UNIVERSIDADE FEDERAL DE JUIZ DE FORA
INSTITUTO DE CIÊNCIAS EXATAS
PÓS-GRADUAÇÃO EM CIÊNCIA DA COMPUTAÇÃO

Rian Dutra da Cunha

Virtual Reality as an Assistive Technology to Support the Cognitive Development of People With Intellectual and Multiple Disabilities

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"Stay hungry, stay foolish."

Steve Jobs

RESUMO

A realidade virtual possui inúmeras aplicações potenciais para o tratamento e desenvolvimento de pessoas com deficiência intelectual e múltipla. Uma combinação do tratamento cognitivo tradicional e métodos baseados em realidade virtual pode oferecer uma abordagem efetiva, segura e interativa ao tratamento de indivíduos com deficiências. Baseado nisso, um método computacional foi proposto para desenvolver um sistema de realidade virtual para auxiliar no desenvolvimento cognitivo e da coordenação motora grossa dessas pessoas, de modo que as tornem mais autônomas e capazes de fazer tarefas diárias, melhorando a participação na comunidade, assim como a inclusão social, a partir da simulação e treinamento de tarefas comuns que as pessoas geralmente executam diariamente. Uma das principais preocupações deste trabalho foi desenvolver com o custo mais baixo possível, utilizando dispositivos padrões e acessíveis à maioria das pessoas. Além disso, uma manipulação baseada na mão feita com marcadores de realidade aumentada foi proposta, para proporcionar uma experiência do mundo real, pois, considerando as dificuldades cognitivas e motoras dos participantes, uma interação feita com suas próprias mãos seria mais fácil, mais intuitiva e efetiva para as pessoas com deficiências. Os resultados dos experimentos demonstraram a eficácia e viabilidade do uso de tecnologias de realidade virtual para o treinamento cognitivo e motor de pessoas com deficiência intelectual e múltipla, mostrando que os participantes conseguiram executar a tarefa 40% mais rápidos em média no estudo de caso 1, que basicamente é um simulador onde o participante deve fazer compras em um mercado, e também mostrando uma melhora de 41% em relação aos erros cometidos no estudo de caso 2, no qual o paciente deve passar por uma série de desafios que treinam sua coordenação motora grossa e equilíbrio. Baseado na análise dos dados feita após a intervenção e também baseado na observação da fisioterapeuta, foi possível provar que métodos baseados em realidade virtual podem ser eficazes no desenvolvimento de habilidades cognitivas e motoras de pessoas com deficiência intelectual.

Palavras-chave: Realidade virtual. Deficiência intelectual e múltipla. Tecnologia assistiva. Interação humano-computador.

ABSTRACT

Virtual Reality has countless potential applications for the treatment and development of people with intellectual and multiple disabilities. A combination of traditional cognitive treatment and virtual reality-based methods can offer an effective, safe and interactive approach to the treatment of individuals with disabilities. Based on that, a computational method was proposed to develop a virtual reality system for supporting the cognitive and gross motor coordination development of those people, in a way that makes them more autonomous and able to do daily tasks, so improving their community participation, hence their social inclusion, by simulating and training common tasks people usually do on a daily basis. One of the main concerns of this work was to develop a low cost system, using standard and accessible devices. Furthermore, a hand-based manipulation made by augmented reality markers into the virtual reality environment was proposed, for providing a real-world experience, because, considering the cognitive and motor impairments of the participants, an interaction performed with their own hand would be easier, more intuitive and effective. The results of the experiments demonstrated the effectiveness and feasibility of using virtual reality technologies for the cognitive and motor coordination training of people with intellectual and multiple disabilities, showing that the participants were able to do the task 40% faster on average in the case study 1, which is basically a simulator where the participant should going shopping in a supermarket, and also showing an improvement of 41% related to the mistakes made in the case study 2, in which the patient must to go through a series of challenges that train the gross motor coordination and body balance. Based on the data analysis done after the intervention and also based on the physiotherapist's observation, it was possible to prove that virtual reality-based method can be effective in the cognitive and motor skills development of people with intellectual disabilities.

Keywords: Virtual reality. Intellectual and multiple disability. Assistive technology. Human–computer interaction.

LIST OF FIGURES

LIST OF TABLES

CONTENTS

1 INTRODUCTION

Virtual reality has many qualities and features that provide people with intellectual and multiple disabilities and physiotherapists rehabilitative potentials. A combination of traditional cognitive treatment and virtual reality-based methods can offer an effective, safe and interactive approach to the treatment of individuals with disabilities. Therefore, the current study discusses the contribution of virtual reality to promote social inclusion of people with intellectual and multiple disabilities, improving their community participation through a cognitive and motor skills training, which makes them more autonomous and able to do daily tasks.

The definition of social inclusion presented in (SIMPLICAN et al., 2015) refers to being accepted as an individual beyond disability, focusing on two domains – interpersonal relationships and community participation. In this context, community participation is the involvement in community activities that promote the development of interpersonal relationships, including leisure activities, political and civic activities or organizations, productive activities, like employment or education, religious and cultural activities and groups and consumption, or access to goods and services, which the current study is focused on.

Virtual Reality (VR) is increasingly being recognized as an effective tool for the rehabilitation of cognitive processes and functional abilities. The VR-cognitive rehabilitation framework was first proposed in (RIZZO; BUCKWALTER, 1997), for children with attention-deficit activity disorder (ADHD). Traditional treatment requires specific exercises to improve the cognitive and motor skills through repetitive training. Intense repetition of tasks is necessary to reorganize the brain in a particular area of understanding; however, it requires immense demands both on the patient and the professional (BUTLER, 2007). In particular, because people with intellectual and multiple disabilities are difficult to engage, cognitive treatment approach applied to them can be a hard and complex task. Virtual reality-based methods, specially when it is game-like activities, are able to make cognitive and motor coordination treatment and rehabilitation more accessible to people with disabilities through their capacity to maintain their attention, providing an effective and safe training and educational media for those people.

1.1 MOTIVATION

Virtual Reality has countless potential applications for the treatment and development of people with intellectual and multiple disabilities. Among others, there could be mentioned:

- Near real-life environment: virtual reality provides a more naturalistic setting, so the experience of being immersed within a virtual environment makes the user to get consciously immersed forgetting they are in a testing situation. Thus, this may allow assessments of the individuals' behavior under more natural conditions, providing insights into their typical behavior as if they were doing the tasks in real life, without any interference from the technology;

- Control of stimulus presentation and response measurement: VR provides full control over stimulus presentation and response measurement, based on the specifications of the supervisor (e.g., physiotherapist, researcher). Data such as time duration, hits and failures, speed and movements made by the individuals during the assessments can be effortlessly manipulated. This is specially useful for treatments, where the rehabilitation interventions could be based specifically on the individuals' needs and skills, increasing the difficulty and challenge gradually, according to their performance. On top of that, it makes possible to provide individual treatments, targeted to each patient, while maintaining consistency in desired outcome measures;

- Safe treatment: VR is very useful for potentially dangerous or challenging assessment situations. For instance, an individual with balance dysfunction can ride a horse for training his or her body balance without suffering the real or dangerous consequences of their errors. It allows treatment professionals to conduct more challenging assessments, while allowing the experience of safety threats, dangers or mistakes, to promote skills and performance development, and self-awareness. By providing exploration in a safe environment, treatment within a virtual environment also allows the individuals to fail, increasing the individuals' awareness of their own limitations;

- Treatment individualization: VR allows the creation of individualized training of a task based on each individual's abilities and impairments. With VR, it is possible to modify the sensory presentation and response requirements according to the patient's impairments (e.g, movement, visual disorders, cognitive impairments). Also, it makes possible to pause the assessment for instructions and other discussions;

- Increased patient participation: by using virtual reality as a mean to conduct treatments, it is possible to include gaming factors into the environment during the assessments, making them enjoyable and enhance the individual's motivation, which is critical to explore the full potential of the application and method, and the treatment itself. Also, it increases the patients' capacity to maintain attention, providing an effective and safe training and educational media for those people.

1.2 OBJECTIVES

The main objective of this study is to investigate the efficacy of a virtual reality-based cognitive and motor coordination treatment for people with intellectual and multiple disabilities by training common tasks people usually do on a daily basis, focusing on their community participation and social inclusion, as well as improve their gross motor coordination abilities.

The secondary objective is to propose and develop a new low-cost innovative interaction interface between the user and the virtual environment provided by the VR system, using augmented reality marker upon the patient's hands to get his or her hands recognized and replaced by virtual hands in the virtual reality environment, so the individual is capable to handle 3D objects in the VR scenario more realistic and intuitively.

This study's hypothesis is that virtual reality can support the cognitive and motor coordination development so that people with intellectual and multiple disabilities improve their autonomous capabilities. Additionally, another hypothesis is that a hand-based interaction in a VR game-like activity may provide a more natural, attractive and intuitive interaction, thus being more effective both for the cognitive and the motor coordination development, instead of using a joystick or another device for the virtual objects manipulation.

1.3 CONTRIBUTIONS

This study has two main contributions. The first one is presenting case studies that demonstrate the effectiveness and feasibility of using virtual reality technologies for the cognitive and motor coordination development of people with intellectual and multiple disabilities, by using low-cost equipment and focusing on a good user experience which provides an enjoyable training through game-based tasks.

The main concern of this one was to develop motor skills and cognitive abilities of the participants, in a way that makes them more autonomous and able to do daily tasks, so improving their community participation and social inclusion. Once the hypothesis that VR-based methods can be effective for the treatment of people with intellectual disabilities is ratified, the method and system developed and presented in this work may be useful for a wide range of professionals and institutions, as well as researches.

The second contribution of this work was developing and presenting a hand-based manipulation which provides a real-world experience, specially considering the cognitive and motor impairments of the participants. An interaction performed with their own hand (e.g., grab products, get money) is easier, more intuitive and effective.

1.4 OUTLINE

The remainder of this work is organized as follows: Chapter 2 presents the fundamentals that contribute to the foundations of this study. Chapter 3 presents studies which use virtual reality as a resource to support the treatment of people with intellectual and multiple disabilities. In Chapter 4, a detailed description of this study's contributions and the virtual reality-based system developed for the proposed method is presented. In Chapter 5, two case studies are presented and discussed, followed by their experimental results. On top of that, a few considerations from the physiotherapist is made available. Lastly, Chapter 6 presented this study's conclusions and discuss the possible future works.

2 FUNDAMENTALS

In this chapter it's presented the main fundamentals of this study.

2.1 INTELLECTUAL AND MULTIPLE DISABILITIES

Intellectual disability is a developmental disability characterized by limitations in intellectual functioning and adaptive behavior, resulting in the need for extraordinary supports for a person to participate in activities involved with typical human functioning (SCHALOCK et al., 2010).

The term intellectual disability is also similar to other terms used in other countries, such as developmental disabilities, learning disabilities, cognitive disabilities and mental retardation. Intellectual disability can be referred to a condition which affects the individuals' ability to make self-determined choices (SCHALOCK et al., 2002).

For those individuals, to achieve a good quality of life, they frequently require support beyond what is typically needed by other people at a similar age and stage of life. That support might include a variety of forms, such as specialist training, guidance, structured opportunities, or specially designed environmental or social arrangements. Providing these forms of support has been a major function of health and human service programs. Furthermore, the presence of disabilities is often associated with problems concerning participation in society, which means the individuals with intellectual and multiple disabilities are in danger of being excluded from many situations and opportunities that usually are available to other people.

Another term related to intellectual disability is multiple disabilities, referring to people with severe disabilities, such as a sensory disability associated with a motor disability. Individuals with multiple disabilities usually presents more than one significant disability related to physical mobility, learning, speech, visual, hearing and brain injury. Besides, they can also exhibit sensory losses and behavior and/or social problems.

Therefore, intellectual disability is a state of functioning in which impairments to the central nervous system (CNS) (i.e., body functions and structures) result in activity limitations and participation restrictions, and, depending on the definition, a severe intellectual disability may be included in the term "multiple disabilities". Intellectual functioning is a type of human functioning, and is defined in the American Association on Intellectual and Developmental Disabilities (AAIDD) Manual on Definition, Classification and Support Systems in Mental Retardation (SCHALOCK et al., 2010) as referring to a general mental ability that includes reasoning, planning, problem solving, abstract thinking, comprehending complex ideas, learning quickly and learning from experience.

