyer, et al. 2014) (WHO 2011). Many therapies go through repetitive exercise sessions, which can usually be adapted to the patient's needs (Delisa, Gans e Walsh 2005). Many patients, depending on the impairment, may experience trauma, and since, in many cases, sequelae can result in paralysis on limbs, speaking problems and difficulties to realize simple tasks. It is common, for example, for stroke survivors to experience depression, and it may be difficult for the patients to engage in therapy. Even though rehabilitation plans attempt to stimulate patients with a variety of rehabilitation exercises, it is a common complaint that traditional rehabilitation tasks can be boring due to their repetitiveness (Burke, et al. 2009). Thus, Serious Games (SG) can be used by patients and therapists, as a motivational tool, helping patients to execute rehabilitation exercise during therapy sessions. To do so, SGs use features, like goals or scores to be reached during the gameplay, increasing motivation and persistence. The possibility to adjust the balance between challenge and skill, the delivery of real-time feedback of the activity, and the experience of improvement of the user's real life movements, are some benefits of SGs in rehabilitation (Bonnechère 2018).

The aim of this study is to compare levels of intrinsic motivation from the usage of four SGs built specifically for rehabilitation purposes, which use commercial and affordable access devices. These SGs were evaluated by groups of participants with physical impairments and groups of participants without physical impairments, using the Intrinsic Motivation Inventory (IMI). Other objectives of this research were to check the usability of these SGs using the System Usability Scale (SUS), by both groups of volunteers, with the addition of a third group, composed of therapists. Finally, an assessment of cybersickness symptoms was also conducted using the Simulation Sickness Questionnaire (SSQ) for one of the SGs which used a Head Mounted Display (HMD).

Materials and Methods

Development of Virtual-R

Virtual-R, an SG platform, was developed here to help rehabilitation professionals and patients through engaging and motivating rehabilitation sessions. Virtual-R was presented, in its early stages, to therapists from the Physical Rehabilitation Centre of Espirito Santo (CREFES/Brazil) and professors from the Department of Occupational Therapy at the Federal University of Espirito Santo (DTO - UFES) to guide the SG development using their knowledge of rehabilitation needs.

Using Virtual-R, a patient who goes through a rehabilitation process can make pre-established tasks, performing movements in conventional sessions, but also interacting with electronic games, which were developed specifically for this purpose. Therapists, who guided and accompanied the patients during the sessions, could register their patients to have their data recorded, and also follow their progress through the sessions. Name, session, number of repetitions, score, and performance data are stored. Before each session, previous scores are shown, so the patients can try to improve their scores, promoting motivation. In this same screen, a menu with different levels is shown, so the therapist can adjust the balance between challenge and skill. In fact, setting an appropriate level for the patient is emphasized as a key feature for SGs by several authors (Bonnechère 2018) (Burke, et al. 2009) (Levac e Sveistrup 2014).

Virtual-R was developed using Unity3D game engine version 2017.1.1.f1 Personal Edition, and C # programming language. The models used in the electronic games were built using Blender 3D, a free 3D modelling and texturing program. Some of the images used in the Virtual-R were treated in GIMP, a free image processing program. A computer with Windows 10, 8GB of RAM, Intel i7 processor, and an MSI GeForce GTX 1060 graphics card was used to run all the software used in the development process. This same computer was used to execute the Virtual-R during the test sessions.

Serious Games and Access Devices

Four SGs compose the Virtual-R, and three affordable access commercial devices can be used: Kinect V2, Myo Armband and HTC VIVE. The main menu screen of Virtual-R presents images of these devices to be selected by the user or the professional as the device to be used in the session (Figure 1). Virtual-R was designed to be expansible and updatable as new SGs can be developed to use these devices and new devices can be introduced, increasing the use scope of the platform

Figure1. Virtual-R main menu with selectable devices.

The Kinect V2 is a sensor used to track the 3D position of the human body. It builds a simplified skeleton model of the user and uses their movements as inputs (Andersen, et al. 2012). In one of the games, named “sky game”, the patient controls a skier skiing on a track with obstacles. The patient needs to jump the obstacles and catch coins to score (Figure 2B, Figure 2C). To execute the jump, the user needs to make the Sit to Stand exercise (Figure 2A). The number of obstacles and the time between each obstacle is set by the therapist before each session. With this option, the therapist can set an appropriate level for each patient, and adjust the challenge.

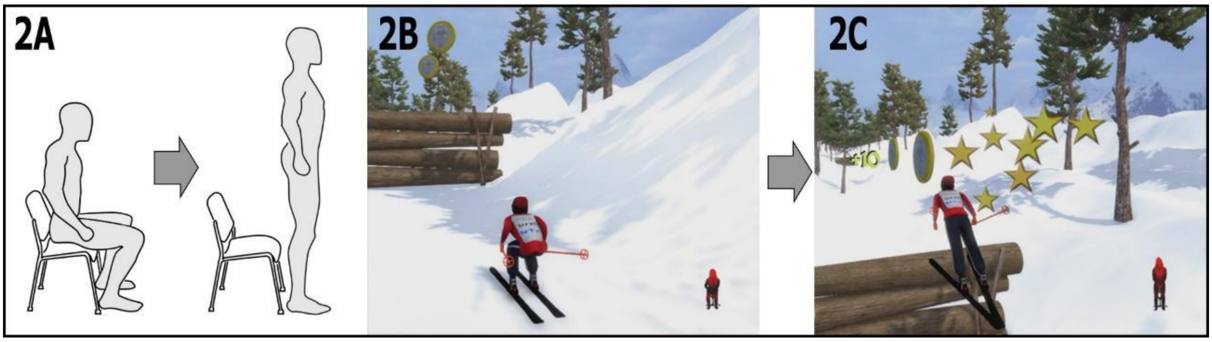

Figure 2. A) Exercise executed by the user to trigger the jump. B) SG screen with skier reaching one of the obstacles. C) SG screen with skier jumping over one of the obstacles, collecting coins. The images on the bottom right corner on images B and C are representations of the user displayed by the Kinect sensor.

Another game, named "snowboarding game" has the same structure of the "ski game" regarding score and repetitions, but instead of obstacles, this game has ramps (Figure 3B, Figure 3C). The user needs to execute the knee extension exercise in order to make the snowboarder jump on each ramp (Figure 3A).

Figure 3. A) Exercise executed by the user to trigger the jump. B) SG screen with snowboarder reaching one of the ramps. C) SG screen with snowboarder jumping using the ramp to collect coins. The images on the bottom right corner on images B and C are representations of the user displayed by the Kinect sensor.

The Myo Armband is a device worn on the forearm, which uses eight surface electromyography (sEMG) sensors to capture the electrical activity of muscles. It has a wireless connection with the computer and built-in gyroscope, accelerometer, and magnetometer (Ganiev, Shin e Lee 2016). It is used, in Virtual-R, to play a circus-like target shooting game, which uses its position and orientation sensors to control the gun movement, and its sEMG sensor to trigger the gun by using the full fist exercise (Figure 4A). In this game, the player has to point their hand to the screen and aim at targets placed on a shelf (Figure 4B). The full fist exercise makes the gun shoot. If the bullet hits a target, this is removed from the shelf and a score is added (Figure 4C). The number of repetitions set by the therapist for a session is equal to the amount of ammunition for that session, so the patient uses all the bullets executing the full fist exercise to shoot the targets. To keep the challenge level, the more the patient advances in the game, the smaller the targets become and therefore more difficult to hit.

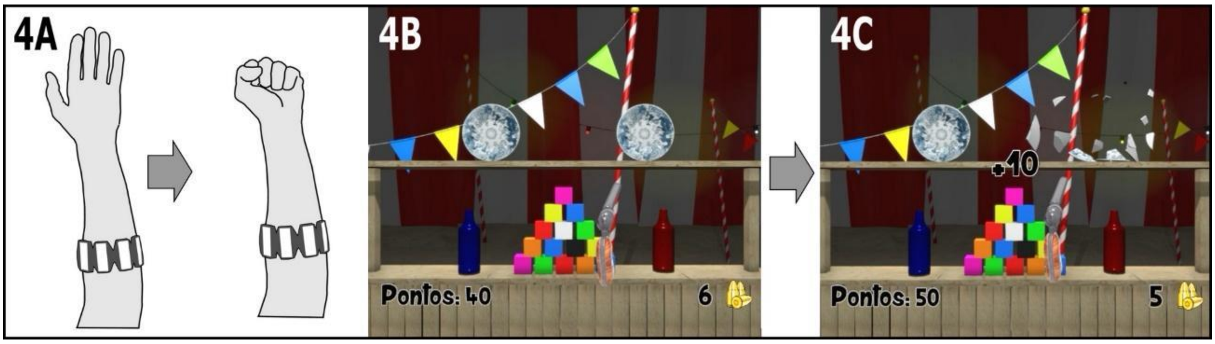

Figure 4. A) Exercise executed by the user to trigger the gun. B) SG screen with shelf and targets. C) After the shot, the plate at the top right is broken, removing it from the shelf. A score is added, and the number of bullets, which represents repetitions, is subtracted by one.

The HTC VIVE is an HMD device composed of an accelerometer, gyroscope, laser tracking and hand controllers (Borrego, et al. 2018). It is used in Virtual-R to play a market game where the player uses the HMD to visualize and move through the market aisle, and the controllers to get items on the shelves. It uses reach movement, with different heights, and a grasping movement. The objective of the game is to collect items from the market shelf and place them in a market cart, which is located in the same aisle. The aim is to make the patient walk through the aisle, searching for the desired item and use, mainly, their upper limbs to reach it (Figure 5A). The grasping is done by pressing and holding pressed a button on the controller while it is touching the object, and this makes a grasp-like action (Figure 5B). The user needs to take the object to the cart and release the controller button to put the collected item in the cart (Figure 5C). There is, above this cart, a sign with the player’s score and an image of the next item they need to pick up (Figure 5C). Each right item collected adds score, and a wrong item adds no score. The number of repetitions, i.e., the number of items to be collected by the patient, is set by the therapist before each session. Also, four different levels of difficulty can be set. These difficulties change the height of the items that the patient must collect. Easier items to collect are in the middle shelves, which require less range of motion and more difficult items to collect are on the top and bottom shelves, requiring a greater range of motion. Also, in the final level, the patient needs to pick up items that require the usage of both hands.

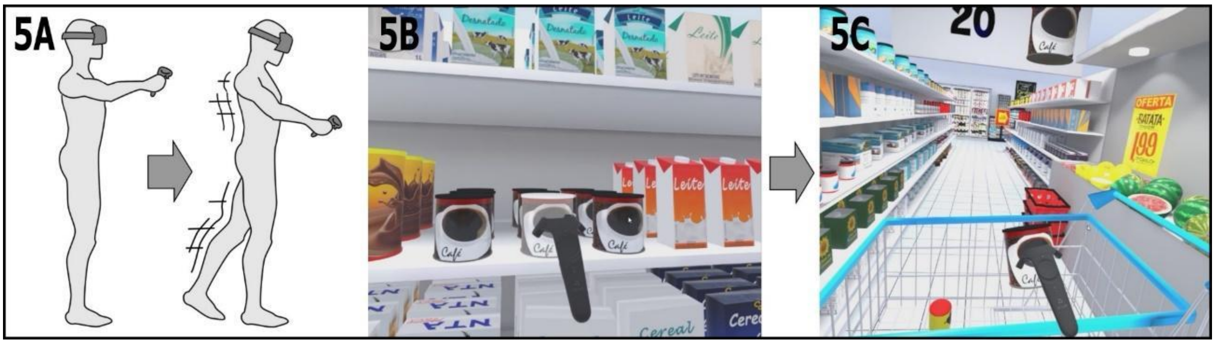

Figure 5. A) This exercise consists of user´s movements, with reach and grasp actions. B) The item is highlighted when the user touches it with the controller, indicating it can now be collected. C) The cart, where the user needs to leave the items, can be seen in the bottom of this image and on top, a sign with player´s score and the next item to be collected.

Questionnaires (IMI, SUS, and SSQ)

Motivation for doing rehabilitation exercises was assessed with the Intrinsic Motivation Inventory (IMI). The IMI is an instrument for evaluating the intensity of individual´s intrinsic motivation for a target activity (Fitzgerald, et al. 2010). The subscales used in this study were: interest/enjoyment, effort, and value/usefulness.

To assay the usability of Virtual-R, SUS, a ten-item five-point Likert scale was used. SUS takes into account three different aspects: effectiveness (the ability of the user to complete the task, and the quality of the output), efficiency (how much effort and resources was needed), and satisfaction (contentment from the system usage). SUS must be responded right after the system usage (Brooke 1996). SUS is a suitable tool to evaluate a system for its ease of use and the need of professional assistance to use it (Sauro 2016).

The Simulation Sickness Questionnaire (SSQ) was used to verify the cybersickness results for the market SG, which used i a Head Mounted Display (HMD) as the input/output device. The SSQ is used to assess symptoms caused by exposure to a VR. It´s results are presented here by the Total Severity (TS) score, which is obtained by applying the TS score to three subscales: Oculomotor, Disorientation and Nausea (Kennedy, et al. 1993).

Participants

The SGs were tested and evaluated by healthy volunteers, therapists, and patients with reduced mobility (Figure 6). After a presentation of the final version of Virtual-R, therapists were invited to participate in the tests with patients who were under their care and could use Virtual-R exercises in their type of rehabilitation. The therapists operated the system during the test, guiding their patients during all sessions. The group of volunteers without physical impairment consisted of graduate students of UFES/Brazil. Table 1 shows the number of volunteers who participated in the tests for each SG, the causes of the physical impairment in the patient group, and the occupation of the therapist. All volunteers were asked to sign two free and informed consent forms, and kept one of them.

Figure 6. A) Patient executing Sit to Stand movement. B) Patient executing knee extension movement. C) Rehabilitation professional accompanying the patient using the Myo Armband with the target shooting SG. D) A patient using the HTC VIVE in a market SG session.

Table 1. Number of participants for each SG, and impairment cause of the participants from the patient group and participants profession of the therapist group.

	Ski	Snowboarding	Target Shooting	Market

Volunteers with physical impairments	6 Stroke (2), GBS (1), Paraplegia (2), Arthrosis (1)	11 Stroke (5), Paraplegia (2), Arthrosis (1). GBS (1), Arthrosis (1), tendon injury (1)	9 GBS (1), nerve injury (1), tendon injury (2), fracture (1), CRPS (2), TBI (1), paraplegia (1)	12 CRPS (2), fracture (1), nerve injury (1), neural leprosy (1), tendon injury (2), nerve injury (2), arthroplasty (1), epicondylitis (2)
Volunteers without physical impairments	15	14	14	13
Rehabilitation professionals	5 Occupational Therapist (3), Physiotherapist (2)	3 Occupational Therapist (2), Physiotherapist (1)	7 Occupational Therapist (6) Physiotherapist (1)	7 Occupational Therapist (6) Physiotherapist (1)

GBS: Guillain Barré Syndrome; CRPS: Complex regional pain syndrome; TBI: Traumatic brain injury;

Procedure

The study was run between September 2018 and November 2018. The test consisted of using the SGs of Virtual-R and their evaluation. The basic protocol was the same for all four SGs. Initially, the user undergoes a training session, where they had free time to test the SG. When the user indicated that they were comfortable with the game mechanics and to the device, a four-session test began, where each session had a different and growing number of repetitions. The number of repetitions was pre-established by the therapists during the development of each SG. For ski and snowboarding SGs, the repetitions were divided in 4, 6, 8 and 10. For the target shooting and the market SGs, 5, 10, 15, and 20 repetitions were used.

All the players responded to the IMI and SUS questionnaires at the end of the test. The players of the group of volunteers with physical impairments responded, in addition, an IMI questionnaire before using the SGs, which happened right after their rehabilitation session. The objective was to make a comparison, regarding motivation, between standard rehabilitation exercises and SGs rehabilitation exercises. All the players who used the HMD responded the SSQ questionnaire before and after the market game session. The therapist also responded to the SUS questionnaire after using Virtual-R with their patients.

The test protocol designed for the experiments was approved by the Federal University of Espirito Santo Ethics Committee (protocol number 2264126).

Results

The average score and standard deviation were calculated for the SUS (see Figure 7) and IMI questionnaires (see Figures 8, 9, 10, and 11) for each SG and for each group of participants. Moreover, the IMI scores are presented in three subscales: “interest/enjoyment”, “effort”, and “value/usefulness”.

Additionally, paired sample student’s t-tests were conducted for people with impairments comparing the IMI scores after using the Virtual-R and after doing a standard therapy session. These comparisons were made for each IMI subscale and for each SG. Furthermore, two-sample t-tests were performed between the group of people without impairments using the Virtual-R and people with impairments using the Virtual-R.

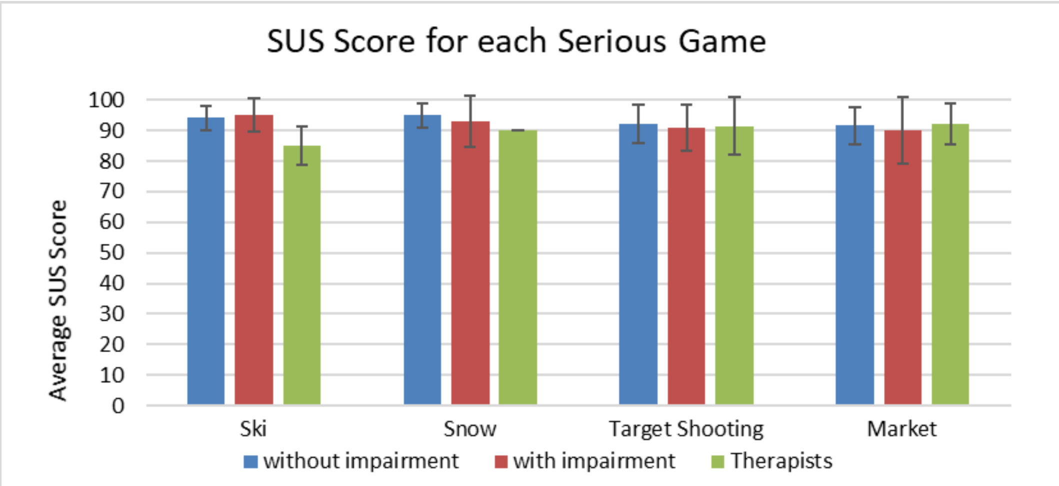

Figure 7. SUS results.

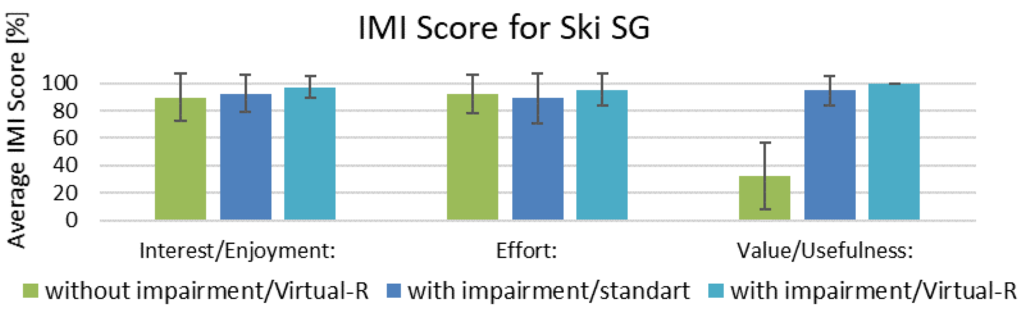

Figure 8. IMI results for ski SG.

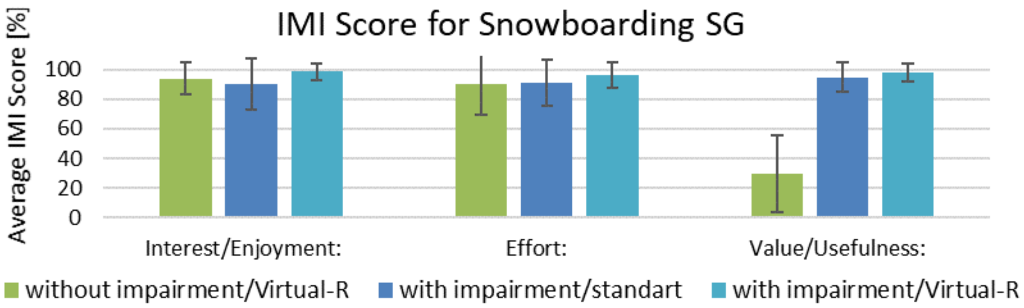

Figure 9. IMI results for snowboarding SG.

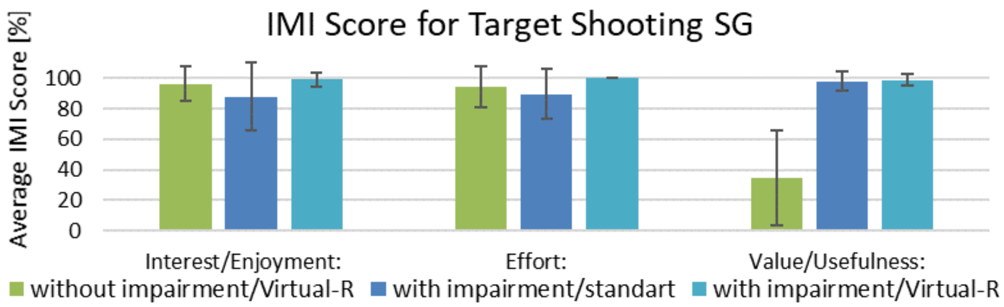

Figure 10. IMI results for target shooting SG.

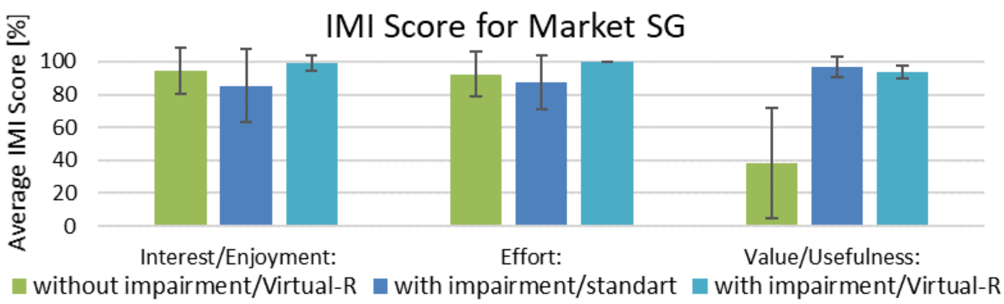

Figure 11. IMI results for market SG.

All average scores from the SUS and IMI questionnaires were above 85% as can be seen in Figures 7, 8, 9, 10, and 11, except for the “value/usefulness” subscale in the IMI questionnaire. This subscale shows lower scores for people without impairment in contrast to the scores from people with impairments.

According the paired-sample t-tests results, there is enough evidence to say that there is no significant difference ($p>0.05$) between any of the average IMI scores for people with impairments, except for the subscales: "effort" in the Target Shooting SG ($t(2)=7.559$, $p=0.0171$), and "interest/enjoyment" in the Target Shooting SG ($t(4)=8.37$, $p=0.0011$) and in the Market SG ($t(4)=6.46$, $p=0.0029$).

The results from the two-sample t-tests show that there is no significant difference ($p>0.05$) between most of the IMI scores from the group of people without impairments and the ones with impairments, both using Virtual-R. However, there is a significant difference ($p<0.01$) in their "value/usefulness" subscale scores.

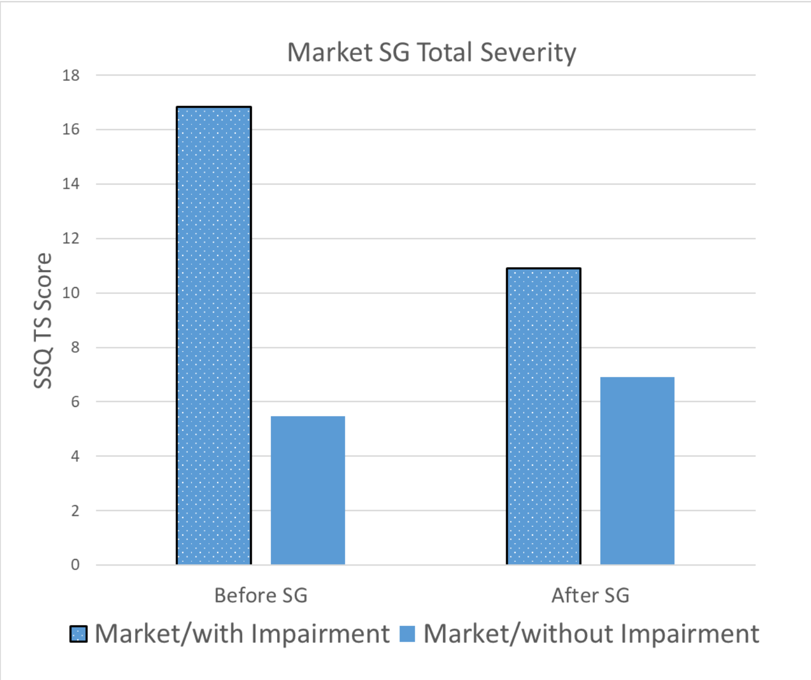

Figure 12. SSQ results for players all who used the HMD in the market SG.

The SSQ TS score from people without impairments shows a slight increase from the test before the SG score (5.46) to the after SG score (6.90). On the other hand, the SSQ TS score for people with impairments decreased from the before SG score (16.83) to the after SG score (10.90).

Discussion and Conclusions

This study examined the usability and intrinsic motivation of a SGs platform, which uses affordable access devices as tools to be used by rehabilitation professionals with patients undergoing physical rehabilitation. Also, the market SG was assessed with the SSQ questionnaire to check cybersickness level.

All the SGs of the Virtual-R platform, and its usage by the therapists as a rehabilitation tool, were assessed as having high usability (above 85%), where systems with SUS scores over 68% are considered to have "above average" usability (Sauro 2016).

The SSQ results show that the usage of the HTC VIVE with the market game had little impact on cybersickness. The reduction of the TS score from before SG to after SG tests on the group of people with impairment can be explained by the fact that the tests were done after their standard rehabilitation session. The experience with the market SG could have caused some relief/diversion from the rehabilitation session.

Some patients verbally reported their experience playing with the SGs as fun, and would like to use it on their rehabilitation sessions independently of the type of SG and its design for specific therapies. This can be seen in the results from the IMI, whose mean value is above 85% for all categories, except for Value/Usefulness for people without impairments. A mean value above 80% suggests that these SGs are highly motivational tools for patients undergoing physical rehabilitation. Furthermore, the t-tests showed a difference in the "effort" and "interest/enjoyment" scores from the target shooting game and the "interest/enjoyment" from the market game for people with impairments, indicating that they were especially engaged playing these SGs. This suggests that the participants had a stronger preference for SGs involving therapies with their arms.

The Value/Usefulness subscale from users without impairments had scores lower than the other groups of participants and categories (lower by 38.19%), such as expected. These IMI Value/Usefulness subscale results are according to the internal studies, where the value and usefulness of an activity influences the intention of performing it (Deci, et al. 1994). As these volunteers were not undergoing any physical rehabilitation, this subscale was understandably assessed with a lower score.

It is worth mentioning that although most mean values for every subscale and group of participants (except for Value/Usefulness) are above 80% and slight non-significant differences can be noticed between them, there is a reduction in the difference for users with disabilities using the Virtual-R. It was observed that rehabilitation therapy patients rated their standard therapy very well in the SUS and IMI. However, the protocol started with standard therapy and the experience with Virtual-R came afterwards. We believe that their perception of a motivating therapy changed as the same well-rated scores in the IMI were more consistent.

We can conclude that there was an intrinsic motivation in the rehabilitation with the SGs used in this research, as well as in the default rehabilitation procedures performed by the patients in their rehabilitation sessions. We conclude that the SGs developed here have, in collaborations to the attractive factor, others that are often not present in standard rehabilitation procedures with repetitive exercises. Thus, maximizing the motivational factor of rehabilitation is important for the clinical evolution of the patients and to increase the intensity of rehabilitation therapy for the patients.

Acknowledgments

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Author Disclosure Statement

No competing financial interests exist.

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3.2 Serious Games for AT projects

Other SGs were developed for AT research projects at NTA-UFES, some of which required the development of new hardware, generating patent applications. Each one of these projects are independent builds, that is, each SG runs independent of the others.

House simulation

This SG was built to be used by ATs under development which require a safe environment for testing. It simulates a house with a living room, bedroom, kitchen, balcony and a yard that surrounds the house, all transitable. Electronic equipment (2 TVs, 2 radios, 2 fans 2 ceiling lamps and 1 desk lamp), distributed between the living room and the bedroom can be turned on and off (Figure 12).

Figure 12. House with its room and electrical devices. Source: produced by the author, 2018.

This SG was used in two different projects at NTA, and is available for other future projects that require this type of environment. The avatar, that is, the representation of the user in the SG, depends on the project using it.

The first project used this SG for training people to use an intelligent environment device controlled by an eye-tracking. This intelligent environment device developed is an AT prototype, which can adapt a common house to an intelligent environment house for people with disabilities. The prototype is a box with several power plugs to connect electrical devices to be controlled by a screen and an eye tracker. A device equipped with an eye tracker enables users to use their eye gaze as input information, which can be combined with other input devices like a mouse, keyboard, or touch and gestures (BISSOLI, SIME, BASTOS-FILHO, 2016a). The house simulator was used for testing in a safe environment before a real life test. The electrical devices of the virtual house were controlled using a screen containing a menu controlled by an eye-tracker. In addition, it also simulates an electric powered wheelchair, controlled by the same menu described before (Figure 13).

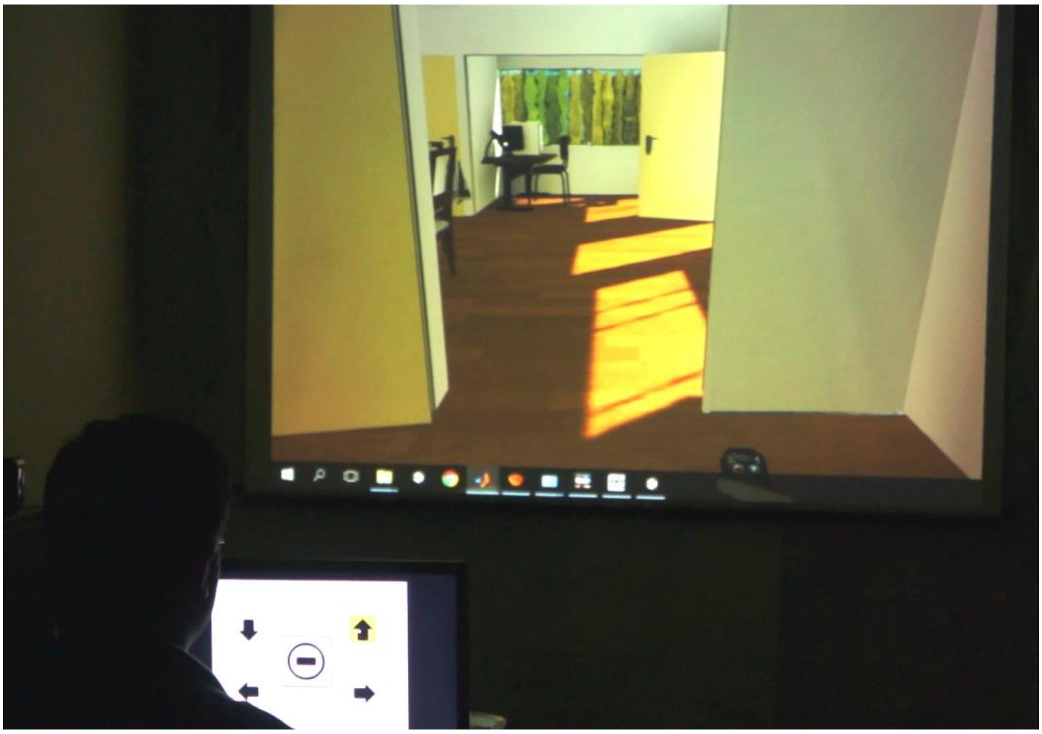


Figure 13. House simulation projected on a screen and volunteer using it with eye tracker. Source: produced by the author, 2018.