2.2 VIRTUAL REALITY FOR HEALTH

Virtual reality is a term commonly used to describe a fully three-dimensional computer generated environment which can be explored and interacted by one or more people simultaneously. The users virtually become part of the virtual environment – using a head-mounted display (HMD) or some other immersive display device, and an interaction device such as a DataGlove, a joystick or by tracking the users' hand – where they are able to manipulate virtual objects and perform a series of actions. Also, besides the technical specification, virtual reality is based on concepts of "presence" and "telepresence", which refer to the sense of being in an environment, generated by natural or mediated means, respectively (STEUER, 1992).

As computer graphics, electronic devices and virtual reality systems evolves and become more affordable, VR applications may provide more benefits and advantages in science and medicine fields, especially for the acquisition and maintenance of skills necessary for independent living. An early study (MOLINE, 1997) states that the use of VR interventions has been studied in a wide range of medical conditions, including phobias, anxiety disorders, stroke rehabilitation, obesity, motor coordination training and others.

Children with intellectual disabilities are often denied real world experiences, which is critical for providing the opportunity to acquire skills that will later allow those individuals to become independent of their parents. In the same sense, when adults, acquiring or maintaining these kind of skills through practice is also difficult for the same set of reasons. However, in the virtual environment, the individual with intellectual and multiple disabilities is able to go wherever they want, even if they have mobility impairments. They can make as many mistakes as they wish without suffering the real, humiliating, or dangerous consequences of their errors (STRICKLAND, 1997). Furthermore, unlike even the most patient of human carer, computers will never express irritation because of the repeated mistakes nor tire of the learner attempting the same task repeatedly (DARROW, 1995a).

Specially for people with disabilities, when attempting to get a skill or try an activity for the first time, the complexity of the environment can make the task even more difficult. In contrast to the real world, virtual world can be manipulated in ways the real world cannot, adapting all environment according to the needs, which is very useful and important in the scenario of treatment of people with intellectual disabilities. In the virtual worlds, for instance, it is possible to provide less challenging versions of a task for the beginner. As the patient becomes familiar with the task itself and the requested challenges, the training support can be removed little by little, making the virtual environment more challenging and complex, and closer to the real life, according to the patient's performance. Thus, after the VR-based training, the patient may be able to do the task by himself without any help (MIDDLETON, 1992).

With the advance of technology (e.g., mobile devices, head-mounted displays, computer vision, computer graphics), virtual reality has become increasingly affordable, both in terms of costs and ease of use, and portability, make it possible to create VR experiences by using smartphones or mid-range computers.

Specially in immersive VR, it has been useful for redirecting the patients' attention away from painful or tough tasks, because they are focused on the virtual environment when they are experiencing the virtual world (WIEDERHOLD; WIEDERHOLD, 2007).

Nevertheless, the use of virtual reality as an assistive tool for the support of cognitive rehabilitation of people with intellectual disabilities is still not very common. VR studies has been carried out with people recovering from traumatice (CHRISTIANSEN et al., 1998), vascular brain injury (ROSE et al., 1999) and other neurological disorders (RIZZO et al., 2000). In the study (PANTELIDIS, 1993), the author claimed that virtual environments encourage active involvement in the education area.

As well as other interactive applications, the user is constantly requested to make choices or decisions about what action to take next (e.g., which direction to choose, which object to select). This characteristic is especially important for people with intellectual and multiple disabilities who have a tendency to have a passive behavior (SIMS, 1994).

In the study (STANDEN; LOW, 1996a), authors recorded the behavior of teenagers with severe intellectual disabilities over repeated sessions working through a virtual environment alongside their teacher. In the first sessions, they needed much assistance from their teacher to the task via software. However, after a few repeated sessions, the amount of help they required from the teacher decreased considerably.

Another area of application that VR can be very useful is the use of virtual environments in social skills training. People with Asperger's syndrome (AS) and autistic spectrum disorders (ASD), as well as other people with intellectual disabilities, all of whom experience deficits in communication and social understanding, may be benefit from virtual reality-based treatments. Early studies suggested that using interactive computer software could encourage language use in children (COLBY, 1973) and responsivity (FROST, 1981). They notice that children with Autism are more enthusiastic when they are working with computers than in a "regular toy situation" (BERNARDOPITZ et al., 1989), probably because the computer usually makes fewer demands on them than a human teacher.

Additionally, VR has been utilized in many studies to distract patients during therapies for phobias or posttraumatic stress disorder. Also, it has been used for the treatment of obesity and eating disorders, allowing patients to promote healthier eating habits by inhabiting realistic avatars in stress-inducing virtual situations, such as food shopping (WIEDERHOLD, 2006). On top of that, virtual reality may be used for the treatment of motor coordination rehabilitation, assisting people to get specific skills back and improve their body movement by experiencing the virtual environments.

Even virtual reality can provide many benefits and advantages in science and medicine fields, it is important to understand that the VR technology is still in constant advance and there is still lacks and weaknesses. Experiments presented in (MUNAFO et al., 2017) showed that virtual reality head-mounted display Oculus Rift may induces motion sickness in some people. The authors measured the postural sway of 72 college students before they were asked to play one of two virtual reality games for 15 minutes using an Oculus Rift DK2. As a result, more than half of the students who played the game, using a hand-held controller to explore a dark environment, reported feeling sick. Therefore, the use of virtual reality should be moderate, observing any lack of body balance, nausea or discomfort of the users during the VR-based experiments and after the use.

2.3 INTERACTION IN VIRTUAL REALITY

Virtual reality is completely different from an on screen applications or games. The user is completely immersed in a virtual environment, so it doesn't make sense to interact only through buttons or menus. The most natural the interaction is in the virtual environment and similar to the real world, the better is the user experience within virtual reality.

When it comes to non-immersive virtual reality, the interaction is usually made by motion detection (e.g., with Kinect sensor, camera tracking) or using a common game controller (e.g., basic controller, Nintendo Wii, PlayStation Move). In the study (ROGLIĆ et al., 2016), a Kinect-based game for children with Autism was presented, which was aimed to develop the fine-tuning of motor skills of them. While the participants interacted by motion detection, therapists was able to assess their performance, based on gesture precision, reflexes and others. On the other hand, when non-immersive VR is made without any motion detector, a game controller is needed, to allow the user interact within the VR environment. Authors in (ANDERSON et al., 2015) discuss about the advantages and limitations of using a hand-held device for virtual reality games to promote movement recovery in stroke rehabilitation. One of the favorable feature is that the game play is not affected by equipment or people around the player because movement is tracked with a hand-held controller, while a limitation is that, since the system tracks only the movement of the controller, intended and compensatory movement patterns are indistinguishable, and many games require the player to hold the controller and press/release small buttons.

In relation to immersive virtual reality, until the date of this work, users are able to handle virtual objects by using game controller (e.g., basic controller, PlayStation Move, Oculus Touch, HTC Vive Controllers, Samsung Rink), by using data gloves or some computer hardware sensor device that supports hand and finger motions as input (e.g., Leap Motion, Magic Leap) or by using the visual interface itself, which users can do actions by staring at some point in the interface. The study presented in (SOARES et al., 2017) aimed to evaluate the applicability of a virtual reality-based motion sensor for post-stroke upper limb rehabilitation, using Leap Motion, where three post-stroke patients were subjected to a VR training for rehabilitation of their upper limbs using the Leap Motion Controller technology and the game Playground 3D for 3 consecutive days.

Regarding the locomotion in virtual reality, it has a direct effect on many aspects of user experience (e.g., enjoyment, frustration, tiredness, motion sickness, presence). As stated in Bozgeyikli et al. (2016), there are some common VR locomotion techniques. The frequently used one are: (1) redirected walking, which is usually considered ideal for locomotion in virtual environments, but it may not be suitable for virtual environments that are larger than the tracked area in the real world, because the user needs to really walk in the physical environment to moves in the virtual one; (2) walk-in-place, which uses the marching gesture to be performed in the same place without moving forward or backward; (3) joystick controller. Other less commonly used are: (4) stepper machine, where participants can use omni-directional treadmills to walk within VR, allowing them sense walking in any direction and keep them at the center, in a secure place; (5) point and teleport, which the users point to wherever they want to be in the virtual world, and the virtual viewpoint is instantaneously teleported to that position.

3 RELATED WORKS

Since computer technologies were adopted in the society, many researches have been conducted to investigate the effectiveness of computer-based treatment of people with disabilities. Early studies, for instance (COLBY, 1973; GOLDENBERG, 1979), suggested that using interactive computer software could encourage language development in children with disabilities. In 1973, Kenneth Mark Colby presented in (COLBY, 1973) a system which consisted of a television-like screen and a typewriter-like keyboard in front of child sits. In the experiment, children could interact pressing the keys and symbols appeared on the screen accompanied by sounds of human voices and common noises. V. Bernard-Opitz said in (BERNARDOPITZ et al., 1989) that children with Autism is more enthusiastic when working with computers than in a "regular toy situation".

In 1981, authors in (GEOFFRION; GOLDENBERG, 1981) reported that computer may be a powerful aid in the process of improving communication skills in handicapped children. Despite these early researches were not specific about virtual reality, it is clear that computer-based methods have potential to support treatment of people with disabilities.

With the advances and popularization of virtual reality technology, in 1991, McLellan said in (MCLELLAN, 1991) that virtual worlds, unlike real worlds, can be manipulated to make a task easier for the user. In 1995, Melissa Salem Darrow presented in (DARROW, 1995b) a summary of VR applications developed for people with disabilities, and discussed about the positive predictions for VR as an assistive technology for people with sensory, physical and emotional impairments.

In 1996, Standen and Low (1996b) recorded the behavior of 18 teenagers with profound intellectual disabilities over repeated sessions working through a desktop virtual environment aside their teacher. After repeated sessions, the amount of self-directed interaction with the computer increased, and the amount of help they required from their teacher decreased.

Authors in (CROMBY et al., 1996) said virtual environments are an effective and safe training and educational media for people with learning disabilities and suggested the need to conduct more researches to understand their full potentials. Also, they said that participants in a VR-based experiments can make as many mistakes as they wish without suffering the real or dangerous consequences of their errors, which is substantially important in this line of research. Dorothy Strickland, in (STRICKLAND, 1997) recommended using virtual reality in the treatment of people with Autism, which offers the potential to regulate a virtual environment to better match the needs of people with ASD.

In 1998, Latash (1998) discussed a different view of VR scenarios, saying that virtual reality may become too safe and too attractive so that the patient can become a computer addict and be reluctant to re-enter the real world. Also, he mentioned that his knowledge of the sensory-motor integration was not sufficient, at that time, to suggest which components of sensations were adequate. Thus, VR would need to provide all the sensations associated with a movement which was not realistic when the author investigated that.

Virtual reality may offer a variety of possibilities within rehabilitation, including the potential to objectively measure behavior in challenging but safe, ecologically valid environments while maintaining experimental control over stimulus delivery and measurement (SCHULTHEIS; RIZZO, 2001). The virtual reality system presented in (BROOKS et al., 2002) was used to teach people with learning disabilities to prepare food. The authors said the VR-based method was more beneficial than real training with workbook.

A virtual reality for vocational rehabilitation system for people with disabilities is presented in (BOZGEYIKLI et al., 2014). The authors said VR enables safe immersion of potential employees in a range of scenarios they may encounter before in a real job. Authors in (BRÜCKHEIMER et al., 2012) argued that VR-based have an important role to play on many therapeutic areas, specially motor rehabilitation ones. Strickland (1997) stated that virtual reality offers the potential to regulate an artificial computer environment to better match the expectations and needs of individuals with Autism. A virtual reality based game is presented in (ANDERSON et al., 2010), which combines the flexibility of VR rehabilitation techniques with the enjoyment of video game.

The following sections present which disabilities were most treated using virtual reality according the previous studies, which methods were used during the experiments, which devices and techniques were used to create virtual reality and whether VR was effective in the previous studies, respectively.