After the test, 17 volunteers (15 without impairment and 2 with impairment) answered the SUS questionnaire. The results of each volunteer are shown in Figure 14.

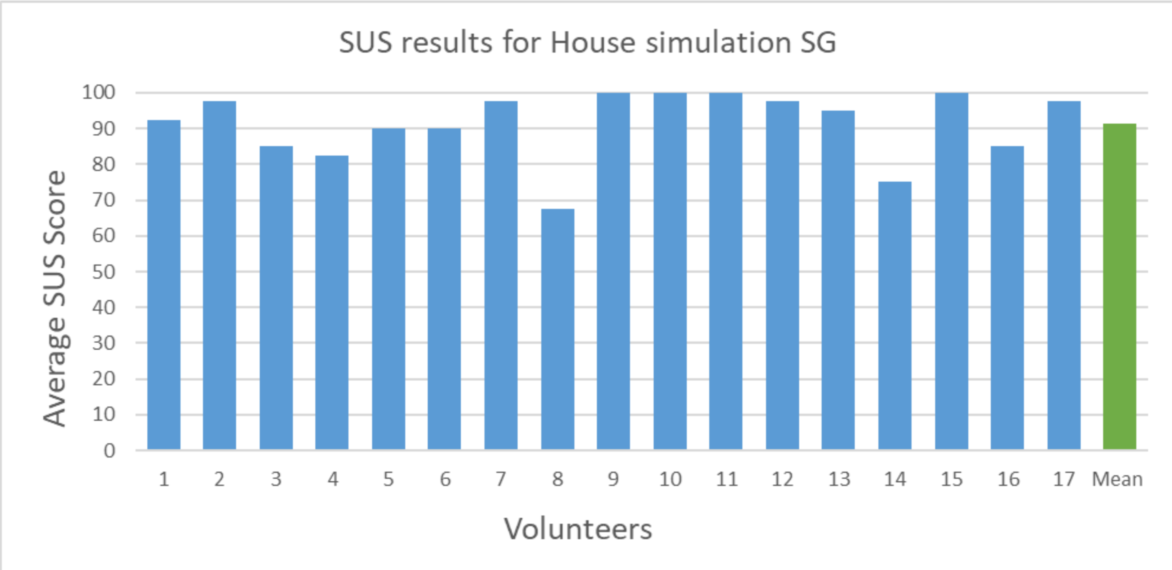


Figure 14. SUS results for 17 volunteers using House Simulator SG. Source: LONGO et al., 2016.

The second project used this SG to test a telepresence robot developed at NTA which uses a Brain-Computer Interface (BCI) to control it using Steady State Visual Evoked Potentials (SSVEP) (FLORIANO, A.; BALDO, G.; LONGO, B. B., 2016b) It used 4 different frequencies on a screen to control the direction the telepresence robot will move (Figure 15). These same commands were used to control the avatar, which in this case is the telepresence robot, in the house simulator (Figure 15). The inputs are sent to the computer using the user´s processed EEG. The EEG device used in this project was at an early stage of development of a modified wireless EEG device developed by the team, which latter originated two patents registrations, here described as Production 3 and 4 (Figure 15). The developed studies using this SG were published in congress proceedings. (LONGO et al., 2016; BISSOLI et al., 2016c; FLORIANO et al., 2016; FLORIANO et al., 2016b).

Figure 15. Volunteer using SSVEP to navigate, as using a telepresence robot, in the House Simulation SG. Source: FLORIANO et al., 2016.

Electric Powered Wheelchair (EPW) Simulation

This SG, named Simcadrom, simulates an EPW in a test room, for training purposes and testing of control interfaces (HERNANDEZ-OSSA et al. 2017a; HERNANDEZ-OSSA et al. 2017b). The aim was to create a simulation with its characteristics as close as possible to the real experience, in addition to a motivational environment, with safer training tasks, providing quantitative feedback that encourages its usage. The room used as a model for the simulator is an NTA-UFES room, the same room used to carry out the test with the same EPW in real life (Figure 16). It has a circuit guide, drawn in the floor, with time checkpoints to store the time spent going from one checkpoint to another. Also, it has cones as obstacles, and collisions with it, and with any other object, are counted. The joystick commands were set to be as similar as possible to the real commands, so the weight of the user can be entered before the tests to change the command for this purpose. Thus, the EPW joystick used as the input device in the simulation is the same as the one used in the real EPW, sending the user commands to the computer using serial communication (Figure 17A). The SG can be displayed to the user using a screen or an HMD (Figure 17B).

Figure 16. Model based on the real test location. Source: produced by the author, 2018.

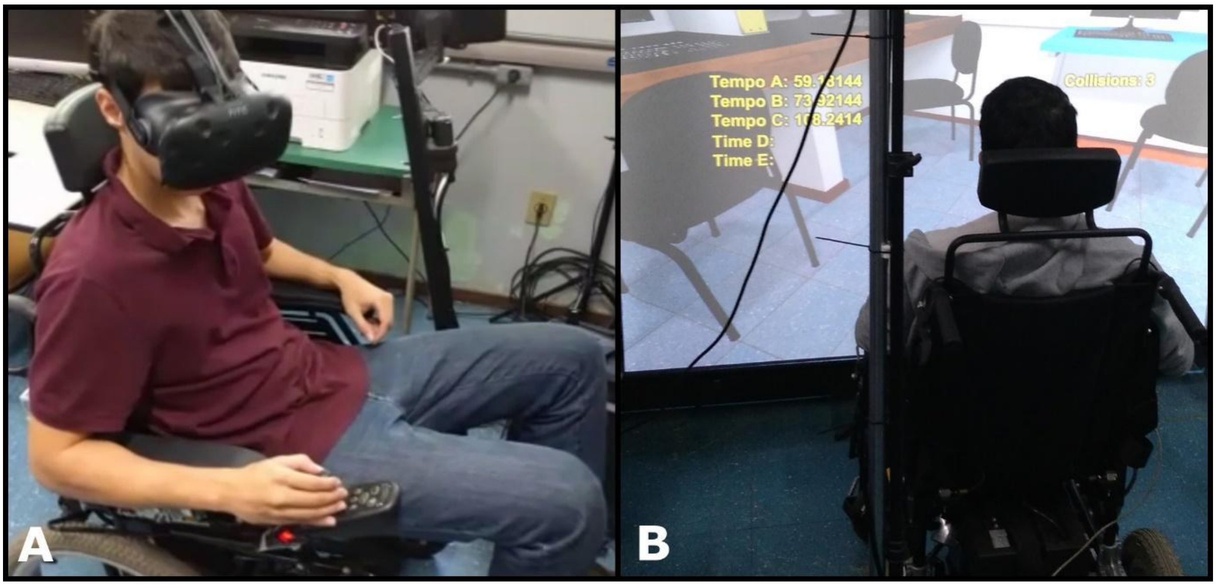


Figure 17. A) Volunteer using Sincadrom using an HMD. B) Volunteer using Sincadrom using a projection screen. Source: produced by the author, 2018.

Five volunteers participated in a test session with Simcadrom. The proposed protocol contains a set of path segments that the participant follows with the EPW, done three times, passing from A to B, C and D as indicated in Figure 16. After completion of all virtual paths, a user experience test was performed consisting of three items, in which participants specified their level of agreement or disagreement on a 5-point symmetric Likert scale, in which "totally disagree" is 1 point and "totally agree" is worth 5. One of the results, shown on Figure 18, strongly indicated evidences of cybersickness, which should be investigated.

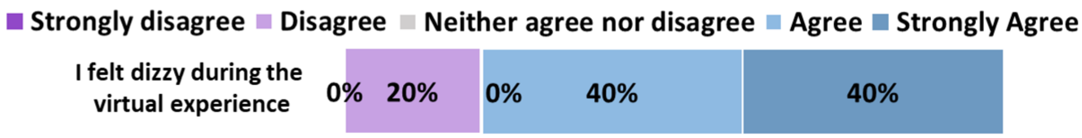


Figure 18. Five-point Likert scale questionnaire. Source: HERNANDEZ-OSSA et al., 2017b. Edited by the author.

In another experiment, now with 11 healthy volunteers, the SSQ was applied, reaching 10.59 TS for before SG, and 32.41 TS for the after SG (RIVERA et al., 2019). The results are shown in Figure 19

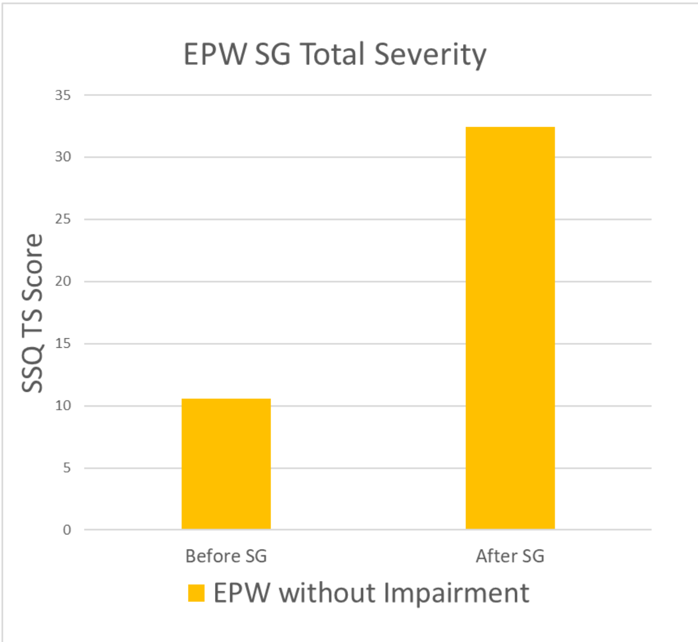


Figure 19. EPW SSQTS results.

The developed studies using Sincadrom were published in congress proceedings (HERNANDEZ-OSSA et al., 2017a, HERNANDEZ-OSSA et al., 2017b, RIVERA et al., 2019). Also, a patent registration is under development.

Pedaling simulation (Minibike)

A SG was designed to be used by patients who need to perform lower limbs rehabilitation using pedaling exercises. It contains a road where the user must pedal to move forward. The road is straight, paved and flat, with vegetation on its sides (Figure 20). The model used in the SG is a recumbent tricycle, so the player does not need to worry about its balance. The player starts atn an initial checkpoint, and passes through other checkpoints while pedaling, earning points for the distance traveled and for maintaining a good balance between the pedals. To use this SG, a minibike device and a chair needs to be used to place the patient in the same position as their avatar in the SG (Figure 20). The synchronization between the pedal position of the minibike and the position of the SG pedal is done through a device developed by the research team, placed at the minibike crank. This device, is based on inertial sensor with triaxial accelerometer input, and uses an ARV microcontroller with Bluetooth communication. It also has a module for EEG and sEMG signals synchronization. Its patent registration is described here at Production 5 session.

Figure 20. Pedaling simulation structure. Source: produced by the author, 2018.

The Minibike SG was tested and evaluated by healthy volunteers (graduate students of UFES/Brazil). Also, after a presentation at CREFES, therapists were invited to participate in the tests with patients who were under their care, were undergoing physical rehabilitation, and could use minibike exercises for their rehabilitation.

The SUS results are shown in Figure 21 and the SSQ TS results are shown in Figure 22.

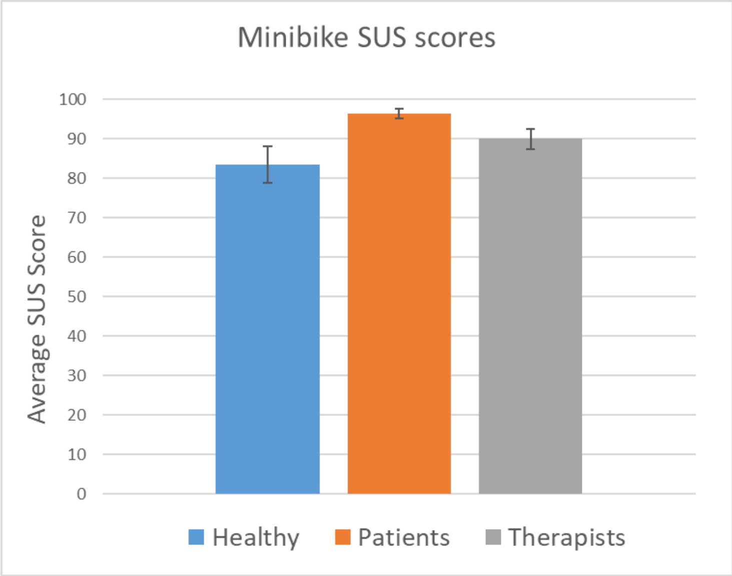


Figure 21. SUS results for pedaling simulation (Minibike). Source: produced by the author, 2019.

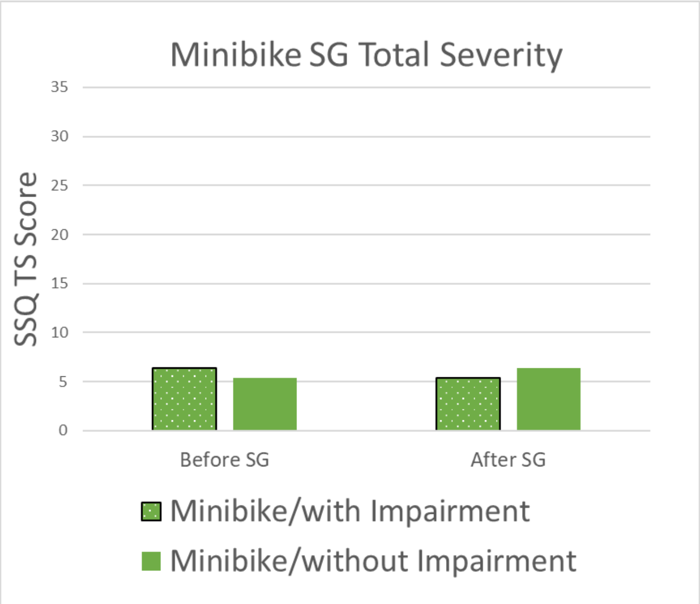


Figure 22. SSQ TS results for pedaling simulation (Minibike). Source: produced by the author, 2019.

The studies developed using this SG were published in congress proceedings (CARDOSO et al., 2018; RIVERA et al., 2019).

3.2.1 Production 3 – Submitted patent 1

Process nº: BR 10 2017 024843 7 (Attachment 3)

Compact Wireless Electroencephalography Device with Interchangeable Electrodes

Description in English:

Electroencephalography (EEG) signals are widely used in medical and research areas nowadays. Despite the technology progress of the equipment used in this technique, there are limitations related to the device physical properties and its purchase costs and maintenance.

Em pesquisas que utilizam sinais EEG, deve-se levar em consideração diversos fatores na escolha do equipamento a ser utilizado. Existem diversos modelos no mercado, variando em diversas características físicas como tamanho, tipo de eletrodos compatíveis, tipo de conexão com o computador, dentre outras. Outro fator importante é o valor do equipamento, pois a grande maioria deles tem preços elevados. Dispositivos com preços mais acessíveis geralmente apresentam limitações, como é o caso do EMOTIV Epoc,

Researchers that uses EEG signals in their study should consider several factors when choosing the equipment to used. There are several models in the market nowadays, varying in several physical characteristics such as size, type of compatible electrodes, type of connection with the computer, among others. Another important factor to consider is the value of the equipment, since the vast majority of them have high prices. Devices with more affordable prices usually have limitations, as, for example, the EMOTIV Epoc device, which has rigid structure and with fixed positions electrodes, which can only be replaced by electrodes produced specifically from its company. The test protocol is usually produced considering a number of factors, including the characteristics of the device used and its limitations. Another important factor that may impair the use of the equipment is the annoyance caused to users by the type of electrode used, especially those using conductive gel, or the use of wires to connect to the computer, which often bothers and limits the user`s movement. In Brazil, the recruitment must be totally voluntary, and it is not possible to pay the volunteer for his participation. Thus, to keep the volunteer interested in participate the research it is important to provide the least hassle as possible.

There is, in the prior art, a wide variety of electrodes types and the way they make contact with the scalp. The majority of the equipment uses conductive gel, which improves the impedance of the signal, but that ca cause annoyance to the users because it leaves residual gel in the used region. Another commonly used electrode type is the dry electrode, which uses no additive and directly contacts the scalp. These electrodes reduce, by not using any additives, the inconvenience caused to the user. The quality of these electrodes, called dry, has already been scientifically demonstrated, as well as its capacity of use for several applications at the present time. There is also, in the prior art, wireless equipment, which transmits data without the use of physical connections, which facilitates the use of such equipment in certain situations, thus presenting greater possibilities for the execution of test protocols. However, many of these wireless devices available in the market have their electrodes attached to the capture equipment, and physically connected as a rigid device. This structure limits the use for certain objectives, such as, for example, devices developed for the use of identification of emotional states, which present their electrodes fixed in the regions of the scalp responsible for these states. This equipment fulfills its objectives but it is not possible to use it to acquire EEG signals from other regions. This rigid and unique structure type also makes it difficult to maintain the equipment, as there is no possibility of performing part replacement or choosing other types of electrodes. This feature considerably reduces the life of the device since the electrodes tend to oxidize and stop working properly. This disadvantage was thought and influenced the final design of the equipment here described, which uses 2mm-diameter touch-proof connectors (EEG DIN standard DIN 42802) so the user can replace their wear electrodes with any electrodes of this standard, which are easily found in the market. With the equipment here described the user can also choose the type of electrode, and place them at any region of interest.

In the light of the foregoing, the present Utility Model Patent Application describes a portable device, developed to acquire electroencephalographic signals. It has 16 channels to connect touch-proof connectors electrodes, and wireless communication with the computer. This equipment is a modification of the Emotiv EPOC device, from which part of the hardware is used, where the printed circuit boards and their components are kept, and the electrodes and their cables were removed, as well as the entire external structure (plastic).

The equipment was designed to be as portable as possible, free of wires connected to external devices, which increases the freedom of movement of the user, and with the possibility of using touch-proof connectors electrodes of any type. Thus, the equipment user or researcher can use any commercial caps or caps made by the own researcher.

The final product captures and amplifies electroencephalographic signals, which shows a dynamic range of 8400 μV, recording 128 samples per second (2048 Hz internal), with a 0.2 to 45 Hz bandwidth and a 60 Hz Notch digital filter. The data is scanned at 16-bit resolution, and sent to the computer by wireless connection through a USB receiver, using a 2.4GHz band.

The printed circuit board is mounted on a protective bracket (Figure 1) that connects to a housing (Figure 2 and 3), in which the touch-proof female connectors are attached to plug the electrodes (Figure 4). To lock the switch and the power cable connector, a lock is used to keep the assembly rigid and prevent it from loosening due to the pressure exerted when connecting the power supply cable (Figure 3 and 5). The details of the box showing the numbering of the touch-proof connectors positions can be seen in figure 6. These pieces were designed in such a way as it could occupy as little space as possible. Thus, this device is 7 cm long, 6 cm wide and 3.5 cm high (Figure 7). The assembly of the device is shown on Figure 8, and the final arrangement of the equipment can be seen in Figure 9.

This device was developed to be used in researches of the Núcleo de Tecnologia Assistiva (NTA) of the Universidade Federal do Espírito Santo (UFES). It is being used in projects of the creators 1, 2 and 3 of this Utility Model Patent application, as well as in other projects of this same laboratory. In order to develop the projects of the mentioned researchers, it was necessary an equipment that carried out the capture of electroencephalography signals while the users executed movements, which was not possible with an equipment that used wires connected to the computer. In addition, the use of electrodes in various regions of the scalp was required, along with the use of other equipment mounted in the same region simultaneously, such as a head mounted Display. Such characteristics and possibilities were not found in equipment available at that time in the laboratory, or to acquire in the market for an affordable price. The prototype used in the projects of the aforementioned researchers had their parts printed in ABS plastic using a 3D printer (Figure 9).

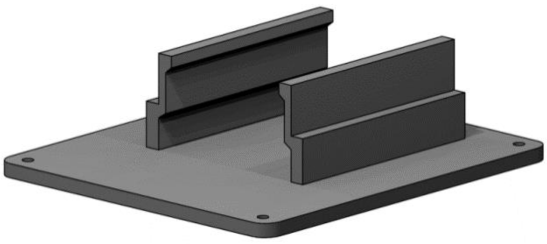


Figura 1. Suporte para montagem do hardware utilizado.

Figura 3. Suporte e caixa utilizados (vista inferior).

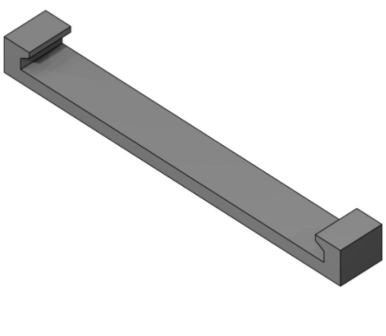


Figura 2. Suporte e caixa utilizados (vista superior).

Figura 4. Vista em perspectiva dos locais onde são fixados os eletrodos.

Figura 5. Trava para fixação do interruptor e plug da fonte de alimentação.

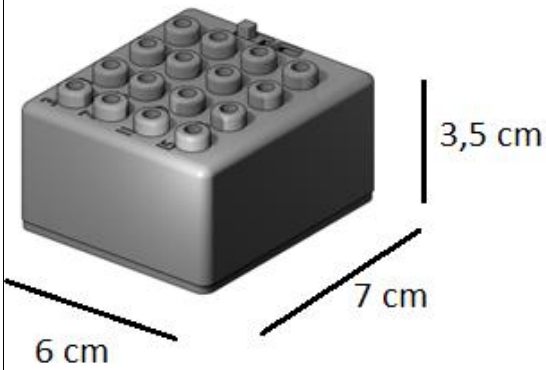


Figura 7. Tamanho do dispositivo e resultado final após montagem.

Figura 8. Placa amplificadora, bateria e conectores fixados ao suporte.

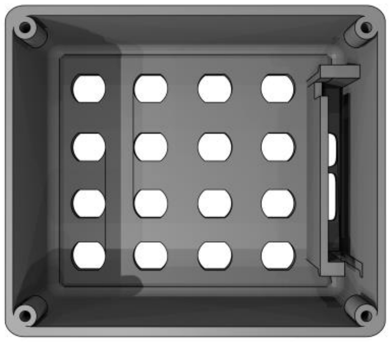
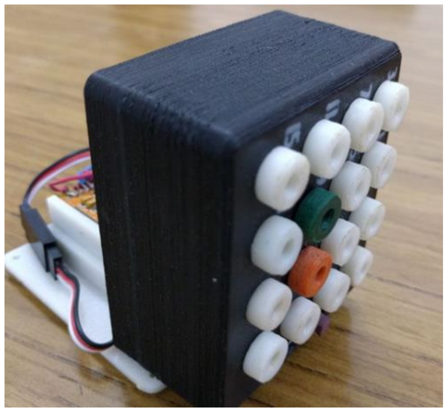
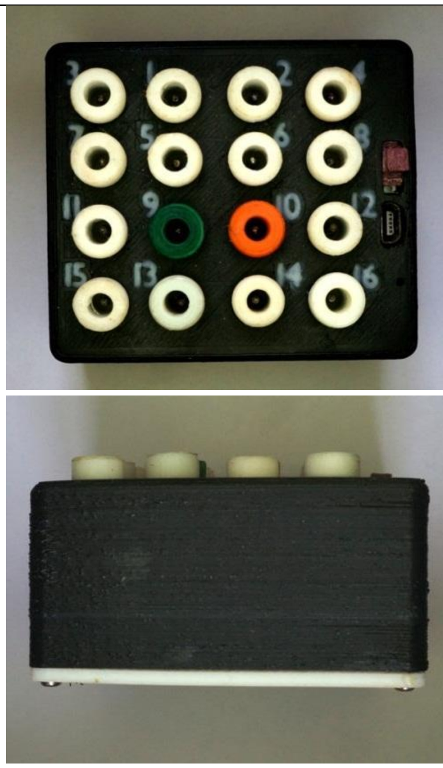


Figura 6. Detalhe da tampa projetada.



	 Figura 9. Dispositivo montado.

Descrição em Português:

Dispositivo Compacto De Eletroencefalografia Wireless Com Eletrodos Intercambiábveis

A eletroencefalografia (EEG) tem sido uma técnica amplamente utilizada nas mais variadas áreas médicas e de pesquisas. Apesar do progresso tecnológico dos equipamentos utilizados atualmente para essa técnica, há ainda uma série de limitações que estão diretamente ligadas às características físicas dos dispositivos utilizados e seus custos de aquisição e manutenção.

Em pesquisas que utilizam sinais EEG, deve-se levar em consideração diversos fatores na escolha do equipamento a ser utilizado. Existem diversos modelos no mercado, variando em diversas características físicas como tamanho, tipo de eletrodos compatíveis, tipo de conexão com o computador, dentre outras. Outro fator importante é o valor do equipamento, pois a grande maioria deles tem preços elevados. Dispositivos com preços mais acessíveis geralmente apresentam limitações, como é o caso do EMOTIV Epoc, que apresenta estrutura rígida e eletrodos com posições fixas, além de serem substituídos apenas por eletrodos produzidos especificamente para modelos dessa empresa. O protocolo de testes geralmente é produzido pensando em diversos fatores que envolvem a pesquisa, incluindo as características do dispositivo utilizado e suas limitações. Outro fator importante que pode prejudicar a utilização do equipamento é o incômodo causado aos usuários pelo tipo de eletrodo utilizado, principalmente os que utilizam gel condutor, ou a utilização de fios para a conexão com o computador, que muitas vezes incomodam e limitam os movimentos do usuário. No Brasil o recrutamento deve ser totalmente voluntário, não sendo possível recompensar o voluntário pela sua participação nas pesquisas. Deste modo, uma forma de manter o voluntário interessado em participar é proporcionar o menor incômodo possível.

No estado da técnica existe uma variedade grande de tipos de eletrodos e a forma como estes fazem contato com a região alvo. A grande maioria dos equipamentos utiliza gel condutor, que melhora a impedância do sinal, mas que acaba incomodando o usuário pois deixa resíduo na região utilizada. Outro tipo de eletrodo comumente utilizado é o eletrodo seco, que não usa nenhum aditivo e entra em contato diretamente com o escalpo. Esses eletrodos reduzem, por não utilizar nenhum aditivo, o incômodo causado ao usuário. A qualidade destes eletrodos, dito secos, já foi cientificamente demonstrada, além de sua capacidade de utilização para diversas aplicações na atualidade. Há também, no estado da técnica, equipamentos wireless, que transmitem dados sem o uso de ligação física, o que facilita o uso desses equipamentos em determinada situações, apresentando assim, uma maior liberdade para a execução de protocolos de teste. Porém, muitos desses equipamentos wireless encontrados no mercado, apresentam seus eletrodos fixos ao equipamento de captura, e fisicamente conectados em um aparato em forma de arco ou prendedor rígido. Isso limita o uso para determinados objetivos, como por exemplos, os dispositivos desenvolvidos para o uso de identificação de estados emocionais, que apresentam seus eletrodos fixos nas regiões do escalpo responsáveis por esses estados. Este equipamento atende devidamente seus objetivos, porém não é possível utilizar este equipamento para adquirir sinais EEG de outras regiões. Essa característica de apresentar uma estrutura rígida e única também dificulta a manutenção do equipamento, pois não existe a possibilidade de realizar a substituição das peças ou escolher outros tipos de eletrodos. Essa característica reduz consideravelmente a vida útil do aparelho uma vez que os eletrodos tendem a oxidar e a deixarem de funcionar corretamente. Tal desvantagem foi pensada e influenciou no desenho final do equipamento, sendo utilizado conectores touch proof de 2mm de diâmetro (EEG DIN padrão DIN 42802) para que o usuário possa substituir seus eletrodos por eletrodos desse padrão, que são facilmente encontrados no mercado, podendo assim, escolher o tipo de eletrodo utilizado, e as regiões onde estes serão posicionados.

Diante do exposto, o presente pedido de Patente de Modelo de Utilidade descreve um dispositivo portátil, desenvolvido para captações de sinais eletroencefalográficos, sendo que aquele possui 16 canais para conexão de eletrodos com conectores touch proof, e realiza comunicação sem fio (wireless) com o computador. Esse equipamento é uma modificação do dispositivo Emotiv EPOC, do qual é utilizado parte do hardware, onde são mantidas as placas de circuitos impressos e seus componentes, e retirados os eletrodos e seus cabos, além de toda a estrutura externa (plástico).

O equipamento obtido foi desenhado para ser o mais portátil possível, livre de fios ligados a dispositivos externos, o que aumenta a liberdade de movimento do usuário, e com a possibilidade de utilização de eletrodos de qualquer tipo, desde que apresentem conectores touch proof. Assim o usuário ou pesquisador pode utilizar qualquer touca comercial ou toucas elaborada pelos próprios pesquisadores / laboratórios. O produto final captura e amplifica sinais eletroencefalográficos, os quais apresentam medida da faixa dinâmica de 8400 µV, gravando 128 amostras por segundo (2048 Hz interno), sendo a largura de banda entre 0,2 a 45 Hz e filtro digital Notch de 60 Hz. Os dados são digitalizados com uma resolução de 16-bit, sendo enviados ao computador por conexão wireless através de um receptor USB próprio, comunicando-se com uma banda de 2,4GHz.

A placa de circuito impresso é montada sobre um suporte de proteção (Figura 1) que se conecta a uma caixa (Figura 2 e 3), na qual são fixados os conectores fêmeas do tipo touch proof para plugar os eletrodos (Figura 4). Para a fixação do interruptor e do conector do cabo da fonte é utilizada uma trava para manter o conjunto rígido e evitar que este se solte devido à pressão exercida quando se conecta o cabo da fonte (Figura 3 e 5). Os detalhes da caixa com a numeração das posições dos conectores touch proof fêmeas podem ser observados na figura 6. As peças foram projetadas de forma a ocupar o menor espaço possível compatível com o hardware utilizado, desta forma o dispositivo possui 7 cm de comprimento por 6 cm de largura e 3,5 cm de altura (Figura 7). A montagem do dispositivo se faz de acordo com a Figura 8, sendo que a disposição final do equipamento pode ser observada na Figura 9.