3.1 DISABILITIES TREATED WITH VIRTUAL REALITY

The vast majority of previous studies investigated the use of virtual reality and augmented reality technologies in the treatment of people with Autism Spectrum Disorders (ASD), covering aspects such as social interactions and verbal and non-verbal communication. Just a few studies examined the feasibility of using VR and AR as means to support the treatment of People with Intellectual Disabilities. Most studies focused on children. Some of the studies aimed to improve characteristics of people with Autism and Intellectual and Developmental Disabilities (IDD), such as: social interactions, facial expression recognition and physical fitness.

The studies presented in (KURIAKOSE et al., 2013; PARSONS, 2015; KE; IM, 2013) explored the potential of VR technology to encourage social interaction among people with ASD. The study (CAI et al., 2013) showed the capability of VR systems to improve, among other social tasks, the nonverbal communication of children with ASD.

The studies (CHEN et al., 2016; BEKELE et al., 2014; GILLESPIE et al., 2017) used VR and AR technologies to improve the recognition and understanding of the emotions in facial expressions in social interaction between people with and without ASD. In (CHEN et al., 2016) the authors focused specially on the 6 basic emotions in the 6 basic facial expressions: anger, fear, disgust, happiness, sadness and surprise. In the system presented in (BEKELE et al., 2014) the authors examined performance and process differences between adolescents with and without ASD on tasks of facial emotion recognition. The authors in (GILLESPIE et al., 2017) developed a game that aims to help people with Autism collaborating with other people, teaching them how to interpret complex emotions, thus, improving their social-communicative skills.

The study (LOTAN et al., 2010) aimed to test the effectiveness of a VR system to improve the physical fitness of people with Intellectual and Developmental Disabilities (IDD). The authors said that most individuals with IDD tend to avoid participation in such activities, showing a lack of physical fitness. Strickland (1996) investigated the potential of VR as a tool for teaching people with ASD, while in (WALKER et al., 2016; SMITH et al., 2014) the authors explored the efficacy and feasibility of coaching in virtual environments for improve social skills performance, such as a job interview.

Although most of the previous studies are related to Autism, in each one the authors focused on testing the technologies to improve specific abilities of the participants. In

(HERRERA et al., 2008) authors presented a system aimed to promote a “pretend play” for children with ASD, which is related to imagination and cognition abilities. The assistive VR-based driving system presented in (BIAN et al., 2015) was developed to improve driving skill of teenagers with ASD. The authors also care about affective states such as engagement, enjoyment, frustration and boredom. Authors in (RAMACHANDIRAN et al., 2015) said children with ASD face difficulties in understanding what others think and feel, so they aim to design a learning environment for them. The study (PARSONS et al., 2004) evaluated intervention of VR system to improve cognitive aspects in children with ASD. The study (JIANG et al., 2016) aimed to enable people with Down Syndrome to be more independent, training, while the (AMARAL et al., 2017) study aimed to improve the attention of people with Autism.

3.2 APPROACHES FOR THE EXPERIMENTS

Many of the previous studies used non-immersive virtual reality system in the experiments, and just a few of them investigated the potential of the immersive virtual reality. For instance, the studies (BEKELE et al., 2014; JIANG et al., 2016; AMARAL et al., 2017) used VR to assist children to recognize geometric shapes, objects, facial expressions and to discriminate pictures as well. In another context, the studies (KANDALAFT et al., 2013; LORENZO et al., 2016; KE; LEE, 2016) investigated the feasibility of an engaging VR social training intervention focused on enhancing social skills. It was noticed that most of the studies which use virtual reality also use some game-based task or serious games features to support the VR-based experiments, such as the studies (CHUNG et al., 2015; GILLESPIE et al., 2017)

3.2.1 CONVERSATION SYSTEM

In (LAHIRI et al., 2013) it was presented a VR-based social conversation system, which the system has a Gaze-sensitive adaptive response technology that uses eye-tracking techniques, which is capable of identifying and quantifying children’s engagement level by measuring viewing patterns and changes in eye physiological responses. Both follow a similar procedure.

In (SMITH et al., 2014) it was presented a simulated job interview VR-based system for improving job interview skills among individuals with Autism. Participants had to start a job interview in a non-immersive virtual environment and should answer questions made by a virtual interviewer. According to the answers, the program scored from 0 to 100, referred to eight domains: negotiation skills, dependable, teamwork, sharing things in a positive way, honesty, sounding interested in the position, acting professionally, and establishing empathy rapport with the interviewer. Similarly, in (WALKER et al., 2016) the authors explored the efficacy of role-playing and coaching in virtual environments for the improvement of social skills in job interview performance.

The work presented in (KANDALAFT et al., 2013) also investigated the feasibility of an engaging VR Social Cognition Training (VR-SCT) intervention focused on enhancing social skills, using Second Life, a three-dimensional virtual world software, where there were different contexts, such as meeting new people, dealing with a roommate conflict, negotiating financial decisions and interviewing for a job.

The study (LORENZO et al., 2016) presented an immersive VR system that trains and improves the emotional skills of children with Austism. The system introduces the participants to 10 social situations (e.g., going to a birthday party, playing soccer) and the users must interact with an individual in the virtual environment, allowing them to learn the appropriate behavior and apply it in different occasions.

3.2.2 IMAGES AND PATTERNS RECOGNITION

It was found that some studies investigated the use of VR to assist children to recognize images and visual patterns, focusing on improving the functional development learning and behavior of people with intellectual disabilities, as the study (CAI et al., 2013) does, which presented a virtual dolphinarium that allows children with ASD to act as dolphin trainers. A few tasks were assigned to them, such as identifying parts of a dolphin, identifying shapes traced on palm, geometric shape copying and copy-drawing of a dolphin. After all, participants had to interact with virtual dolphins using hand gestures.

Dorothy Strickland in 1996 presented a VR-based learning tool in (STRICKLAND, 1996) aimed to efforts at treatment and intervention for children with Autism. Two autistic children were selected for the experiments, which consisted of over 40 virtual exposures during a 6-week period. In the initial test, the child had to recognize a common object (e.g., car) in an immersive virtual reality three-dimensional world.

Authors in (RAMACHANDIRAN et al., 2015) presented a virtual environment system for face-to-face interviews, where participants were asked to give the correct picture to a pattern of objects or specimens.

The authors in (HERRERA et al., 2008) examined the effectiveness of using a virtual reality tool for teaching understanding of "pretend play" of children with Autism. The (JIANG et al., 2016) study aims to enhance the autonomy of people with Autism, training them for handling money using a screen of an application to a palpable table. The interactive table combines the size of a table with 3D hand position recognition. Authors in (AMARAL et al., 2017) presented a VR-based Brain Computer Interface paradigm using social cues to direct the focus of attention of people with Autism.

3.2.3 GAME-BASED APPLICATIONS

Although most of the previous studies used some game-based task or serious games features to support VR-based experiments, the following articles presented a clearer game-oriented methodology.

Authors in (PARSONS, 2015) proposed a two-player block challenge task where two children had to communicate verbally and collaborate with each other to complete the game successfully, thus teaching the individuals to work together. In the game, after the children select a block, it appears in the middle of the room with incorrect orientation relative to the two participants. Then, the children needed to collaboratively rotate the block into its correct orientation.

The serious game showed in the (BIAN et al., 2015) study was a VR-based driving environment for skill training of teenagers with Autism. During the experiments, physiological signals were collected from the participants to detect affective states: engagement, enjoyment, frustration and boredom. There were six sixty-minutes sessions in several days. Through the task, participants tried to follow the navigation system and tried to obey traffic rules. In (LOTAN et al., 2010; CHUNG et al., 2015) the authors conducted experiments using Active Video game Play which included game-like exercises, investigating the effectiveness of the use of games in physical activities.

The game developed by authors in (GILLESPIE et al., 2017) used Kinect to create a non-immersive virtual reality experiment and to help people with Autism collaborate with others, improving the social-communicative skills of them. Participants can play the game with gestures. In (KE; LEE, 2016), the authors conducted qualitative analyses with the data collected from an exploratory case study of a VR-based collaborative design tested with children with Autism. The design required participants to work in partnership to build a virtual neighborhood which was devastated by a tsunami earthquake.

3.2.4 FACIAL EXPRESSION RECOGNITION

The (KE et al., 2015; KE; IM, 2013) studies presented a VR-based methodology which focused on the improvement of the perceptions of facial expression and emotions of the participants. The method contained three social interaction tasks: facial expression and gestures recognition of a virtual communication partner, responding and maintaining interactions at a virtual school cafeteria, and maintaining interactions at a birthday party.

The authors in (BEKELE et al., 2014) selected two groups of ten people with Autism. In a room with a desktop monitor and an eye tracker, they were submitted to the experiments, which consisted in a non-immersive virtual reality system. A few 3D avatars were placed in front of the participants, each one with specific facial expressions and different emotion intensity levels. So, participants should choose the correct facial expression through a menu. Thus, authors were able to examine performance between adolescents with and without ASD on tasks of facial emotion recognition.

3.3 VIRTUAL REALITY EFFECTIVENESS

Many authors in the previous studies discussed about the advantages of virtual reality and suggested that virtual reality could be very useful for the treatment of people with intellectual and multiple disabilities. However, many of the studied did not present real results of the experiments nor any statistical data that proves the actual efficiency of the VR-based methods.

A few articles presented significant and reliable results. For instance, authors in the studies (LOTAN et al., 2010; CHUNG et al., 2015; BEKELE et al., 2014) said the participants' performances were just slightly enhanced, showing that the VR methods were not effective indeed. However, in (BAI et al., 2015; HERRERA et al., 2008) results indicated a positive effect of increased elicited "pretend play" in frequency, duration and relevance with the augmented reality system compared with a non-computer setup.

In (KANDALAFT et al., 2013; LORENZO et al., 2016; KE; LEE, 2016) the studies indicated the potential of the VR system to improve social task performance and to induce variation in participant's physiological markers. In (KURIAKOSE et al., 2013), the authors showed a table demonstrating an improvement in performance score for all participants. In (KURIAKOSE; LAHIRI, 2015) the authors said the system has the potential to use individuals' real-time physiological signals as markers of their anxiety level. In (KANDALAFT et al., 2013), results found that a social skills training intervention may enhance performance on emotion recognition from faces.

Authors in (WALKER et al., 2016; SMITH et al., 2014) stated the intervention demonstrated to be effective to improve job interview skills in the virtual environment as well as generalization in face-to-face interviews. However, the findings in (SMITH et al., 2014) suggested that the training is still generalizable to adults with Autism, as they demonstrated significantly improved job interview skills between the baseline and follow-up role-play sessions.

Authors in (WANG; REID, 2013) presented the percentage accuracy on the virtual reality experiments demonstrated by the participants. All children who participated in the experiments demonstrated statistical improvements in overall contextual processing ability. In (LORENZO et al., 2016), for data analysis from the psychopedagogy, a qualitative, quantitative and experimental methodology was used, and statistical results were showed, presenting a significant presence of more appropriate emotional behaviors in the immersive environments in comparison with the use of desktop virtual reality applications, according to authors.

The study (STRICKLAND, 1996) concluded about the essence of virtual reality worlds and the sense of presence it is able to create, and the author said more tests would be necessary to determine the effectiveness of the method which uses virtual reality. Also, the (KE et al., 2015; PARSONS et al., 2004) studies indicated that virtual reality is still in need of further development to support better social skill training, although the authors said the findings should enrich the research area of technology-enhanced special education.

There is still no consensus on the effectiveness of virtual reality in the treatment of intellectual disabilities, mainly because of the lack of a standard method to measure the improvements of the individuals performance along with the experiments.

Regarding the human beings involvement, to measure the performance of each individual is a complex task, as well as detecting their improvements. Specially when the study attempts to improve the socialization abilities of the participants as well as their communication skills, it is totally dependent on other professionals from other areas such as psychologists and therapists.

Even in some articles the authors presented statistical data, for instance in (WANG; REID, 2013; HERRERA et al., 2008; KE; LEE, 2016), in most cases the results are given by the authors' and other area professionals' observation made during the experiments. Although most of the articles indicated the potential and possible benefits of the virtual reality based methods in the treatment of intellectual and multiple disabilities, there aren't strong evidences to assess how reliable are the results and how effective virtual reality is in fact.

4 PROPOSED METHOD

The main focus of the proposed method was to develop a virtual reality system to support the cognitive and gross motor coordination development of people with intellectual and multiple disabilities, by simulating and training common tasks people usually do on a daily basis (e.g., going shopping in a supermarket, cooking dinner, crossing the street).

One of the main concerns of this work was to develop with the lowest cost possible, using standard and accessible devices (e.g., smartphones, laptops), without harming the virtual reality near real life experience, as well as without decreasing the effectiveness of the treatment. Thus, once it is a low-cost project easily replicable and reusable, other professionals (e.g., physiotherapist, researchers) will be able to implement it in their treatment methods.

In this work, two case studies were used in which ten people with intellectual and multiple disabilities were selected and assigned to the VR-based tasks. Each case study had different objectives and they were focused on the improvement of different skills of the selected people for the experiment, even both were complementary to each other. The first case study was aimed to enhance the patients' community participation and their social inclusion. The second case study focused on improving the selected people's gross motor coordination (arms and hands), as well as their reflex and visual perception.

4.1 METHOD

In this work it is presented a virtual reality-based treatment done in two case studies. Each one has a different focus. The first one aimed to develop the cognitive abilities, and the second one focused on the motor coordination skills development of the participants.

Regarding the method itself, both case studies done in this work had the same participants and procedure, and they are describe below.

4.1.1 PARTICIPANTS

Once intellectual and multiple disabilities consist of a wide range of people with distinct impairments and disabilities, an inclusion criteria was defined for this work: (1) diagnosis of intellectual and multiple disabilities; (2) motor coordination non-severe, that is, patient should be able to use his or her hand to do the task; (3) basic cognitive capability, that is, individual had to be aware about what was to be done in the task; (4) chronological age greater than 18 years.

A group of 10 people with intellectual and multiple disabilities was selected from APAE for both case studies, which is an institutional care for people with disabilities, supervised by their physiotherapist.

4.1.2 PROCEDURE

In order to define an approach to teach daily activities for people with intellectual and multiple disabilities using assistive technology, two case studies were defined.

In both case studies, as mentioned in 1.3 as one of the contributions of this work, a hand-based interaction was proposed and developed. The hand-based interaction is made by augmented reality markers into the virtual reality environment. The smartphone is placed in a VR head-mounted display and the system uses its camera to recognize the augmented reality marker, which is located over the hand of the participant (Figure 4.1). The system replaces the marker with a virtual hand in real-time and the individual is capable to handle 3D objects in the VR scenario. For instance, if patients puts the hand over a product, it is outlined, and if he or she keeps the hand over it during three seconds, the product is selected. Thus this specific task trains both the movement precision and the arm extension.

The first case study consisted of a common daily task which involved go shopping in a supermarket, where patients should check, from a shopping list (e.g., Cookies x 2, Coffee x 3), what products they had to select from the supermarket shelves using their hands. The case study had the objective to identify the level of autonomy and understanding, and improve the performance of the patients to do common daily tasks. For example, how much time they spent to do the full task, how many mistakes they made when they were selecting the products and the quantity of each item, check if they understand the shopping list and if they could identify the supermarket sections where the products should be, as well as if they could pay the correct price of the purchase, selecting and giving the correct amount of money to the supermarket cashier. Figure 4.2 shows the virtual environment and the augmented reality hand-based interaction. Each participant run the task around 5 minutes.

Figure 4.1: The first picture shows the AR marker on the back of the hand, which is used to display the virtual hand in the virtual environment, by the recognition of the marker pattern done via the smartphone camera and the VR system, thus providing a hand-based interaction within VR. The second picture is the same hand, but seen from the opposite side, showing the velcro.

In contrast to the first case study, the second was placed in a fantasy scenario, which consisted of a task where the participants had to go from a platform to the last one, crossing bridges over an ocean, and in each platform they had to go through challenges: (1) collect fruits from the ground; (2) hit rats with a ball bazooka; (3) grab flying butterflies. Figure 4.3 shows screenshots of all three challenges. In each one of the challenges they had to get the highest score they could in a limited time. Also, to go from a platform to the next one, they were required to cross a bridge, in each one a penalty was counted every time the virtual body touches the bridge wall. As well as the first case study, each participant run the task around 5 minutes.

4.1.3 METRICS

During tasks, data were collected from the participants' actions, so they can be analyzed after the experiment to check the individual's performance, comparing to each other and comparing to their own performance in the previous sessions.

For the first case study (go shopping in a supermarket), the metrics proposed in this version of the VR-DAD system were: total quantity of products to be taken, quantity of product type, price to be paid, time spent, attempts to select products off the shopping

Figure 4.2: Virtual reality supermarket task and the augmented reality hand-based interaction.

list, attempts to select quantity of products higher than requested, failed product selection attempts, how many times participant gave more/less money and how many times the money selection was reset.

For the second case study, the metrics used to analyze the participants' performance were: how many fruits were collected, how many rats were hit, how many butterflies were grabbed, how many times participant touches the bridge wall, failed fruit selection attempts, attempts to select wrong fruits, failed butterfly selection attempts, failed attempts to hit rats.

4.1.4 DESIGN PRINCIPLES

Based on the ten usability heuristics proposed by Nielsen (2005) and good usability practices, it was established a list of design principles recommended for an adequate development of serious games for cognitive and motor disabilities, organized in 4 categories. This list, defined specific for this work, aims to help the improvement of the effectiveness of the VR-based treatment, focusing on the user interface (UI) and user experience (UX).

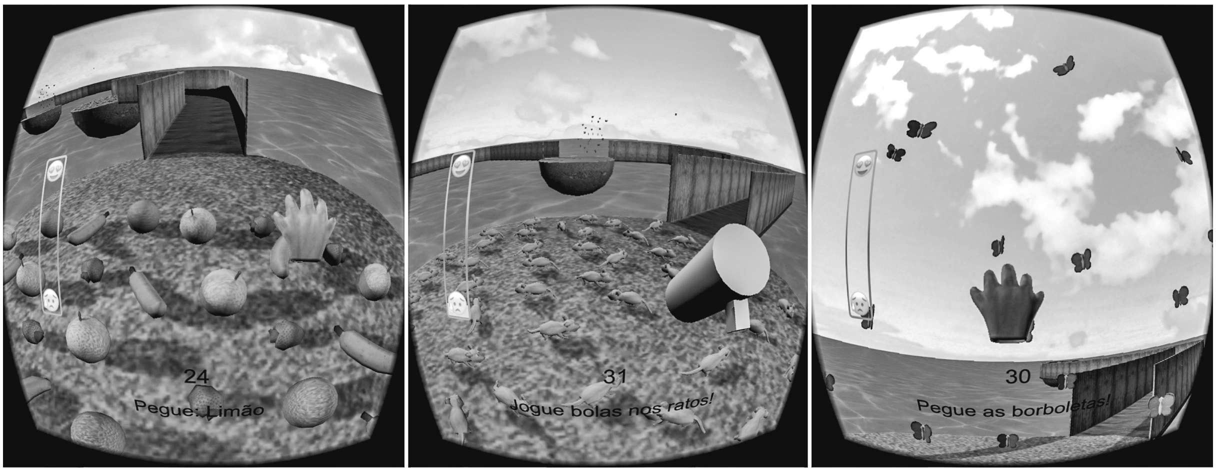


Figure 4.3: Challenges presented in the second case study. Participants should: 1) Collect fruits from the ground; 2) Hit rats with a ball bazooka; 3) Grab flying butterflies.

4.1.4.1 Interface

(a) A minimalist design may be preferred. Layouts should not contain any information nor visual element which is irrelevant for the requested task. It may increase concentration of the users during the session;

(b) The icons should be large to help users with fine motor skills difficulties (LOPRESTI et al., 2008);

(c) Elements should act like in real world, following real-world conventions, making information appear in a natural and logical order;

(d) Instructions should be clearly displayed and always in the same place;

(e) Colours should be in harmony with the overall interface, while ensuring sufficient contrast for people with limited vision.

4.1.4.2 Hand-Based Manipulation

(a) It should not require the use of many controls, keeping the user control as simple as possible;

(b) Selectable elements (e.g. products in the supermarket) should be properly spaced to avoid wrong selections;

(c) When the virtual hand is over a selectable element, the element has to be outlined in red;

4.1.4.3 Feedback

(a) Language should be simple, clear and direct, using native language;

(b) Every action should have feedback, giving through: visual, text or auditive;

(c) When an element is selected or grabbed, the system should notify the user hiding the element and showing alerts (e.g. text or sounds);

(d) It must not create any kind of frustration, which could be very negative to the patients. The errors committed should be corrected without discouraging the patients;

(e) When users achieve a desired score, the system should congratulate them, and when it does not happen, it should encourage them to get a better score;

(f) Show the user's current results and the task to be done.

4.1.4.4 Accessibility

(a) To focus on the core objectives of the treatment and minimize skills needed to control the walking, the walking of the patients within the virtual environment should be automatic;

(b) Do not use elements that can cause seizures, like elements that flash or have particular spatial frequencies;

(c) Use accessibility features, like sign language;

(d) Provide alternatives to text content. Sounds, spoken language and visual elements should support the instructions presentation;

(e) The walking and movement should be slow to avoid seasickness and to facilitate the interaction between user and virtual environment.

4.2 COGNITIVE TRAINING

The cognitive training in the virtual reality scenario comprised several daily life activities that were devised to develop cognitive functions, such as: visuospatial orientation tasks (e.g., finding the right way to find the products in the supermarket), working memory tasks (e.g., finding the correct product sections and buying items), selective attention tasks (e.g., finding the correct products and money bills) and calculation (e.g., quantity of products and money).

4.3 GROSS MOTOR COORDINATION TRAINING

With respect to the motor coordination training, virtual reality can afford enriched tasks that can be used to provide meaningful motor repetitions in the context of cognitive rehabilitation tasks, together with immediate feedback, thereby maximizing motor learning (LAVER et al., 2015). This work was focused on the individuals' gross motor skills improvement (i.e., extension of arms, precision of arm's and hand's movements).

4.4 VIRTUAL REALITY SYSTEM

A system called VR-DAD (Virtual Reality-Based Daily Activities Development) was developed for this study, which uses immersive virtual reality to provides a virtual environment for teaching people with intellectual and multiple disabilities regarding to common daily activities, offering the possibility for individuals to improve their skills and to be more autonomous. The development of this system depended on other areas such as physiotherapy and pedagogy, and it was accompanied by specialists of these areas, as well as design and computer science. The prototype presented in this article, provides the following advantages over other systems discussed in Chapter 3:

- Low cost. It is not required any desktop computer nor extra device, such as movement and depth sensors. It is functional from a mid-range smartphone and simple virtual reality glasses (e.g., Google Cardboard);

- Hand-based manipulation using augmented reality in a virtual reality environment, providing a more realistic and intuitive interaction;

- Results-Based Monitoring. Through an online dashboard, which can be accessed on any internet browser, it is possible to monitor the results according to the activities metrics.

4.4.1 RESULTS-BASED MONITORING

Through an online dashboard, which can be accessed on any internet browser, it is possible to monitor the results according to the activities metrics. As soon as each game is initialized, the feedback system starts to get relevant data regarding to the participant performance. Lastly, when the game ends, the result is sent to the online system. Thus, from the data collected by the system, specialists are able to analyze the cognitive and motor improvement of the patients and make more precise decisions regarding their treatment.

The web system was developed using PHP with CakePHP Framework and MySQL as a database management system. While participants do the tasks, wearing the virtual reality glasses and using the VR-DAD system developed for this work, the VR system gathers all data related to the metrics described in Section 4.1.3. Before starting the session, the participant's profile is selected from the start screen. Thus, at the end of each session, the system automatically saves the gathered data on the online system, using a RESTful API, which is an approach that provides the VR system with endpoints to create data using HTTP calls (POST). Figure 4.4 shows an example of the results dashboard for the case study 1, accessed from an internet browser.