Este dispositivo foi desenvolvido para ser utilizado em pesquisas do Núcleo de Tecnologia Assistiva (NTA) da Universidade Federal do Espírito Santo (UFES) sendo utilizado em projetos dos criadores 1, 2 e 3 deste pedido de Patente de Modelo de Utilidade, além de outros projetos desse mesmo laboratório. Para o desenvolvimento das pesquisas dos pesquisadores citados era necessário um equipamento que realizasse a captura de sinais de eletroencefalografia enquanto os usuários executavam movimentos, o que não era possível com um equipamento que utilizasse fios ligados ao computador. Além disso, era necessária a utilização de eletrodos em regiões variadas do escalpo, juntamente com a utilização de outros equipamentos montados na mesma região simultaneamente, como óculos de realidade virtual. Tais características e possibilidades não foram encontradas em equipamentos disponíveis naquele momento no laboratório, ou para adquirir no mercado com um valor acessível. O protótipo utilizado nas pesquisas dos pesquisadores supracitados teve suas partes impressas em plástico ABS utilizando uma impressora 3D (Figura 9).

3.2.2 Production 4 – Submitted patent 2

Process nº: BR 102017011628-0 (Attachment 4)

Description in English:

Disk Form Electrodes Support for Electroencephalography

The Encephalography (EEG) is a monitoring method used to register brain electrical activity using electrodes. When these electrodes are used in a non-invasive way, they are placed over the scalp, next to the brain region to be analyzed, acquiring a stronger brain signals from this region than from further regions. These signals are generated by the tension fluctuation resulted from the ionic current inside the brain neurons. When it is used in researches or clinically, the EEG test is the recoding of the electrical activity of brain regions during a period of time, in which the electrodes are placed next to the brain region of interest and an EEG equipment record it. These placement positions usually follow international pre-established patterns (10-20 International System and its variations).

The electrodes are the first link between the brain signals and the EEG recording devices. These electrodes, when non-invasive, are usually found in a disk shape, the ideal form to be pressed on the scalp. They are made of a metal alloy or other electrically conductive materials.

The electrodes for which the mounting of this patent was developed are reusable silver chloride electrodes, and it can be found in two different forms. In one of them, the area that makes contact with the scalp has 12 projections of 2mm each, which make a contact area of 10mm and it is useful to go through the hair in a more efficient way (Figure 1). Another form of this electrode does not present these projections and it is completely flat in the region that makes contact with the scalp (Figure 2). It is more adequate to be used in hairless regions of the scalp. Both have a hole in the center which go through the electrode vertically, and allows them to be used with conductive gel to improve the contact between the electrode and the scalp, by the injection of the conductive gel through the hole. They can also be used in a dry way, without any liquid or conductive gel. These electrodes use a cable (Figure 3) that fits on the posterior region of the electrode (Figure 4).

This patent describes a bracket for the electrodes here described, that, by its usage, it's possible to adapt these electrodes to a large variety of caps. For this purpose, this bracket was designed to be divided in two parts that fits each other (Figure 5), by the usage of pins that passes through the cap's cloth, pressing it between the two parts, making it to be fixed at the desired position on the cap. The bigger part of the bracket has a shape that follows the shape of the connector where the electrode is fitted, and by the usage of small projections at the bottom, locks the electrode connector on this part (Figure 6). It also has holes at its upper side. The 3 holes at the peripherical region are used to hold the pins of the smaller part that is fit over the bigger part, locking the whole set at the desired position. The center hole can be used by the user to have access to the scalp and the internal part of the electrode. The smaller part also presents this hole, making the whole set to present an orifice, where, by the usage of a syringe, some conductive gel can be injected. When the set is mounted, the part of the electrode that makes contact to the user`s scalp is project out (Figure7). The height of the bracket assure that the electrode makes pressure against the user`s scalp to ensure its contact. This pressure is regulated by the way (tight or loose) the cap is set. This electrode bracket was built as part of the creator number 1`s master degree in Biotechnology. A prototype was printed with a 3D printer in ABS plastic (Figure 8). The brackets were used in a test with a cap of elastic cloth and with the electrodes here described and an EEG recording device (Figure 9). They were set in specific regions of the scalp from where the electrical signals were recorded using the EEG equipment, to be used in Brain Computer Interface (BCI) projects. A BCI is a communication system between a subject and a computer, which uses the user`s brain electrical activity to generate information. This technology allows people to send messages or commands directly from their brains to the outside world, without the usage of their peripherical nerves or muscular activities. The BCIs are extremely useful for persons that have mobility loss. Furthermore, it can be used by health people, augmenting the interaction possibilities between humans and machines.

Thus, it was possible to use the reusable silver chloride disc electrodes in an elastic cap that couldn`t receive them, by the usage of the brackets here described. The electrodes placement positions were chosen according to each project necessity, which were different from each other. The electrode position change is another possibility of these bracket usage, which can be changed at any moment.

Figure 1. Electrode with projections.

Figure 2. Electrode without projections.

Figure 3. Cable with electrode coupled through a connector at one of its tips, and touchproof connector at its other end.

Figure 4. Electrode posterior region.

Figure 5. Two parts support.

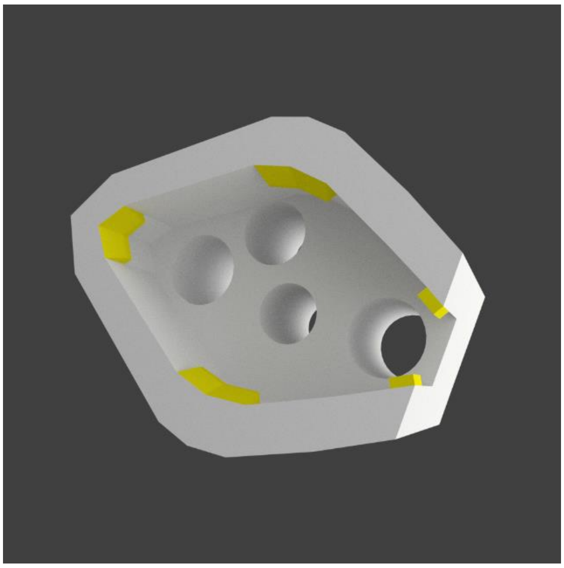


Figure 6. Support with latches highlighted in yellow.

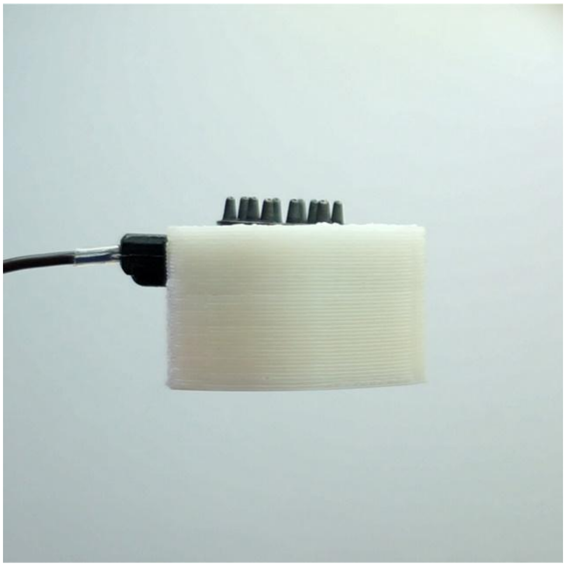


Figure 7. Bracket and electrode assembly with detail of electrode projections.

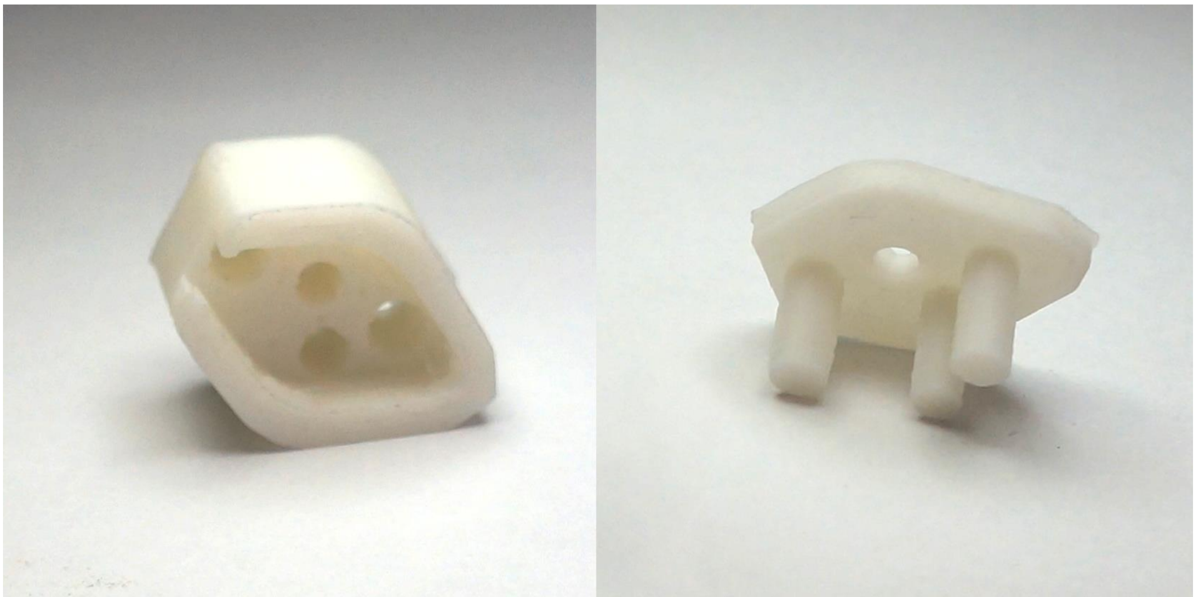


Figure 8. Both parts of the prototype printed in ABS plastic.

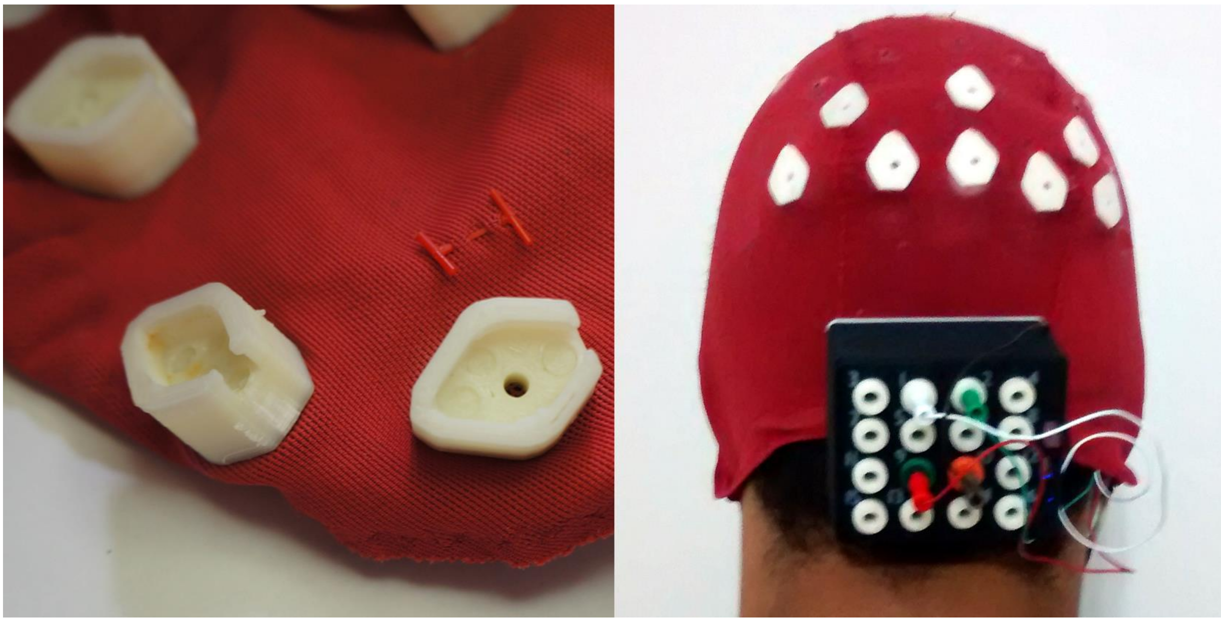


Figure 9. Elastic fabric cap with assembled supports.

Descrição em Português:

Suporte para Eletrodos em Forma de Disco para Eletroencefalografia

A Eletroencefalografia (EEG) é um método de monitoramento que registra a atividade elétrica do cérebro utilizando eletrodos. Quando estes são utilizados de forma nãoinvasiva, são colocados sobre o escalpo, próximo à região cerebral que se deseja analisar, adquirindo sinais cerebrais mais intensos dessa região do cérebro que das regiões mais distantes dali. Esses sinais são gerados pelas flutuações de tensão resultante da corrente iônica dentro dos neurônios do cérebro. Quando utilizado para pesquisa ou clinicamente, o exame de EEG refere-se à gravação da atividade elétrica de regiões do cérebro durante um período de tempo, onde os eletrodos são posicionados perto da região ou regiões de interesse, e um equipamento faz o registro destes sinais. Esse posicionamento geralmente segue padrões pré-estabelecidos internacionalmente (Sistema Internacional 10-20 e suas variações).

Os eletrodos são a primeira ligação entre os geradores de sinais elétricos do cérebro e os instrumentos que capturam esses sinais. Eles, quando não-invasivos, são geralmente encontrados em forma de disco, formato ideal para serem pressionados contra o escalpo, e são geralmente feitos de uma liga metálica ou algum outro material condutor de eletricidade.

Os eletrodos para os quais foi desenvolvido o suporte desta patente são eletrodos reutilizáveis feitos de cloreto de prata, e podem ser encontrados em dois formatos diferentes. Em um deles, a área que entra em contato com o escalpo apresenta 12 projeções de 2mm que criam uma área de contato de 10mm, e servem para atravessar de forma mais eficiente o cabelo do usuário e chegar ao escalpo (Figura 1). Uma outra versão desses eletrodos não apresenta essas projeções, sendo completamente lisos na região que entra em contato com o escalpo (Figura 2), sendo este último mais apropriado para ser utilizado em regiões onde não apresentam cabelos. Ambos possuem um furo que atravessa o eletrodo verticalmente, e permite utilizá-los com gel condutor para melhorar o contato do eletrodo com o couro cabeludo, onde o gel é introduzido pelo orifício. Eles também podem ser utilizados de forma seca, ou seja, sem nenhum líquido ou gel condutor. Esses eletrodos utilizam um cabo (Figura 3) que se encaixa na região posterior do eletrodo (Figura 4).

O presente pedido de patente descreve um suporte para os eletrodos acima descritos, onde, por meio de sua utilização, pode-se adaptar os eletrodos em questão em diversos tipos de toucas. Para tal, o suporte foi desenhado em duas partes que se unem (Figura 5), prensando o tecido da touca entre eles e, através de pinos que atravessam o tecido, se encaixam um ao outro, ficando assim, fixos na posição desejada. A peça maior do conjunto apresenta um formato que acompanha o formato do conector onde o eletrodo é fixado. Por meio de pequenas projeções na parte inferior, travam esse conector ao corpo dessa peça (Figura 6). Ela também apresenta furos na região superior. Os 3 furos que ficam na região periférica servem para segurar os pinos da peça que é encaixada por cima e trava o conjunto no local desejado. O furo central pode ser utilizado para que o usuário tenha acesso ao escalpo e a parte interna do eletrodo. A peça menor também apresenta esse furo, fazendo com que o conjunto completo apresente um orifício central, onde, por meio de uma seringa, pode ser adicionado gel condutor. Quando o conjunto inteiro está montado o eletrodo fica com a parte de contato com o escalpo projetada para fora (Figura 7). A altura do suporte assegura que o eletrodo exerça a pressão necessária para garantir o contato do eletrodo com o escalpo. Essa pressão é regulada pela forma (apertada ou frouxa) com que a touca é colocada.