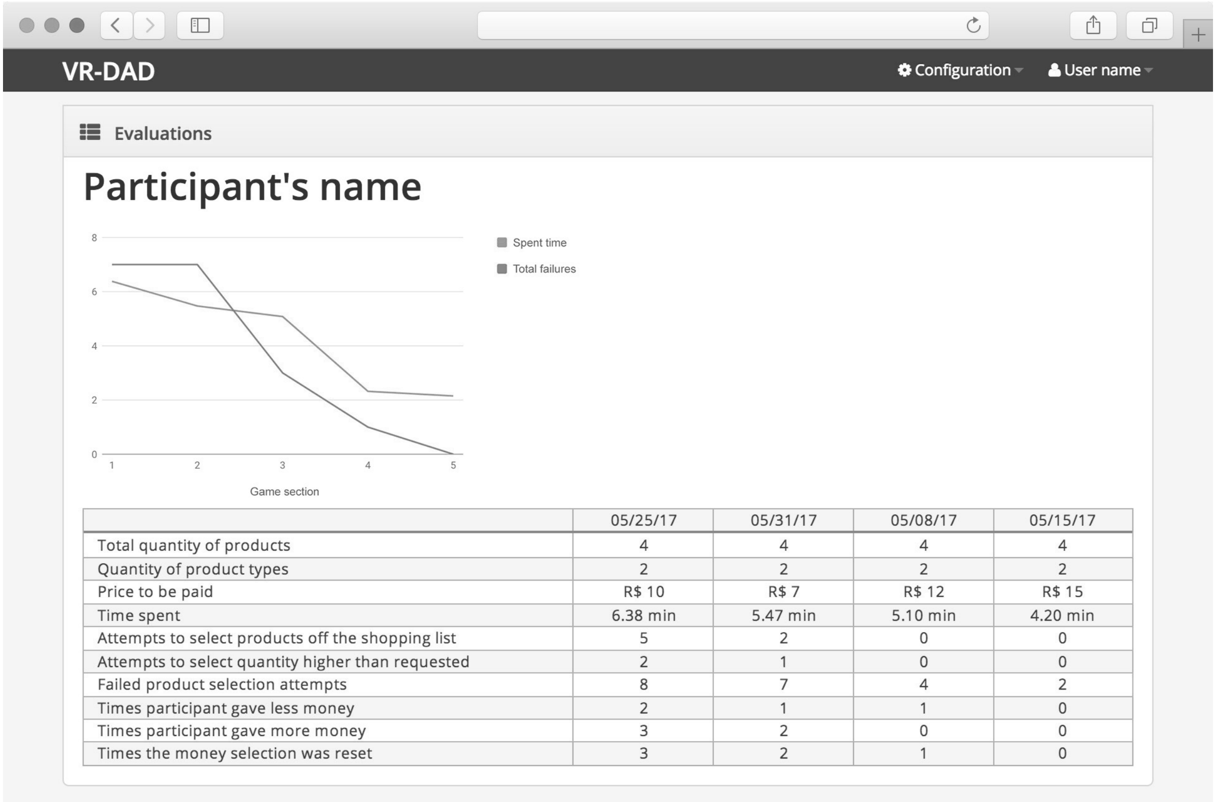
4.4.2 EQUIPMENT

Regarding the virtual reality glasses, it was used a custom version of Beenoculus[1], a low-cost VR head-mounted display for smartphones created and distributed in Brazil. Because this VR application uses an augmented reality system to track the participant's hand, it had to be customized with a frontal cut, right over the smartphone camera, so it is able to register the image and so create the augmented reality experience (Figure 4.5).

Beenoculus was used in the application of this work specially for creating an immersive virtual reality experience. When a participant wears the virtual reality headset, the picture in front of him or her shifts as he or she looks up, down and side to side or angle the person's head.

Furthermore, during the experiments, an *iPhone 6 Plus* was used and placed inside the virtual reality head-mounted display connected to a *Macbook Pro Apple* via USB. In this case, *Macbook* was only needed for the researcher and physiotherapist be able to

[1]http://www.beenoculus.com



	05/25/17	05/31/17	05/08/17	05/15/17
Total quantity of products	4	4	4	4
Quantity of product types	2	2	2	2
Price to be paid	R$ 10	R$ 7	R$ 12	R$ 15
Time spent	6.38 min	5.47 min	5.10 min	4.20 min
Attempts to select products off the shopping list	5	2	0	0
Attempts to select quantity higher than requested	2	1	0	0
Failed product selection attempts	8	7	4	2
Times participant gave less money	2	1	1	0
Times participant gave more money	3	2	0	0
Times the money selection was reset	3	2	1	0

Figure 4.4: Example of the results dashboard for the case study 1, accessed from an internet browser.

have the same vision of the participant, that is, to be able to see what the participant was seeing during the task. Both *iPhone* and *Macbook* could be replaced by a mid-range *Android* device and any low-cost laptop.

4.4.3 DESIGN AND 3D ENVIRONMENT

The virtual reality system presented in this work was developed using the *Unity 5.4* game engine in C#, in which the *Vuforia SDK* was added. Unity enables to create 2D and 3D games and applications, which is a cross-platform game engine developed by Unity Technologies and used to develop video games for PC, consoles, mobile devices and websites. The *Vuforia SDK* is an augmented reality software development kit for mobile devices that allows the creation of augmented reality applications. It uses computer vision technology to recognize image targets in real-time, and in this project it was used to track the hand of the participants, who used an augmented reality target attached to their hands (Figure 4.1).

In this work, the purpose was not to create a realistic scenario, which would use real-

Figure 4.5: Custom version of Beenoculus used during the VR sessions

time illumination, rendering shadows and high resolution textures. Realistic graphics would require a robust processing and it would not be possible to play it on mid-range smartphones, which is important to maintain a low cost. Although the scenario was not much realistic, the project was designed to provide a real-world experience, and the immersion and the hand-based interaction were capable to offer that sensation to the participants. The 3D modeling was made using the software *Autodesk Maya 2017* and the textures are a mix of digital painting and real pictures, using the software *Adobe Photoshop CC*.

5 EXPERIMENTAL RESULTS

In this chapter the experimental results of this work are presented, obtained from the two case studies carried out, both described below. Also, a data analysis and the physiotherapist's feedback is presented in the following sections.

5.1 PARTICIPANTS

Ten people with intellectual and multiple disabilities were selected from APAE Três Rios, which is an institutional care for people with disabilities. They were selected under the ethical approval obtained from the ethics committee of the Federal University of Juiz de Fora, as well as done with the consent of the responsible for the patients.

As defined in Section 4.1.1, the inclusion criteria was as follows: (1) diagnosis of intellectual and multiple disabilities; (2) motor coordination non-severe, that is, patient should be able to use his or her hand to do the task; (3) basic cognitive capability, that is, individual had to be aware what was to be done in the task; (4) chronological age greater than 18 years.

5.2 CASE STUDY 1

In order to define an approach to daily activities teaching for people with intellectual and multiple disabilities using assistive technology, the first case study was aimed to enhance the patients' community participation and social inclusion.

The experiment sessions of the case study 1 were done in APAE in Três Rios city (Rio de Janeiro, Brazil), an institutional care for people with disabilities, and they were supervised by their physiotherapist and pedagogue. Besides the 10 selected patients, there were other patients and professionals who were present and watched the sessions. Each participant run the task an average of 5 minutes and all the session spent an average of one hour. As described in Section 5.2.2, the case study 1 took 5 weeks in total.

The first case study consisted of a common daily task which involved go shopping in a supermarket, where patients should check, from a shopping list (e.g., Cookies x 2, Coffee x 3), what products they had to select from the supermarket shelves using their hands. To do that, during the sessions, the participants used the hand-based manipulation proposed and developed in this work. Also, Figure 5.1 shows a participant trying to select a product from the supermarket shelf using his hand through the augmented reality marker.

The main objective was to identify the level of autonomy and understanding, and improve the performance of the patients to do common tasks people usually do on a daily basis. For instance, how much time they spent to do the full task, how many mistakes they made when they were selecting the products and the quantity of each item, check if they understand the shopping list and if they could identify the supermarket sections where the products should be, as well as if they could pay the correct price of the purchase, selecting and giving the correct amount of money to the supermarket cashier.

Figure 5.1: Virtual hand used for the hand-based manipulation in the case study 1. This figure shows a participant trying to select a product from the supermarket shelf using his hand through the augmented reality marker.

5.2.1 TRAINING PHASE

A training phase was conducted to verify the acceptance and reaction of the selected people regarding the use of the virtual reality head-mounted display. Therefore, before initial testing, the patients were provided with a pilot experiment to ensure that they would understand the instructions associated to the VR task, as well as possible nausea, dizziness or any rejection behavior from them.

Among the 10 selected patients, one had major deficiency with balance. Despite he could stand and walk without any help from other people, he naturally had motor impairment in his legs. Thereby, after he used the VR head-mounted display during about six minutes for the pilot task, he lost his balance when he took it out, but he did not fall to the ground because the researcher and the physiotherapist were right behind him and they held the participant. After that experience, even with the suggestion and possibility to do the task from a wheelchair for avoiding this situation of losing balance, the patient and the physiotherapist decided not to do that task anymore.

Another patient got a little dizzy, much less than the previous one, when she took the VR-HMD out. So, she was asked if she would like to continue the experiment and, also with the consent of the physiotherapist, that participant decided to keep on doing the VR-based treatment, specially because she said she enjoyed the experience and she did not get dizzy anymore, over the other sections.

Based on participants' reactions (excitement, joy, focus on the task), as well as based on what they said during the first pilot experiment, all of them (except the first one who had the balance issue) really enjoyed the virtual reality experiment. Because it was presented a new technological device to them, which used a game system for the accomplishment of a requested task, which it would likely more boring if it were not in a virtual reality environment, the selected people were extremely excited to do the task and looked forward to the next sessions.

Almost all the patients had difficulty in doing math (i.e., addition and subtraction), thus, in a few times it was needed to help them at the moment of payment (i.e., select the money notes). Also, three of them could not read perfectly. In these cases, the researcher had to read the shopping list and sections' name for them, but they understood and identified clearly what were the products in the supermarket shelves, and this factor did not interfered nor affected the final results.

After the pilot experiment, some bugs and issues were identified in the application. For instance, money bills were too far from the player in the virtual environment, making the task difficult to be accomplished; sometimes money bills were selected twice at the time; and some issues related to the 3D graphics. However, none of those bugs interfered dramatically on the results (e.g., game score, player failures, other metrics). All the issues and bugs were fixed.

5.2.2 FOUR-WEEK FOLLOW-UP SESSION

After the pilot experiment (Training Phase), a section per week was performed with each one of the selected patients (Figure 5.2). The experiment was the same as the pilot task and the difficulty was increased at every task. For instance, for the latest tasks the patients were requested to pick up products located at the top and at the bottom of the shelves. Additionally, in each task the participants were more autonomous, that is, physiotherapist interfered less and less during the task. In the latest task, almost all the patients could shopping without any help.

At the end of the case study, the results were analyzed (section 5.4) to verify if there was an improvement regarding the patients' performance. Besides that, the physiotherapist gave her conclusion according to her observation during the period of the experiments. After the experiments, she observed an improvement related to balance and gross motor skills, in this case, specific to movement and coordination of the arms (section 5.4).

Figure 5.2: Some participants doing the task during the case study 1.

5.2.3 CONSIDERATIONS

In order to avoid any kind of extra investment for this project, keeping the project at low cost even for the researcher, it was used devices belonging to the researchers (i.e., laptop, smartphone). Therefore, as said in Section 4.4 an *iPhone 6 Plus* was used which was placed inside the virtual reality head-mounted display. This smarphone has a 5.5-inch screen, which is a large screen, and it weighs 172 grams, which is 40 grams more than the most mid-range smarphones. As a result, the smartphone was a little heavy for the heads of some participants. Because of this, in a few moments it was uncomfortable and the researcher had to adjust the position of the VR-HDM on their heads. Nevertheless, even with this discomfort, specially because the tasks spent an average of 5 minutes, this factor did not interfered the final results. Based on that observation, it is advisable to use smartphones with 130 grams or less, specially for providing more comfort for the individual's head.

Another issue that could be observed from the sessions with the participants was related to the hand-based manipulation made by augmented reality markers. For providing a low-cost hand-based manipulation, which makes the interaction between the individual and the virtual environment possible, it was used an augmented reality marker that was located over the hand of the participant (Figure 4.1). So, by the images captured from the smartphone's camera, the VR system had to recognize the AR marker in the real environment. Doing so, the system replaces the marker with a virtual hand and the participant is capable to handle 3D objects in the VR scenario.

Although that is an intuitive effective ease-to-use low-cost hand-based manipulation tool, the AR marker was a 2D image (i.e., AR marker printed on a rigid paper), which means sometimes the smartphone's camera struggles with the marker recognition because it simply was not able to capture the marker's image in a few moments. When that happened, the researcher helped the participant to adjust the AR marker in a position that the camera could detect it. Despite this issue, it did not happen frequently, and the hand-based manipulation proposed in this work proved to be effective during the sessions and related to the final results, specially because none of the participant had difficulty to understand how to use the hand-base manipulation. The participant simply wore the "glove" and started to use it easily.

As well as in the Training Phase (Section 5.2.1), the participants really enjoyed the virtual reality experiment. At no time, none of the participants exhibited any level of resistance to perform the task. All the 9 remaining selected people were very willing to participate in the experiment, which for them was a kind of fun and leisure time. Their reaction was very positive, which is crucial to get better and effective final results.

5.3 CASE STUDY 2

With the objective of improving the gross motor coordination (i.e., arms and hands) of the participants, the second case study was proposed as a multiple-challenges task, mainly focused on the extension of the patient's arms and the movement precision of their hands.

As well as the first case study, the experiment sessions of the case study 2 were done in APAE in Três Rios city (Rio de Janeiro, Brazil), and they were supervised by their physiotherapist and pedagogue. Once one of the 10 selected patients had a balance issue during the Training Phase 5.2.1 in the case study 1, the second case study were done with the 9 remaining selected people. Each participant run the task an average of 5 minutes and all the session spent an average of one hour. This case study took 4 week in total.

In contrast to the first case study, the second was placed in a fantasy scenario, which consisted of a task where the participants had to go from one platform to the last one, crossing bridges over an ocean, and in each platform they had to go through challenges: (1) collect fruits from the ground; (2) hit rats with a ball bazooka; (3) grab flying butterflies. Figure 5.3 shows screenshots of each challenge. In each one of the challenges they had to get the highest score they could in a limited time. Also, to go from one platform to the next one, they were required to cross a bridge, in each one a penalty was counted every time the virtual body touches the bridge wall.

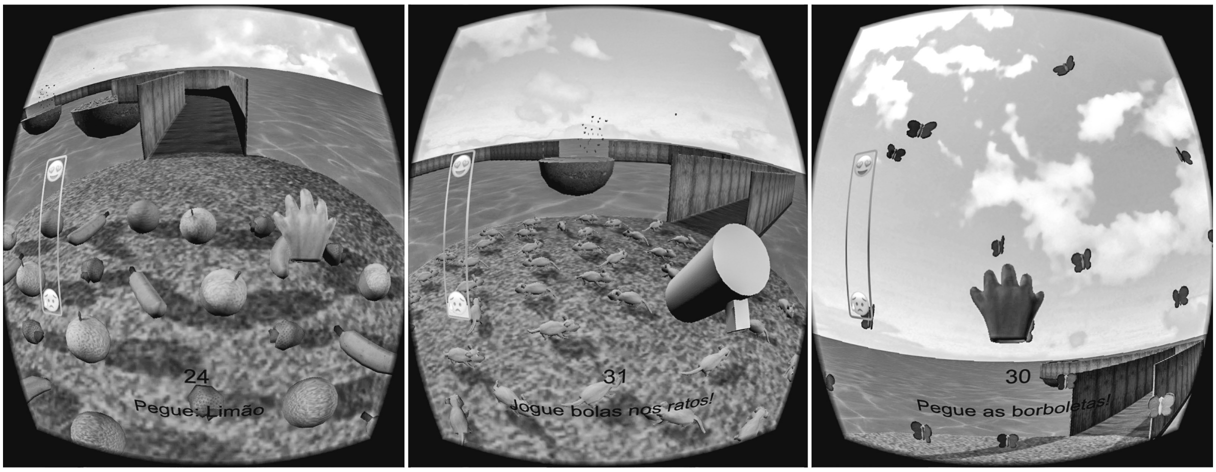


Figure 5.3: Challenges presented in the second case study. Participants should: 1) Collect fruits from the ground; 2) Hit rats with a ball bazooka; 3) Grab flying butterflies.

The main objective was to improve the performance of the patients to do the requested tasks, enhance their gross motor coordination abilities (i.e., arms and hands). In order to analyze the participants' performance the following metrics were used: how many fruits were collected, how many rats were hit, how many butterflies were grabbed, how many times participant touches the bridge wall, failed fruit selection attempts, attempts to select wrong fruits, failed butterfly selection attempts, failed attempts to hit rats.

As this case study consisted in predetermined-time tasks, the time spent by the participants remained basically the same, which is an average of 5 minutes. Thus, the time spent was not considered as an evaluation metric for this case study.

5.3.1 CONSIDERATIONS

Almost all the 9 selected patients had difficulty in doing the second challenge, where participants should hit rats with a ball bazooka. To do that, the user should extend the arm to see the virtual bazooka and move the fist positioning the bazooka toward any rat over the ground. A ball was thrown from the bazooka every two seconds, automatically. So, the user only needed to get the correct direction to hit the rats. However, the task was hard for them, because it required greater precision in the fist and more stabilized movement for hitting the balls in the virtual rats. Most of the time, they were assisted in doing this task. Nevertheless, it was possible to note an improvement regarding the patients' performance in this task: an average of improvement of 110% related to the obtained score (i.e., rats hit) and an average decrease in errors committed (i.e., failed attempts to hit rats) of 13.63%.

It is remarkable that in case study 2 it was obtained much more mistakes made during the tasks 5.3. This fact does have to do with the bridge through which the users had to pass. Once a penalty was counted every time the virtual body touches the bridge wall, it was obtained a high number or mistakes, because almost all patients felt difficulty to keep in the correct path between the bridge walls (i.e., left and right sides) when they were walking and going to the next challenge platform. However, it was possible to notice an improvement of their body balance and precision of movement coordination throughout the sessions.

As well as in the case study 1, the patients enjoyed the game-like activities provided by virtual reality. All the 9 remaining selected people immediately understood clearly each one of the task that were requested, where they could exercising the movement, precision, strength and extension of the arms and hands, and body balance.

Table 5.1: Case study 1. This table shows the result related to time spent by participants during the sessions of the case study 1.

Game section	1 (pilot)	2	3	4	5
Mean	5.996 min	5.517 min	3.860 min	3.606 min	2.429 min
Standard deviation	1.576	1.036	1.338	1.245	0.544
Margin of error	0.864	0.568	0.734	0.683	0.298

5.4 RESULTS

After the training phase together with the four-week follow-up session of the case study 1, the results sent to the online system by the VR application stored at the end of each game were analyzed. Overall, it was noticed there was an improvement regarding the time spent and the mistakes made, indicating the virtual reality-based method was effective in this study, as can be seen in Figure 5.4.

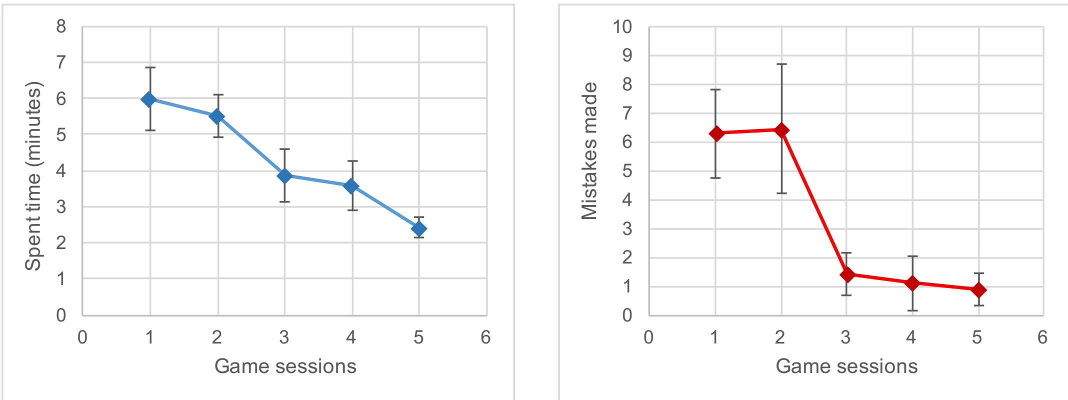


Figure 5.4: Case study 1. Game sessions result - Spent time (minutes) and mistakes made.

In the first game session, the mean time spent by the selected patients was 5.996 minutes and after the intervention, they presented a mean time spent of 2.429 minutes, as can be verified in Table 5.1, which describes mean, standard deviation and margin of error using a confidence interval of 90% in order to make this study feasible.

During five weeks, the patients were submitted to tasks available by the VR-based game. Thus, at the end of each game session, each participant obtained his or her game session result provided by the game system. Table 5.2 shows the mean mistakes made over the five game sessions, as well as it presents standard deviation and margin of error using a confidence interval of 90%. In order to make a more visible analysis, all mistakes were merged and counted, which are: attempts to select products off the shopping list, attempts to select quantity of products higher than requested, failed product selection

Table 5.2: Case study 1. This table shows the result related to mistakes made by participants during the sessions of the case study 1.

Game section	1 (pilot)	2	3	4	5
Mean	6.286	6.444	1.444	1.111	0.889
Standard deviation	2.812	4.096	1.333	1.691	1.054
Margin of error	1.542	2.246	0.731	0.927	0.578

attempts, how many times participant gave more/less money and how many times the money selection was reset.

Based on the results, it is possible to notice the participants spent less and less time to do the tasks and made less mistakes, showing an improvement on their performance. They could understand more clearly and faster what products they had to pick up from the shopping list according to the supermarket sections and then pay for them, showing us they were more autonomous after the training.

Regarding the case study 2, after the four-week follow-up session, it was also analyzed the results received in the VR-DAD online system. Table 5.3 shows the mean mistakes made over the four game sessions and it also presents standard deviation and margin of error using a confidence interval of 90%. As well as the first case study, overall, it was noticed there was an improvement related to the positive scores obtained during the sessions as well as the mistakes made by the participants while they were doing the tasks, indicating the virtual reality-based method was also effective in this second study, as can be seen in Figure 5.5.

In the first game session, the mean score obtained by the 9 selected people was 7.111 points and after the intervention, they presented a mean score of 15.000 points, as can be verified in Table 5.4, which describes mean, standard deviation and margin of error using a confidence interval of 90% in order to make this study feasible. In relation to the mistakes made while they were doing the task, in the first game session, the mean mistake was 78.778 mistakes and after all the four sessions, they got a mean mistake of 46.333 mistakes, which represents an improvement of 41.18%.

Based on the results of the second case study, it is possible to notice the participants improved their performance and made less mistakes over the four sessions.

Table 5.3: Case study 2. This table shows the result related to mistakes made by participants during the sessions of the case study 2.

Game section	1	2	3	4
Mean	78.778	68.667	53.000	46.333
Standard deviation	20.774	12.787	9.247	12.349
Margin of error	11.390	7.011	5.070	6.771

Table 5.4: Case study 2. This table shows the result related to score obtained by participants during the sessions of the case study 2.

Game section	1	2	3	4
Mean	7.111	8.889	11.667	15.000
Standard deviation	4.372	3.296	2.598	5.025
Margin of error	2.397	1.807	1.424	2.755

5.5 PHYSIOTHERAPIST'S FEEDBACK

All the nine patients had their performance improved after the experiments, both in cognitive capabilities and in motor coordination. Some had greater improvement than others. The physiotherapist also said it was perceived a gradual advance in the perception, the concentration and the elevation of the self-esteem of the selected patients. The experiment was focused on the capability of the participants to go shopping on a supermarket, as autonomous as possible.

In addition to verifying an improvement in the results of the tasks (section 5.4), the physiotherapist and the instructor of the institution said there was an improvement related to their cognitive capabilities, such as logical reasoning and decision-making on common daily tasks, as well as doing math, even the researcher and the physiotherapist had to help the patients in a few times.