Este suporte para eletrodos foi construído como melhoramento de parte do projeto de Mestrado em Biotecnologia do Criador No 1. Um protótipo foi impresso utilizando impressora 3D e plástico ABS (Figura 8). Os suportes foram utilizados em um teste com uma touca de tecido elástico juntamente com os eletrodos acima descritos e um equipamento de captura de sinais EEG (Figura 9). Estes foram posicionados em regiões específicas do escalpo de onde os sinais cerebrais foram adquiridos por um equipamento EEG para serem utilizados em projetos de Interface Cerebro-Computador (ICC). Uma ICC é um sistema de comunicação entre um indivíduo e um computador, que utiliza a atividade elétrica cerebral para gerar informações. Essa tecnologia permite às pessoas enviarem mensagens ou comandos diretamente de seus cérebros para o mundo externo, sem a necessidade de utilizarem seus nervos periféricos ou atividades musculares. As ICCs são extremamente útileis para pessoas que apresentam problemas de perda de mobilidade. Além disso, elas podem ser utilizadas também por pessoas saudáveis, aumentando as possibilidades de interações entre homens e máquinas.

Assim, através dos suportes aqui apresentados, foi possível utilizar eletrodos discoidais de cloreto de prata reutilizáveis em uma touca elástica que não poderia recebê-los sem a utilização desses suportes. As posições utilizadas foram escolhidas de acordo com a necessidade de cada projeto, que foram diferentes em cada um deles. A mudança de posicionamento dos eletrodos é outra possibilidade desses suportes, que podem ser colocados e retirados a qualquer momento.

3.2.3 Production 5 – Submitted patent 3

Deposit receipt (Attachment 5)

Description in English:

Electronic Device for Position Sensing and Synchronization of Biological Data

The invention described here is referred as an Electronic Device for Position Sensing and Biological Data Synchronization, composed of two modules: Position and Synchronism Sensor (SPS) and Converter and Synchronizer (CS). The SPS module consists of an IMU sensor (Inertial Measurement Unit), an AVR microcontroller for internal processing, and has wireless communication through Bluetooth protocol. The CP module is a digital signal converter for two independent analog signal outputs, uses Bluetooth protocol for communication with the SPS module and serial communication through a micro USB connector.

The SPS acts as a biomechanical signal transducer in digital signals, which can be used to synchronize the movement performed by the patient during the rehabilitation exercises to his/her avatar in a virtual reality (VR) environment. This module can be used directly through Bluetooth communication when used for interaction with the VR. However, to synchronize the lower / upper limbs movements to electroencephalography (EEG) and surface electromyography (sEMG) signals, it is necessary to use the CS module, which has biomechanical and bioelectrical signals synchronization function. Thus, it is possible to obtain data from different amplifiers with a common signal, facilitating data processing.

BACKGROUND OF THE INVENTION

Patients with lower limbs motor impairment may benefit from physical rehabilitation, in which the most targeted goal is the recovery of individual's independence in basic tasks (walking, bathing, doing household chores). Functional recovery of motor deficits in neurological patients may require a considerable amount of movement repetition to induce changes in neuroplasticity. The gold standard method in rehabilitation, aerobic exercises, in addition to inducing a high number of repetitions, has the potential to promote improvements in the circulatory, respiratory and muscular systems. Improved blood supply and uptake of oxygen by tissues, increase and maintenance of active joint amplitude, and preservation of muscle tissue are some benefits that help to preserve the patients' health and contribute to their recovery and rehabilitation.

As an example, walking and cycling training are useful because they are repetitive tasks, easy to perform, activate various muscle groups, promote improved blood circulation, respiratory capacity and maintenance of muscle tissue.

Because it is a repetitive and monotonous training, the patient may present lack of attention, demotivation and even withdrawal from therapy. It is important that patients play an active role in their rehabilitation process, since those who are more motivated do have a better recovery. As a way to increase the patient motivation, Serious Games (SG) in a Virtual Reality (VR) environment can be an alternative, as they provide a playful form of rehabilitation, providing immersive biofeedback, and also provide a cognitive rehabilitation, since the patient needs to pay attention to the goals of the game.

In this way, VR can provide the patients with a varied and enjoyable environment that implies their motivation to practice the movements needed for rehabilitation over long periods of time. The possibility of adding to these patients simultaneous feedback, knowledge of performance and the results achieved in the rehabilitation process are important for learning as well as motivation, and will directly influence their recovery. Studies indicate that patient motivation is a highly important factor for the end result of the therapeutic process.

Additionally, incorporating information on biological signals through EEG and sEMG in VR-based games aims to provide the rehabilitation professional with information to evaluate the evolution of the patients and to establish individualized and more precise goals aimed at their rehabilitation. It is important that the biological signals are synchronized with the biomechanical signals so that the phase of movement in which the muscle is contracted or which region of the brain is being activated can be determined. These data can be compared to the pattern of people without motor impairment, already described in the scientific literature.

SUMMARY OF THE INVENTION

The invention described here aims to provide accurate synchronization of the positioning angles either in apparatuses as monocycle or bicycle or even positioned directly on limbs or other body regions of the patient. It uses can be used in physical rehabilitation research protocols, as well as in physiotherapy and occupational therapy protocols, and para-sport training.

The present invention proposes two modules, which, when used together, allow the synchronization between the patient´s movement and his/her EEG/sEMG signals. Also, while using only the Position and Synchronization Sensor (SPS), the patient´s movements can be used directly on computer or smartphone applications.

The apparatus described here allows the acquisition of positioning by transducing the signals obtained by the inertial sensors into digital signals, which are transmitted using Bluetooth protocol. The SPS module is responsible for this transduction and data transmission. Data can be sent to computers or other portable devices, such as Android-based devices.

The data can also be received by the CS module, where it is converted into an 8-bit analogue resolution signal. After this conversion, the signal is provided, isolated, through two channels. These channels can be configured via a mini-switch to use the 0-5 V DC of the module itself, or to use the voltage of the EEG / sEMG equipment. The information processing is performed by AVR microcontroller, which manages two digital potentiometers for generating the output signals. This signal can be configured to have power independent of the device, that is, be supplied by the devices themselves where it will be used, or, if necessary, be fed by the internal circuit. Unlike the SPS module, which can be used separately, this module only has its functionalities when used in conjunction with the SPS module. It is a tool with great utility when it is desired to relate inertial information to other signals, such as sEMG and EEG. Due to the fact that it has two isolated outputs providing a common signal, it can be used with a reference signal to perform the synchronization between the two devices, facilitating subsequent data processing.

The sensor can also be configured via numerical commands to provide information from temperature, gyroscope and accelerometer data without any processing. The data sampling frequency can also be changed, set by default to 100 Hz, depending on its signal sending mode, configurated as continuous or request dependent.

The invention described here proposes, through the CS module, a new functional concept that resides in the analogous synchronization of EEG and sEMG signals to physical events. Such synchronization is performed by generating a common signal sent to both equipment and voltage levels isolated and proper to each one.

The implementation of this invention allows the obtaining of signals through different equipment, with great ease for synchronization without complex processing. In addition, the devices constructed have the characteristic of being easy to use and low cost.

UTILITIES

The SPS module can be used on a unicycle crank to identify its angles during pedaling and thus reproduce (faithfully) the movement in a SG. That is, the patient will pedal a unicycle containing the module and the patient will have this same movement being done in the virtual environment by an avatar. It also identifies the propulsive phase (0° to 180°), where the rider applies the greatest force on the pedal, the recovery phase (180° to 360°) and the rotation of the crank.

In addition, the SPS module can send information about the positioning of the crankcase to the CS module. Thus, the CS module, connected to a biological signal acquisition device, will synchronize both signals. This synchronization allows biological signals to be analyzed offline. The pattern of muscle activation (acquired through sEMG) and analysis of patterns of brain signals (acquired through EEG) can be used to evaluate the progression of patient recovery, among others.

Another utility of SPS is its use on the patient's body. With SPS disposed on the ankle or pelvis, it is possible to identify support phases and gait balance. Specifically, with the positioning on the pelvis, it is possible to evaluate the gait symmetry, a variable widely used for the evaluation of walking improvement in some patients, such as patients with post-stroke hemiparesis. This information on gait phases is important even if one wants to analyze the muscular activation pattern in this task, in whose case the CS would be used to synchronize IMU signals with biological signals.

The acquired data, in addition to be used for the physical evaluation of the patients, can be used to reproduce the movements of the individual in a serious game. For this, the patient can use a treadmill or walk on the ground, depending on how the AV is presented to the him/her. It can be displayed in front of him/her using a projector, displayed on a screen, or use a Head Mounted Display, as examples. The SPS can also be positioned on the arm in order to reproduce the movement performed by the patient in the virtual environment.

CLAIMS

Position and Synchronism Sensor (SPS) comprising:

an IMU sensor "Inertial Measurement Unit"

an AVR microcontroller for internal processing

a micro USB connector (12), which is used to charge the internal battery

wireless communication through Bluetooth protocol, characterized by acting as a transducer of biomechanical signals in digital signals, which can be used to synchronize the movement performed by the patient during the rehabilitation exercises to his/her avatar in a virtual reality environment.

Converter and synchronizer (CS) comprising:

a digital signal converter for two independent analog signal outputs (22, 23)

wireless communication via Bluetooth protocol for communication with the SPS module

a charging connector (21)

a connector for serial communication via USB, characterized by having the functionality of synchronizing two biological signal monitoring apparatuses, such as Electroencephalography (EEG) and surface Electromyography (sEMG), among others, to an inertial signal from SPS (according to claim 1) through the two analog outputs (22, 23).

Fastening bracket, comprising:

holder for fixing to the crank, characterized by having the ability to position the SPS module to the bicycle and monocycle crank used for physical rehabilitation;

fastening bracket to the body, characterized by having the ability to position the SPS module to the ankle, arm or hip of the patient.

FIGURES

Figure 1 shows a drawing of the SPS device.

Figure 2 is a presentation of the CS module.

Figure 3 is the fastening bracket of the SPS device for positioning the monocycle and/or bicycle crankcase.

Figure 4 is the fastening bracket of the SPS device for positioning, using elastic band, adjacent to the subject's body (arm, leg or back)

Figure 5 is a representation of the SPS device mounted adjacent to the tape holder.

Figure 6 is a representation of the SPS device mounted adjacent the crank support.

Figure 1 shows the on/off button (11), the micro USB connector (12), which is used for charging the internal battery. The region of the cover represented by the number 13 indicates the location where the operation LED flashes. The lower base of the device (14) and its side (15) are used as reference for positioning.

Figure 2 shows the CS signal converter module, the charging connector (21) can also be used for serial communication via USB. The analog outputs (22, 23) are used to connect the biological signal amplifiers, such as EEG and sEMG. Due to the wide variety of cables available for each type of amplifier, a generic connector was used, on which the grip is done by tightening the screws (24, 25). LED function indicator is represented by the number 28. Each of the output channels (22, 23) is composed of a 3-way connector: ground (GND) (26), analogic signal (SIGNAL OUT) (27) and power (VCC) (28), in which the devices that will amplify the biological signals are connected. The power input can be made either external (26, 28) or directly by the CS, being the choice made through the programming parameters. When the devices used have two-way channels only, the connectors represented by numbers 26 and 27 are used, and, in this case, the power input is done by the internal circuit of the CS.

The fastening bracket (Figure 3) is positioned to the crank through the recess (32) and is secured by means of M3 screws 30 mm long, inserted into the holes represented by the numeral 33. The SPS device is placed in the part represented by the number 31, being fixed by pressure without any other form of locking, and the area represented by the number 15 is positioned to the right side, regarding the positive direction of the linear movement.

The body attachment support (Figure 4) is used to position the SPS device (Figure 1) on the ankle, wrist or back of the subject.

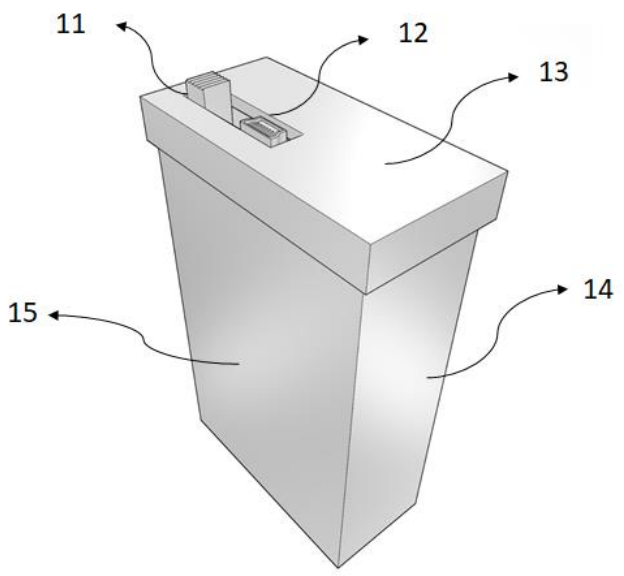


Fig. 1

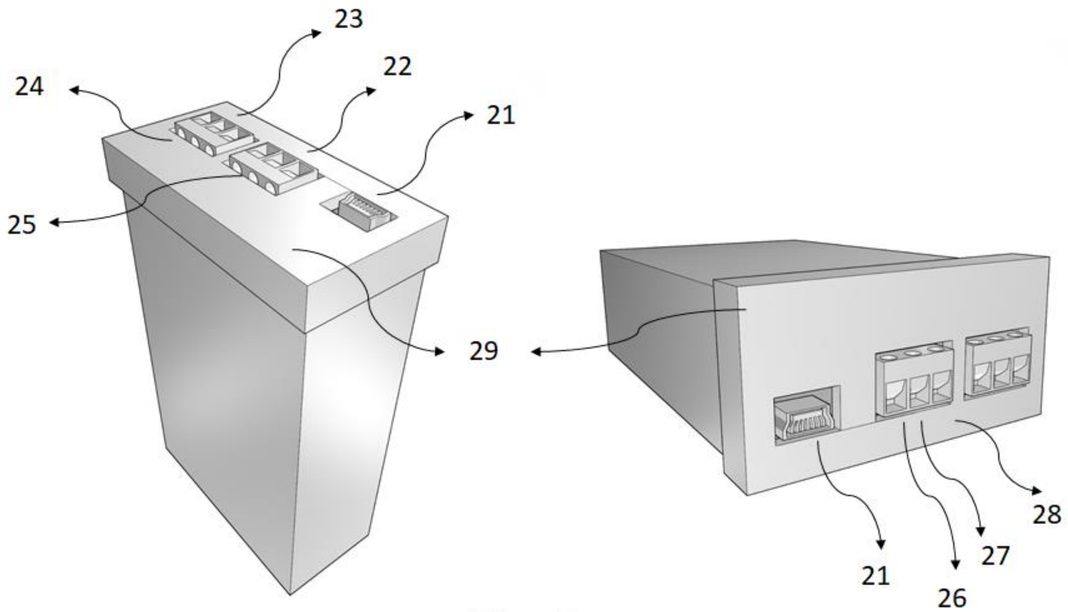


Fig. 2

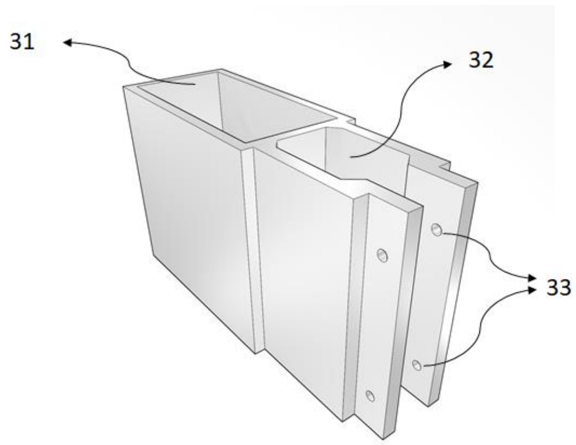


Fig. 3

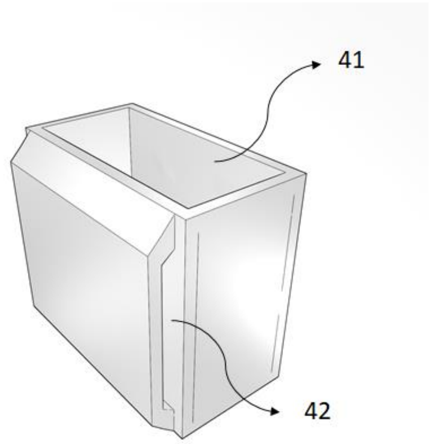


Fig. 4

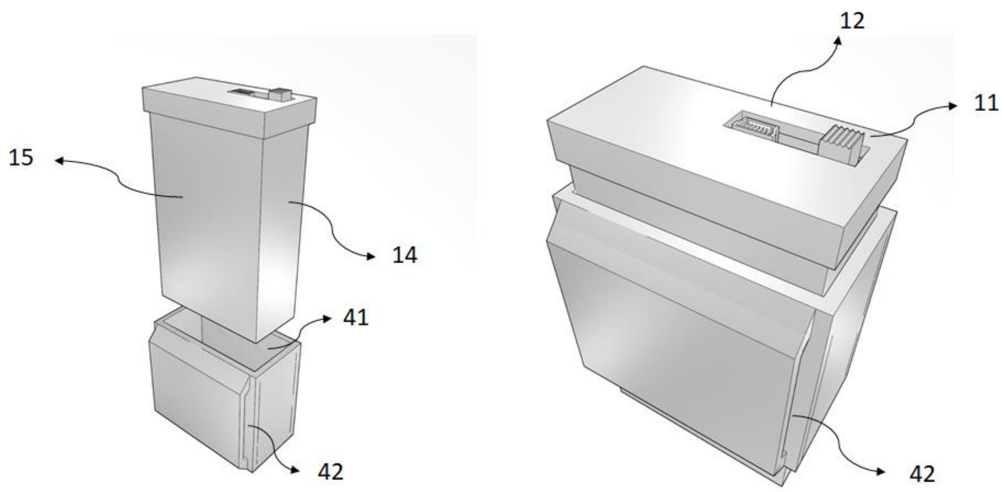


Fig. 5

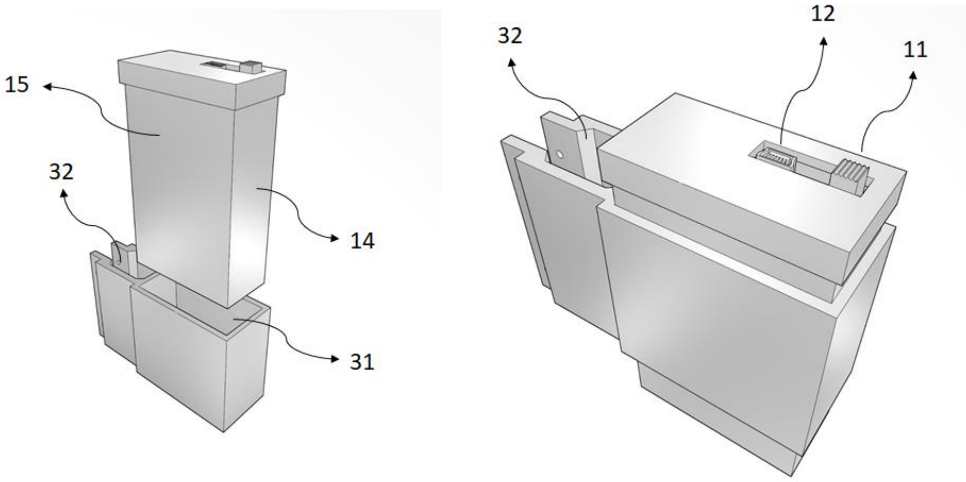


Fig. 6

Descrição em Português:

Dispositivo Eletrônico para Leitura de Posição e Sincronia de Dados Biológicos

A presente invenção é denominada como Dispositivo Eletrônico para Leitura de Posição e Sincronia de Dados Biológicos, composto por dois módulos: Sensor de Posicionamento e Sincronismo (SPS) e Conversor e Sincronizador (CS). O módulo SPS consiste em um sensor IMU “Inertial Measurement Unit”, um microcontrolador AVR para processamento interno, e possui comunicação sem fio através de protocolo Bluetooth. Já o módulo CP é um conversor de sinal digital para analógico, com duas saídas independentes, e utiliza protocolo bluetooth, para comunicação com o módulo SPS, e comunicação serial através de um conector micro USB.

O SPS atua como um transdutor de sinais biomecânicos para sinais digitais, o qual pode ser utilizado para a sincronização do movimento realizado pelo usuário, durante exercícios de reabilitação, para o seu avatar em um ambiente de realidade virtual (RV). Esse módulo pode ser utilizado diretamente através da comunicação Bluetooth quando empregado para interação com o ambiente de RV. Entretanto, para sincronizar os movimentos dos membros inferiores / superiores com os sinais biológicos, tais como os sinais de eletroencefalografia (EEG) e eletromiografia de superfície (sEMG), é necessário utilizar o módulo CS, que possui a função de sincronização dos sinais biomecânicos e bioelétricos. Desta forma, tem-se a possibilidade de obter dados de diferentes amplificadores com um sinal em comum, facilitando o processamento dos dados obtidos.

FUNDAMENTOS DA INVENÇÃO

Pacientes com acometimento motor nos membros inferiores podem ser beneficiados com reabilitação física, na qual o objetivo mais visado é a recuperação da independência do indivíduo em tarefas básicas (locomoção, tomar banho, fazer tarefas domésticas). A recuperação funcional de déficits motores em pacientes neurológicos pode requerer uma quantidade considerável de repetições de movimentos para induzir mudanças na neuroplasticidade. Considerado o “padrão ouro” em reabilitação, os exercícios aeróbicos, além de induzir um alto número de repetições, têm o potencial de promover melhorias nos sistemas circulatório, respiratório e muscular. A melhoria no suprimento sanguíneo e captação de oxigênio pelos tecidos, o aumento e manutenção da amplitude articular ativa e a preservação do tecido muscular são benefícios que ajudam a preservar a saúde do indivíduo, além de contribuir para sua recuperação e reabilitação.

Como exemplo, os treinamentos de caminhada e pedalada são úteis por serem tarefas repetitivas, de fácil execução, e por ativarem vários grupos musculares, promoverem melhoria da circulação sanguínea, capacidade respiratória e manutenção do tecido muscular.

Entretanto, pelo fato de ser um treinamento repetitivo e monótono, o paciente pode apresentar falta de atenção, desmotivação e, até mesmo, desistência da terapia. Ressalta-se que é importante que os pacientes tenham um papel ativo no seu processo de reabilitação, pois os que se mostram mais motivados apresentam uma melhor recuperação. Assim, como forma de aumentar a motivação do paciente para a realização da terapia de reabilitação, jogos sérios em ambiente de Realidade Virtual (RV) podem ser uma alternativa, já que estespossibilitam uma forma lúdica de reabilitação, proporcionando um biofeedback imersivo, e também propiciam uma reabilitação cognitiva, pois o paciente precisa prestar atenção aos objetivos do jogo.

Desta forma, a RV pode proporcionar ao paciente um ambiente variado e agradável que implica em sua motivação para a prática dos movimentos necessários à reabilitação durante longos períodos de tempo. A possibilidade de acrescentar para estes pacientes feedback simultâneo, conhecimento do seu desempenho e dos resultados alcançados no processo de reabilitação são importantes para a sua aprendizagem, assim como para a sua motivação, e irão influenciar diretamente na sua recuperação. Estudos indicam que a motivação do paciente é um fator altamente importante para o resultado final do processo terapêutico.

Adicionalmente, incorporar informações de sinais biológicos por meio de EEG e sEMG em jogos baseados em RV tem por objetivo fornecer ao profissional de reabilitação informações para avaliar a evolução do paciente e estabelecer metas individualizadas e mais precisas visando sua reabilitação. É importante que os sinais biológicos estejam sincronizados com os sinais biomecânicos para que se possa determinar em qual fase do movimento o músculo está contraído ou qual região do cérebro está sendo ativada. Esses dados podem ser comparados ao padrão de pessoas sem acometimento motor, já descrito pela literatura científica.

SUMÁRIO DA INVENÇÃO

A presente invenção tem como objetivo fornecer uma sincronização precisa dos ângulos de posicionamento de pedivelas de um monociclo ou bicicleta utilizados para reabilitação, ou dos membros ou outras regiões do corpo do paciente. Seu uso pode ser realizado em protocolos de pesquisa de reabilitação física, assim como em protocolos de fisioterapia e terapia ocupacional, e também para treinamento de para-desporto (atividades esportivas de pessoas com deficiência).

A presente invenção propõe dois módulos que, quando usados em conjunto, permitem a sincronização entre o movimento do paciente e seus sinais EEG / sEMG. Além disso, enquanto estiver usando apenas o Sensor de Posição e Sincronização (SPS), os movimentos do paciente podem ser transferidos diretamente para aplicativos de computador ou smartphone, de forma a registrar o progresso de sua reabilitação.

O aparato da presente invenção permite obtenção de dados de posicionamento, através da transdução dos sinais obtidos pelos sensores inerciais em sinais digitais, os quais são transmitidos utilizando protocolo Bluetooth. O módulo SPS é o responsável por essa transdução e envio de dados. Os dados podem ser envidos aos computadores ou outros dispositivos portáteis, como por exemplo, aparelhos com sistema Android.

Os dados também podem ser recebidos pelo módulo CS, onde são convertidos em um sinal analógico de 8 bits de resolução. Após essa conversão, o sinal é disponibilizado, isoladamente, através de dois canais. Tais canais podem ser configurados através de um mini-switch para utilizarem o nível CC 0-5 V do próprio módulo, ou para utilizarem a tensão do equipamento de EEG ou sEMG a ser utilizado. O processamento das informações é realizado por microcontrolador AVR, o qual gerencia dois potenciômetros digitais para geração dos sinais de saídas. Esse sinal pode ser configurado para ter alimentação independente do dispositivo, ou seja, ser fornecido pelos próprios aparelhos em que será utilizado ou, se necessário, ser alimentado pelo circuito interno. Diferentemente do módulo SPS, que pode ser utilizado separadamente, este módulo só possui suas funcionalidades quando utilizado em conjunto com o SPS. Trata-se de uma ferramenta com grande utilidade quando se deseja relacionar informações inerciais a outros sinais, como sEMG e EEG. Por possuir duas saídas isoladas fornecendo um sinal comum, este pode ser utilizado com um sinal de referência para realizar a sincronização entre os dois dispositivos, facilitando os processamentos de dados subsequentes.

O sensor ainda pode ser configurado via comandos numéricos para disponibilizar os dados do sensor de temperatura, de velocidade de giro (giroscópio) e de aceleração (acelerômetro), sem qualquer processamento. Também pode ser ajustada a frequência de amostragem de dados, configurada por padrão em 100 Hz, e seu modo de envio de sinal, como contínuo ou dependente de solicitação.

A presente invenção propõe, através do módulo CS, um novo conceito funcional que reside na sincronização analógica de sinais de EEG e sEMG aos eventos físicos. Tal sincronização é realizada através da geração de um sinal comum enviado a ambos os equipamentos e níveis de tensão isolados e próprios a cada um.

A implementação da invenção em questão permite a obtenção de sinais através de diferentes equipamentos, com grande facilidade para sincronização sem complexos processamentos. Adicionalmente os dispositivos construídos têm a característica de ser de fácil utilização e de baixo custo.

UTILIDADES

O módulo SPS pode ser utilizado nos pedivelas de um monociclo ou bicicleta para identificar os ângulos durante a pedalada, e assim reproduzir (copiar fielmente) o movimento para um jogo sério. Ou seja, o paciente irá pedalar o monociclo ou bicicleta contendo o módulo, sendo que o paciente verá este mesmo movimento sendo feito por um avatar no ambiente virtual do jogo. O módulo também permite identificar a fase propulsiva de 0° de 180° do ângulo de giro (na qual o paciente aplica a maior força no pedal), a fase de recuperação (de 180° a 360°) e a rotação do pedivela.

Além disso, o módulo SPS permite o envio de informações sobre o posicionamento do pedivela ao módulo CS e este, conectado a um dispositivo de captura de sinais biológicos, irá sincronizar ambos os sinais. Essa sincronia permite que os sinais biológicos sejam analisados off-line. O padrão de ativação muscular (adquiridos através de sEMG) e a análise de padrões de sinais cerebrais (adquiridos através de EEG) podem ser usados para avaliação da progressão da recuperação do paciente, entre outros.

Outra utilidade do SPS é a sua utilização sobre o corpo do usuário. Por exemplo, com o SPS disposto sobre o tornozelo ou pélvis é possível identificar fases de apoio e balanço da marcha. Especificamente, com o posicionamento sobre a pélvis é possível avaliar a simetria da marcha, variável bastante utilizada para a avaliação da melhoria da caminhada de alguns pacientes, como por exemplo, pacientes com hemiparesia pós-AVC. Essas informações sobre as fases da marcha são importantes ainda quando se quer analisar o padrão de ativação muscular nessa tarefa; neste caso o CS seria utilizado para sincronizar os sinais da IMU com os sinais biológicos.

Os dados adquiridos, além de serem utilizados para avaliação física dos pacientes, podem ser utilizados para reproduzir os movimentos do paciente em um jogo sério. Para isso pode-se utilizar uma esteira ergométrica ou caminhar sobre o solo, dependendo de como o AV é apresentado ao paciente. O AV pode ser projetado à sua frente, exibido em uma tela ou utilizado de forma imersiva através de óculos de realidade virtual, por exemplo. O SPS pode, ainda, ser posicionado sobre o braço do paciente, com o intuito de reproduzir o movimento realizado pelo mesmo no ambiente virtual.

REIVINDICAÇÕES

Sensor de Posicionamento e Sincronismo (SPS), compreendendo:

um sensor IMU “Inertial Measurement Unit”

um microcontrolador AVR para processamento interno

um conector micro USB (12), o qual é utilizado para carregamento da bateria interna

comunicação sem fio através de protocolo Bluetooth **caracterizado por** atuar como um transdutor de sinais biomecânicos em sinais digitais, o qual pode ser utilizado para a sincronização do movimento realizado pelo paciente durante os exercícios de reabilitação com o seu avatar em um ambiente de realidade virtual.

Conversor e Sincronizador (CS), compreendendo:

um conversor de sinal digital para duas saídas independentes (22, 23) de sinal analógico

comunicação sem fio através de protocolo Bluetooth para comunicação com o módulo SPS

um conector para carregamento (21)

um conector para comunicação serial (21) via USB **caracterizado por** ter a funcionalidade de sincronizar dois dispositivos de monitoramento de sinais biológicos, como Eletroencefalografia (EEG), Eletromiografia de Superfície (sEMG), entre outros, a um sinal inercial proveniente do SPS (de acordo com a reiv. 1) através das duas saídas analógicas (22, 23).

Suporte para fixação, compreendendo:

suporte para fixação ao pedivela, **caracterizado por** ter a capacidade de posicionar o módulo SPS ao pedivela de bicicletas, monociclos e similares utilizados para reabilitação física

suporte para fixação ao corpo, **caracterizado por** ter a capacidade de posicionar o módulo SPS ao tornozelo, braço ou quadril do usuário.

FIGURAS

A Figura 1 apresenta um desenho do dispositivo SPS.

A Figura 2 é uma apresentação do módulo CS.

A Figura 3 é o suporte de fixação do dispositivo SPS para posicionamento ao pedivela de monociclos e/ou bicicletas.

A Figura 4 é o suporte de fixação do dispositivo SPS para posicionamento, utilizando cinta elástica, junto ao corpo do indivíduo (braço, perna ou costas)

A Figura 5 é uma representação do dispositivo SPS montado junto ao suporte de cinta.

A Figura 6 é uma representação do dispositivo SPS montado junto ao suporte de pedivela.

Na Figura 1 estão evidenciados o botão de liga/desliga (11), o conector micro USB (12), o qual é utilizado para carregamento da bateria interna, a região da tampa representada pelo número 13 indica o local onde é possível observar o LED indicativo de operação. A base inferior do dispositivo (14) e sua lateral (15) são utilizados como referência para posicionamento junto ao suporte.