Based on these study cases, the hypothesis that virtual reality could support the cognitive development, improving the autonomous capabilities of people with intellectual and multiple disabilities was ratified, proving virtual reality has real potential to support the treatment of people with intellectual and multiple disabilities. Regarding the second hypothesis that hand-based interaction in a VR game-like activity could provide a more natural, attractive and intuitive interaction, being more effective both for the cognitive and the motor coordination development, instead of using a joystick or another device for the virtual objects manipulation, it was based on the observational analysis of the professionals, who noticed a small improvement on their gross motor skills, such as

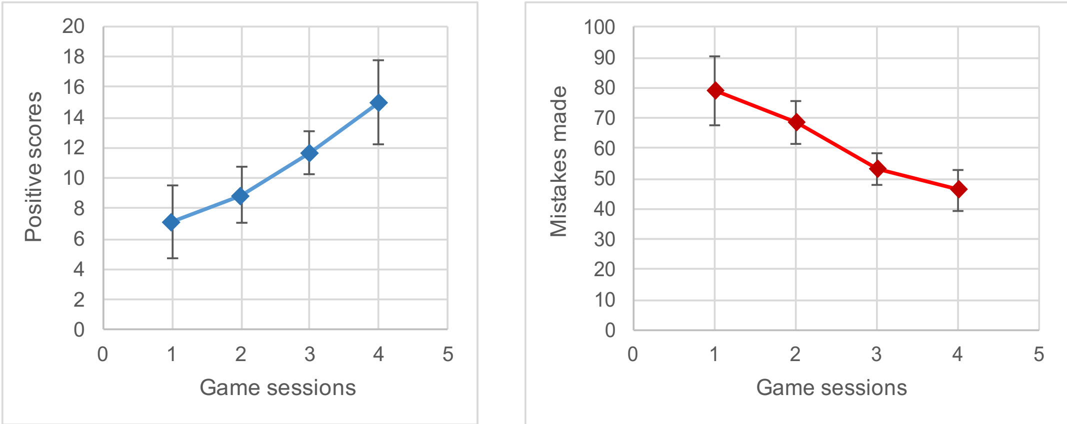


Figure 5.5: Case study 2. Game sessions result - Positive scores and mistakes made.

arm extension and more precision movements. The results related to the mistakes made (Figures 5.4 and 5.5) also show they were more precise in the latest game sessions.

Lastly, over the tasks, sometimes the patients were requested to pick up products located at the top and at the bottom of the shelves, which is more difficult. Thus, it was possible to observe they perform these tasks easier.

6 CONCLUSION

In this study, it was proposed a virtual reality-based method for cognitive and motor coordination treatment for people with intellectual and multiple disabilities. Also, a low-cost innovative interaction interface between the user and the virtual environment, provided by the VR system, was proposed to accomplish a more realistic and intuitive interaction during the requested tasks.

A system called VR-DAD (Virtual Reality-Based Daily Activities Development) was developed for this study, which uses immersive virtual reality to provide a virtual environment for teaching people with intellectual and multiple disabilities regarding to common daily activities, offering the possibility for individuals to improve their skills and to be more autonomous. A few advantages are offered by the VR-DAD system, such as: (i) Low cost, because it only requires a mid-range smartphone and simple virtual reality glasses; (ii) Hand-based manipulation; and (iii) Results-based monitoring through an online dashboard.

Two case studies were used in which ten patients with intellectual and multiple disabilities were selected and assigned to the VR-based tasks. The first case study focused on the individuals' community participation and their social inclusion, by training common tasks they usually do on a daily basis, which was illustrated by a task that consisted in going shopping in a supermarket. The second case study aimed to improve the patients' gross motor coordination of arms and hands, as well as their reflex and visual perception.

The results of the experiments demonstrated the effectiveness and feasibility of using virtual reality technologies for the cognitive and motor coordination training of people with intellectual and multiple disabilities. The low-cost intuitive hand-based manipulation made the task more natural and easier to be performed, letting the participants more autonomous into the virtual environment, acting like in real world. Once the participants didn't have to learn how to use any devices (i.e., joysticks), they were able to focus on the provided task, indeed.

Overall, after the four-week follow-up session of the case study 1, the participants were able to do the task 40% faster on average, which represents an effective improvement, considering the short period, demonstrating improvement of the overall cognitive functioning of individuals with intellectual and multiple disabilities. Even in each session the task was not the same before (i.e., the shopping list changed every session, asking to grab different products in different locations), it was noticed they were more confident and autonomous doing the task.

The improvement may be attributed to exercising attentional processes during the engagement of the virtual reality training. As stated in Brenner et al. (1992), the attentional processes are considered the basic component of cognitive function. The immersive and interactive nature of the VR-based method might offer an pleasurable experience for the participants, motivating them to further engage in the provided task.

The current study was not only about a simple task such as shopping in a supermarket, the objective was to present a pilot of a virtual reality-based task system which effectively support the cognitive and motor skills development of people with intellectual and multiple disabilities, focusing on their community participation, thus their social inclusion.

Lastly, based on the analysis in Chapter 5 it was possible to prove that virtual reality-based method can be effective in the cognitive and motor skills development of people with intellectual disabilities.

6.1 FUTURE WORKS

As future works, a few new features and system improvements may be important for more accurate results, greater applicability in real treatments and a better user experience regarding the patients while doing the task with the VR system.

With the rapid pace of change in computer vision technology and the constant technological enhancement of mobile devices, it makes the augmented reality more accurate and improved. The implementation and use of markeless augmented reality would even enhance the user experience and make the tasks more natural and near real life. By using sensors in the mobile devices to accurately detect the real users' hands, it would allow them to handle 3D objects with no AR marker upon their hands, providing free hands movements regardless the hand's rotation.

For future versions of the VR-DAD system, an auto leveling system is a topic of interest. By using Machine Learning, it would be possible to provide automatic evaluation according to the data collected. Thus, automatically VR-DAD would analyze the patients' performance and give the professionals feedback based on the scores, and also it would predict the results based on the latest sessions, giving the pedagogue and the physiotherapist a more precise direction for the cognitive and motor coordination training of a patient; for instance, it would require a more complex shopping list to improve the patient's cognitive capabilities or it would direct activities that exercise the extension of the patient's arms if it is required for him or her.

Lastly, due this work being an initial study for the investigation of the efficacy of a virtual reality-based cognitive and motor coordination training for people with intellectual and multiple disabilities, two case studies were presented alone. Therefore, a long-term study is important for covering several daily task and analyzing the results and feedback from a larger group of patients.

REFERENCES

AMARAL, C. P.; SIMÕES, M. A.; MOUGA, S.; ANDRADE, J.; CASTELO-BRANCO, M. A novel brain computer interface for classification of social joint attention in autism and comparison of 3 experimental setups: A feasibility study. **Journal of Neuroscience Methods**, Elsevier, v. 290, p. 105–115, 2017.

ANDERSON, F.; ANNETT, M.; BISCHOF, W. F. Lean on wii: physical rehabilitation with virtual reality wii peripherals. **Stud Health Technol Inform**, v. 154, n. 154, p. 229–34, 2010.

ANDERSON, K. R.; WOODBURY, M. L.; PHILLIPS, K.; GAUTHIER, L. V. Virtual reality video games to promote movement recovery in stroke rehabilitation: a guide for clinicians. **Archives of physical medicine and rehabilitation**, Elsevier, v. 96, n. 5, p. 973–976, 2015.

BAI, Z.; BLACKWELL, A. F.; COULOURIS, G. Using augmented reality to elicit pretend play for children with autism. **IEEE transactions on visualization and computer graphics**, IEEE, v. 21, n. 5, p. 598–610, 2015.

BEKELE, E.; CRITTENDON, J.; ZHENG, Z.; SWANSON, A.; WEITLAUF, A.; WARREN, Z.; SARKAR, N. Assessing the utility of a virtual environment for enhancing facial affect recognition in adolescents with autism. **Journal of autism and developmental disorders**, Springer, v. 44, n. 7, p. 1641–1650, 2014.

BERNARDOPITZ, V.; ROOS, K.; BLESCH, G. Computer-assisted instruction in autistic-children. **ZEITSCHRIFT FUR KINDER-UND JUGENDPSYCHIATRIE UND PSYCHOTHERAPIE**, VERLAG HANS HUBER LANGGASSSTRASSE 76, CH-3000 BERN 9, SWITZERLAND, v. 17, n. 3, p. 125–130, 1989.

BIAN, D.; WADE, J. W.; SWANSON, A.; WARREN, Z.; SARKAR, N. Physiology-based affect recognition during driving in virtual environment for autism intervention. In: **PhyCS**, 2015. p. 137–145.

BOZGEYIKLI, E.; RAIJ, A.; KATKOORI, S.; DUBEY, R. Locomotion in virtual reality for individuals with autism spectrum disorder. In: ACM. **Proceedings of the 2016 Symposium on Spatial User Interaction**, 2016. p. 33–42.

BOZGEYIKLI, L.; BOZGEYIKLI, E.; CLEVENGER, M.; GONG, S.; RAIJ, A.; ALQASEMI, R.; SUNDARRAO, S.; DUBEY, R. Vr4vr: Towards vocational rehabilitation of individuals with disabilities in immersive virtual reality environments. In: IEEE. **Virtual and Augmented Assistive Technology (VAAT), 2014 2nd Workshop on**, 2014. p. 29–34.

BRENNER, H. D.; HODEL, B.; RODER, V.; CORRIGAN, P. Treatment of cognitive dysfunctions and behavioral deficits in schizophrenia. **Schizophrenia bulletin**, National Institute of Mental Health, v. 18, n. 1, p. 21, 1992.

BROOKS, B.; ROSE, F.; ATTREE, E.; ELLIOT-SQUARE, A. An evaluation of the efficacy of training people with learning disabilities in a virtual environment. **Disability and rehabilitation**, Taylor & Francis, v. 24, n. 11-12, p. 622–626, 2002.

BRÜCKHEIMER, A. D.; HOUNSELL, M. da S.; SOARES, A. V. Dance2rehab3d: A 3d virtual rehabilitation game. In: IEEE. **Virtual and Augmented Reality (SVR), 2012 14th Symposium on**, 2012. p. 182–190.

BUTLER, R. W. Cognitive rehabilitation. In: HUNTER, S. J.; DONDERS, J. (Ed.). **Pediatric Neuropsychological Intervention**, 2007. p. 444–464.

CAI, Y.; CHIA, N. K.; THALMANN, D.; KEE, N. K.; ZHENG, J.; THALMANN, N. M. Design and development of a virtual dolphinarium for children with autism. **IEEE transactions on neural systems and rehabilitation engineering**, IEEE, v. 21, n. 2, p. 208–217, 2013.

CHEN, C.-H.; LEE, I.-J.; LIN, L.-Y. Augmented reality-based video-modeling storybook of nonverbal facial cues for children with autism spectrum disorder to improve their perceptions and judgments of facial expressions and emotions. **Computers in Human Behavior**, Elsevier, v. 55, p. 477–485, 2016.

CHRISTIANSEN, C.; ABREU, B.; OTTENBACHER, K.; HUFFMAN, K.; MASEL, B.; CULPEPPER, R. Task performance in virtual environments used for cognitive rehabilitation after traumatic brain injury. **Archives of physical medicine and rehabilitation**, Elsevier, v. 79, n. 8, p. 888–892, 1998.

CHUNG, P. J.; VANDERBILT, D. L.; SOARES, N. S. Social behaviors and active videogame play in children with autism spectrum disorder. **Games for health journal**, Mary Ann Liebert, Inc. 140 Huguenot Street, 3rd Floor New Rochelle, NY 10801 USA, v. 4, n. 3, p. 225–234, 2015.

COLBY, K. M. The rationale for computer-based treatment of language difficulties in nonspeaking autistic children. **Journal of Autism and Developmental Disorders**, Springer, v. 3, n. 3, p. 254–260, 1973.

CROMBY, J.; STANDEN, P. J.; BROWN, D. J. The potentials of virtual environments in the education and training of people with learning disabilities. **Journal of Intellectual Disability Research**, v. 40, n. 6, p. 489–501, 1996.