Na Figura 2 é apresentado o módulo conversor do sinal CS, o conector para carregamento (21), que também pode ser utilizado para comunicação serial via USB, e as saídas analógicas (22, 23), onde são conectados os amplificadores de sinais biológicos, como, por exemplo, EEG e sEMG. Devido à grande variedade de cabos existentes para cada tipo de amplificador, o conector utilizado é genérico, sendo a fixação realizada através do aperto de parafusos (24, 25). Para a indicação de funcionamento há um LED verde (28). Cada um dos canais de saída (22, 23) é composto por um conector de 3 vias, sendo aterramento GND (26) sinal análogico SIGNAL OUT (27) e alimentação VCC (28), onde devem ser conectados os aparelhos que irão amplificar os sinais biológicos. A alimentação pode ser feita tanto externa (26, 28) ou diretamente pelo CS, sendo a escolha realizada através dos parâmetros de programação. Quando os dispositivos utilizados possuem canais de apenas duas vias, são utilizados apenas os conectores representados pelos números 26 e 27 e, neste caso, a alimentação passa a ser feita pelo circuito interno do CS.

O suporte para fixação (Figura 3) é posicionado ao pedivela através do encaixe (32), sendo fixado com auxílio de parafusos M3 de 30 mm de comprimento, inseridos nos furos representados pelo número 33. O dispositivo SPS é colocado na parte representada pelo número 31, sendo fixado por pressão sem necessidade de outra forma de travamento, devendo somente a área representada pelo número 15 ser posicionada para o lado direito em relação ao sentido positivo do movimento linear.

O suporte para fixação junto ao corpo dos indivíduos (Figura 4) é utilizado para posicionar o dispositivo SPS (Figura 1) no tornozelo, punho ou costas do indivíduo.

4 CONCLUSIONS

New technologies and innovations play a crucial role in healthcare. Biomedical engineering, biotechnology, pharmaceuticals, and other health areas responsible for the development of medical devices and equipment, are credited with improving and saving innumerous lives. The success of providing healthcare requires effective medical devices as tools for prevention, diagnosis, treatment, and rehabilitation. However, poor countries have little access to new health technologies (WHO, 2017).

This research proposed the design, development and testing of a SGs platform (Virtual-R) with affordable access multi-devices, and carried out a series of evaluation methods. Also, SGs were developed to be used with AT under research and development at NTA-UFES, which also passed through an evaluation process.

The development of a SG passes through a sequence of design, implementation, tests and modifications, until reaching its final version. Some of the changes made in the first developed SG were applied in the next ones. These changes were made based on the evaluative results, opinions from users and patients, and requests from the health professional responsible for these patients. The SGs showed in this work went through many versions until reaching a usable stage, when it was assessed with the described questionnaires.

All the SGs assessed with the SUS questionnaires received high scores, meaning they are ready as products regarding their usability. This can be confirmed by checking Figure 23 and comparing its results with the interpretation scale proposed by BANGOR, KORTUM, and MILLER (2009), where they pair SUS results with other scales to facilitate SUS score interpretation. Thus, all SUS results from Table 2 are Acceptable, received B and A grade scale and are between Good and Best Imaginable (Figure 24).

Serious Game			SUS Score
House simulation			91,32
Minibike		people without impairment	83,57
		people with impairment	96,43
		therapists	90
Market	Ski	people without impairment	94,16
		patients with impairment	95
		therapists	85
	snow	people without impairment	95
		people with impairment	92,95
		therapists	90
	Target shooting	people without impairment	92,14
		people with impairment	90,83
		therapists	91,42
	market	people without impairment	91,53
		people with impairment	90,2
		therapists	92,14

Figure 23. SUS score for all SGs of this work assessed with it. Source: produced by the author, 2019.

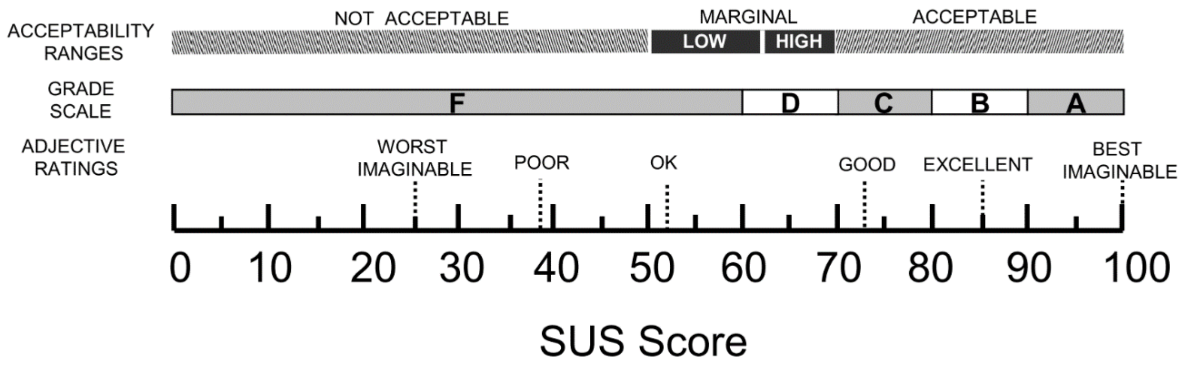


Figure 24. Adjective ratings, acceptability scores, and school grading scales, in relation to the average SUS score. Source: BANGOR, KORTUM, and MILLER (2009).

The EPW simulator was not assessed with the SUS because the intent of the project was to provide a tool to safely test and develop input devices for EPWs, so it was not intended to be a final product, but a simulator to test and develop other products. Regarding cybersickness, Figure 25 is a compilation of all the SSQ TS results, made to facilitate interpretation, which uses the analysis of the results from before and after HMD usage.

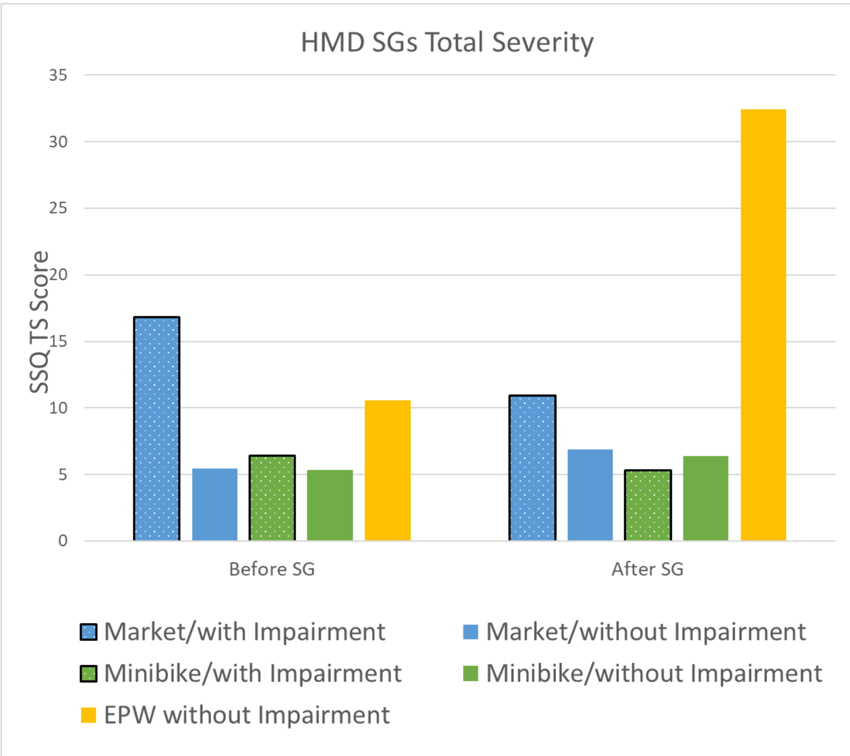


Figure 25. SSQ TS for all HMD SGs. Source: produced by the author, 2019.

Despite the use of the HTC VIVE with the Market and Minibike game, they had little or no impact on cybersickness, the results for EPW show a considerable increase on the SSQ TS results. This difference might be caused by sensory mismatch, since the simulation, to match the real EPW speed and acceleration, has values high enough to cause cybersickness. Also, in addition to the forward movement, the EPW simulator has backward and left/right turning movements, which may increase the sensory mismatch. Verbal reports of sickness were common after the EPW simulator usage, which was not observed after the Minibike or Market usage.

The Minibike SG, despite having forward movement, it has low acceleration and deceleration, and has no backward or turning movement. This can explain the low impact on the SSQ TS results.

The Market SG, on the other hand, might have the lowest impact on sensory mismatch once the user moves inside the SG the same way they move in the real world.

These are important results to take further action to reduce, as much as possible, the cybersickness effects of the EPW simulation. Future works, in this direction, might consider the use of augmented reality for the EPW training. It could drastically reduce the sensory mismatch, since the EPW would move with the user. The VIVE has already announced the VIVE Pro, which is a Software Development Kit (SDK) that will give access to the stereo front facing cameras of the HMD to enable the implementation of augmented reality (VIVE, 2019).

The high values of the IMI scores (above 85%) from patients for all the SGs from Virtual-R is evidence that the SGs can be used, successfully, in rehabilitation. Long term tests need to be done to assess the motivation levels over long term usage. Future work includes the addition of other games, exercises and new devices. The possibility of using different exercises in the same game, and vice versa, to amplify its usage possibility, is another future objective. There is, yet, the possibility to expand from personal computers to consoles and mobiles, increasing SG usage to home-based rehabilitation, once the Unity engine has option to build its projects to a wider variety of platforms.

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6 ATTACHMENTS

Attachment 1 - Computer Software Registration

REPÚBLICA FEDERATIVA DO BRASIL
Ministério Da Indústria, Comércio Exterior e Serviços
Instituto Nacional da Propriedade Industrial
Diretoria de Patentes, Programas de Computador e Topografias de Circuitos Integrados

Certificado de Registro de Programas de Computador

Processo nº: BR 51 2018 000826-7

O Instituto Nacional da Propriedade Industrial expede o presente certificado de Registro de Programas de Computador, válido por 50 anos a partir de 1º de janeiro subsequente à data de Publicação: 01 de setembro de 2017 , em conformidade com o parágrafo 2º , artigo 2º da Lei Nº 9.609, de 19 de Fevereiro de 1998.

Título: **VIRTUAL-R: Jogos Eletrônicos para Reabilitação Motora**

Data de Criação: 01 de setembro de 2017

Data de publicação: 01 de setembro de 2017

Titular(es): UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO - UFES

Autor(es): BERTHIL BORGES LONGO
/ GUSTAVO GLÁSGIO BRAVIN ANDRADE
/ MARIANA MIDORI SIME
/ TEODIANO FREIRE BASTOS FILHO

Linguagem: C#

Campo de Aplicação: AD-01

Tipo Programa: AP-01

Algoritmo Hash: SHA-512

Resumo Digital: 4a2b0d8d2ce77dadf29b05d78680d48f40b206d1c3018f80d7798b66dc48ad8caf4f6c126b5edf
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Expedido em: 05 de junho de 2018

Aprovado por Julio Cesar Castelo Branco Reis Moreira

15 de Novembro REPÚBLICA FEDERATIVA DO BRASIL de 1889

Attachment 2 - Submitted article

Mary Ann Liebert, Inc.

Games for Health Journal
Research, Development, and Clinical Applications

Development and Evaluation of a Multi-Device Serious Games Platform for Rehabilitation Purposes

Journal:	*Games for Health Journal*
Manuscript ID	Draft
Manuscript Type:	Original Article
Date Submitted by the Author:	n/a
Complete List of Authors:	Longo, Berthil; Universidade Federal do Espirito Santo, Biotechnology;
Keywords:	exergames, game therapy, occupational therapy, physical therapy, rehabilitation
Manuscript Keywords (Search Terms):	serious games, physical rehabilitation, intrinsic motivation, system usability, simulation sickness

Attachment 3 - Submitted patent 1

INSTITUTO NACIONAL DA PROPRIEDADE INDUSTRIAL

21/11/2017 870170089474 13:55

29409161710480121

Pedido nacional de Invenção, Modelo de Utilidade, Certificado de Adição de Invenção e entrada na fase nacional do PCT

Número do Processo: BR 10 2017 024843 7

Dados do Depositante (71)

Depositante 1 de 1

Nome ou Razão Social: UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO - UFES

Tipo de Pessoa: Pessoa Jurídica

CPF/CNPJ: 32479123000143

Nacionalidade: Brasileira

Qualificação Jurídica: Instituição de Ensino e Pesquisa

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Estado: ES

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Email: josecarlos.init@gmail.com

Attachment 4 - Submitted patent 2

República Federativa do Brasil
Ministério da Indústria, Comércio Exterior e Serviços
Instituto Nacional da Propriedade Industrial

(21) BR 102017011628-0 A2

(22) Data do Depósito: 01/06/2017

(43) Data da Publicação Nacional: 18/12/2018

(54) Título: SUPORTE PARA ELETRODOS EM FORMA DE DISCO PARA ELETROENCEFALOGRAFIA

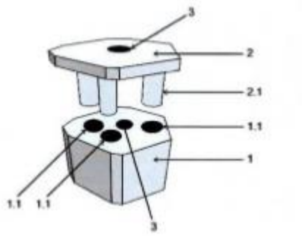
(51) Int. Cl.: A61B 5/0478; A61N 1/05.

(52) CPC: A61B 5/0478; A61N 1/05.

(71) Depositante(es): UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO.

(72) Inventor(es): BERTHIL BORGES LONGO; ALAN SILVA DA PAZ FLORIANO; TEODIANO FREIRE BASTOS FILHO.

(57) Resumo: SUPORTE PARA ELETRODOS EM FORMA DE DISCO PARA ELETROENCEFALOGRAFIA. Trata-se de um suporte para toucas de eletrodos de captação de sinais elétricos do cérebro, capaz de se adaptar a qualquer tipo de touca sem a necessidade de substituição da mesma, de forma a apresentar um funcionamento universal para esse tipo problema; Portanto, o suporte que será adaptado a qualquer tipo de touca (A) de eletrodos (B) para eletroencefalografia, será constituído principalmente por duas peças, peça inferior (1) e peça superior (2); Onde a peça inferior (I) compreenderá furos (1.1) e furo central (3); A peça superior será composta por pinos (2.1), furos (2.2) e furo central (3).



Attachment 5 - Submitted patent 3

UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO
Pró-Reitoria de Pesquisa e Pós-Graduação
Instituto de Inovação Tecnológica

DECLARAÇÃO

Declaro, para os devidos fins, que foi protocolado junto a este INIT – Instituto de Inovação Tecnológica da UFES, na data de 08 de janeiro de 2019, a solicitação de pedido de patente com o título "**Dispositivo Eletrônico para Leitura de Posição e Sincronia de Dados Biológicos**", tendo a UFES – Universidade Federal do Espírito Santo como titular e seus inventores, Alexandre Geraldo Pomer-Escher, Berthil Borges Longo, Flávia Aparecida Loterio, Vivianne Flávia Cardoso e Teodiano Freire Bastos Filho.

Vitória/ES, 16 de janeiro de 2019.

José Carlos Fundão Farias
Administrativo – INIT/UFES

Jose Carlos Fundão Farias
Pró Reitoria de Pesquisa e Pós Graduação - INIT
Assistente em Administração
SIAPE Nº 1903217

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NORTHEASTERN NETWORK OF BIOTECHNOLOGY (RENORBIO)

FEDERAL UNIVERSITY OF ESPIRITO SANTO

HEALTH SCIENCES CENTER

POSTGRADUATE PROGRAM IN BIOTECHNOLOGY

BERTHIL BORGES LONGO

Development and Evaluation of Serious Games as Assistive Technology through Affordable Access Multi-Devices

VITÓRIA

2019

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