DARROW, M. Virtual reality's increasing potential for meeting needs of persons with disabilities: What about cognitive impairments. In: **Proc. of the Annual International Conference on Virtual Reality and Disabilities**, 1995.

DARROW, M. Virtual reality's increasing potential for meeting needs of persons with disabilities: What about cognitive impairments. **Proceedings of the Third International Conference on Virtual Reality and Persons with Disabilities**, 1995.

FROST, R. An interactive computer environment for autistic children. In: **Proceedings of The Johns Hopkins First National Search for Applications of Personal Computing to Aid the Handicapped**, 1981.

GEOFFRION, L. D.; GOLDENBERG, E. P. Computer-based exploratory learning systems for communication-handicapped children. **The Journal of Special Education**, Sage Publications, v. 15, n. 3, p. 325–332, 1981.

GILLESPIE, K.; GOLDSTEIN, G.; SMITH, D. S.; RICCIO, A.; KHOLODOVSKY, M.; MERENDINO, C.; LESKOV, S.; ARAB, R.; ELSHERBINI, H.; ASANOV, P. et al. Connecting through kinect: Designing and evaluating a collaborative game with and for autistic individuals. In: SPRINGER. **International Conference of Design, User Experience, and Usability**, 2017. p. 398–413.

GOLDENBERG, E. P. Special technology for special children. **Baltimore: University Park Press**, 1979.

HERRERA, G.; ALCANTUD, F.; JORDAN, R.; BLANQUER, A.; LABAJO, G.; PABLO, C. D. Development of symbolic play through the use of virtual reality tools in children with autistic spectrum disorders: Two case studies. **Autism**, Sage Publications Sage UK: London, England, v. 12, n. 2, p. 143–157, 2008.

JIANG, X.; HU, Z.; WANG, W. Research on the rehabilitation of autistic children based on virtual motion system. In: IEEE. **Information Technology in Medicine and Education (ITME), 2016 8th International Conference on**, 2016. p. 267–270.

KANDALAFT, M. R.; DIDEHBANI, N.; KRAWCZYK, D. C.; ALLEN, T. T.; CHAPMAN, S. B. Virtual reality social cognition training for young adults with high-functioning autism. **Journal of autism and developmental disorders**, Springer, v. 43, n. 1, p. 34–44, 2013.

KE, F.; IM, T. Virtual-reality-based social interaction training for children with high-functioning autism. **The Journal of Educational Research**, Taylor & Francis, v. 106, n. 6, p. 441–461, 2013.

KE, F.; IM, T.; XUE, X.; XU, X.; KIM, N.; LEE, S. Experience of adult facilitators in a virtual-reality-based social interaction program for children with autism. **The Journal of Special Education**, SAGE Publications Sage CA: Los Angeles, CA, v. 48, n. 4, p. 290–300, 2015.

KE, F.; LEE, S. Virtual reality based collaborative design by children with high-functioning autism: design-based flexibility, identity, and norm construction. **Interactive Learning Environments**, Taylor & Francis, v. 24, n. 7, p. 1511–1533, 2016.

KURIAKOSE, S.; KUNCHE, S.; NARENDRANATH, B.; JAIN, P.; SONKER, S.; LAHIRI, U. A step towards virtual reality based social communication for children with autism. In: IEEE. **Control, Automation, Robotics and Embedded Systems (CARE), 2013 International Conference on**, 2013. p. 1–6.

KURIAKOSE, S.; LAHIRI, U. Understanding the psycho-physiological implications of interaction with a virtual reality-based system in adolescents with autism: A feasibility study. **IEEE Transactions on Neural Systems and Rehabilitation Engineering**, IEEE, v. 23, n. 4, p. 665–675, 2015.

LAHIRI, U.; BEKELE, E.; DOHRMANN, E.; WARREN, Z.; SARKAR, N. Design of a virtual reality based adaptive response technology for children with autism. **IEEE Transactions on Neural Systems and Rehabilitation Engineering**, IEEE, v. 21, n. 1, p. 55–64, 2013.

LATASH, M. L. Virtual reality: a fascinating tool for motor rehabilitation (to be used with caution). **Disability and Rehabilitation**, Taylor & Francis, v. 20, n. 3, p. 104–105, 1998.

LAVER, K. E.; GEORGE, S.; THOMAS, S.; DEUTSCH, J. E.; CROTTY, M. Virtual reality for stroke rehabilitation. **The Cochrane Library**, Wiley Online Library, 2015.

LOPRESTI, E. F.; BODINE, C.; LEWIS, C. Assistive technology for cognition [understanding the needs of persons with disabilities]. **IEEE Engineering in Medicine and Biology Magazine**, IEEE, v. 27, n. 2, 2008.

LORENZO, G.; LLEDÓ, A.; POMARES, J.; ROIG, R. Design and application of an immersive virtual reality system to enhance emotional skills for children with autism spectrum disorders. **Computers & Education**, Elsevier, v. 98, p. 192–205, 2016.

LOTAN, M.; YALON-CHAMOVITZ, S.; WEISS, P. L. T. Virtual reality as means to improve physical fitness of individuals at a severe level of intellectual and developmental disability. **Research in developmental disabilities**, Elsevier, v. 31, n. 4, p. 869–874, 2010.

MCLELLAN, H. Virtual environments and situated learning. **Multimedia Review**, v. 2, n. 3, p. 30–37, 1991.

MIDDLETON, T. Advanced technologies for enhancing the education of students with disabilities. **Journal of microcomputer applications**, Elsevier, v. 15, n. 1, p. 1–7, 1992.

MOLINE, J. Virtual reality for health care: a survey. **Studies in health technology and informatics**, IOS PRESS, p. 3–34, 1997.

MUNAFO, J.; DIEDRICK, M.; STOFFREGEN, T. A. The virtual reality head-mounted display oculus rift induces motion sickness and is sexist in its effects. **Experimental brain research**, Springer, v. 235, n. 3, p. 889–901, 2017.

NIELSEN, J. **Ten usability heuristics**, 2005.

PANTELIDIS, V. S. Virtual reality in the classroom. **Educational Technology**, ERIC, v. 33, n. 4, p. 23–27, 1993.

PARSONS, S. Learning to work together: designing a multi-user virtual reality game for social collaboration and perspective-taking for children with autism. **International Journal of Child-Computer Interaction**, Elsevier, v. 6, p. 28–38, 2015.

PARSONS, S.; MITCHELL, P.; LEONARD, A. The use and understanding of virtual environments by adolescents with autistic spectrum disorders. **Journal of Autism and Developmental disorders**, Springer, v. 34, n. 4, p. 449–466, 2004.

RAMACHANDIRAN, C. R.; JOMHARI, N.; THIYAGARAJA, S.; MAHMUD, M. M. Virtual reality based behavioural learning for autistic children. **The Electronic Journal of e-Learning**, Academic Conferences and Publishing International Limited, v. 13, n. 5, p. 357–365, 2015.

RIZZO, A.; BUCKWALTER, J.; BOWERLY, T.; ROOYEN, A. V.; MCGEE, J.; ZAAG, C. Van der; NEUMANN, U.; THIEBAUX, M.; KIM, L.; CHUA, C. Virtual reality applications for the assessment and rehabilitation of attention and visuospatial cognitive processes: an update. In: **Proceedings of the third international conference on disability, virtual reality and associated technologies, Alghero, Italy**, 2000. p. 197–207.

RIZZO, A. A.; BUCKWALTER, J. G. Virtual reality and cognitive assessment. **Virtual Reality in Neuro-Psycho-Physiology: Cognitive, Clinical and Methodological Issues in Assessment and Rehabilitation**, v. 44, p. 123, 1997.

ROGLIĆ, M.; BOBIĆ, V.; DJURIĆ-JOVIČIĆ, M.; DJORDJEVIĆ, M.; DRAGAŠEVIĆ, N.; NIKOLIĆ, B. Serious gaming based on kinect technology for autistic children in serbia. In: IEEE. **Neural Networks and Applications (NEUREL), 2016 13th Symposium on**, 2016. p. 1–4.

ROSE, F. D.; BROOKS, B.; ATTREE, E.; PARSLOW, D.; LEADBETTER, A.; MCNEIL, J.; JAYAWARDENA, S.; GREENWOOD, R.; POTTER, J. A preliminary investigation into the use of virtual environments in memory retraining after vascular brain injury: indications for future strategy? **Disability and Rehabilitation**, Taylor & Francis, v. 21, n. 12, p. 548–554, 1999.

SCHALOCK, R. L.; BORTHWICK-DUFFY, S. A.; BRADLEY, V. J.; BUNTINX, W. H.; COULTER, D. L.; CRAIG, E. M.; GOMEZ, S. C.; LACHAPELLE, Y.; LUCKASSON, R.; REEVE, A. et al. **Intellectual disability: Definition, classification, and systems of supports**, 2010.

SCHALOCK, R. L.; BROWN, I.; BROWN, R.; CUMMINS, R. A.; FELCE, D.; MATIKKA, L.; KEITH, K. D.; PARMENTER, T. Conceptualization, measurement, and application of quality of life for persons with intellectual disabilities: Report of an international panel of experts. **Mental retardation**, v. 40, n. 6, p. 457–470, 2002.

SCHULTHEIS, M. T.; RIZZO, A. A. The application of virtual reality technology in rehabilitation. **Rehabilitation psychology**, Educational Publishing Foundation, v. 46, n. 3, p. 296, 2001.

SIMPLICAN, S. C.; LEADER, G.; KOSCIULEK, J.; LEAHY, M. Defining social inclusion of people with intellectual and developmental disabilities: An ecological model of social networks and community participation. **Research in developmental disabilities**, Elsevier, v. 38, p. 18–29, 2015.

SIMS, D. Multimedia camp empowers disabled kids. **IEEE Computer Graphics and Applications**, IEEE, v. 14, n. 1, p. 13–14, 1994.

SMITH, M. J.; GINGER, E. J.; WRIGHT, K.; WRIGHT, M. A.; TAYLOR, J. L.; HUMM, L. B.; OLSEN, D. E.; BELL, M. D.; FLEMING, M. F. Virtual reality job interview training in adults with autism spectrum disorder. **Journal of Autism and Developmental Disorders**, Springer, v. 44, n. 10, p. 2450–2463, 2014.

SOARES, N. M.; PEREIRA, G. M.; FIGUEIREDO, R. I. da N.; MORAIS, G. S.; MELO, S. G. de. Terapia baseada em realidade virtual usando o leap motion controller para reabilitação do membro superior após acidente vascular cerebral. **Scientia Medica**, Pontificia Universidad Católica de Río Grande del Sur, v. 27, n. 2, p. 3, 2017.

STANDEN, P.; LOW, H. Do virtual environments promote self-directed activity? a study of students with severe learning difficulties learning makaton sign language. In: **Proceedings of the First European Conference on Disability, Virtual Reality and Associated Technologies**, 1996. p. 123–127.

STANDEN, P.; LOW, H. Do virtual environments promote self-directed activity? a study of students with severe learning difficulties learning makaton sign language. In: **Proceedings of the First European Conference on Disability, Virtual Reality and Associated Technologies**, 1996. p. 123–127.

STEUER, J. Defining virtual reality: Dimensions determining telepresence. **Journal of communication**, Wiley Online Library, v. 42, n. 4, p. 73–93, 1992.

STRICKLAND, D. A virtual reality application with autistic children. **Presence: Teleoperators & Virtual Environments**, MIT Press, v. 5, n. 3, p. 319–329, 1996.

STRICKLAND, D. Virtual reality for the treatment of autism. **Studies in health technology and informatics**, Ios Press, p. 81–86, 1997.

WALKER, Z.; VASQUEZ, E.; WIENKE, W. The impact of simulated interviews for individuals with intellectual disability. **Educational Technology & Society**, JSTOR, v. 19, n. 1, p. 76–88, 2016.

WANG, M.; REID, D. Using the virtual reality-cognitive rehabilitation approach to improve contextual processing in children with autism. **The Scientific World Journal**, Hindawi Publishing Corporation, v. 2013, 2013.

WIEDERHOLD, B. K. The potential for virtual reality to improve health care. **The Virtual Reality Medical Center**, 2006.

WIEDERHOLD, M. D.; WIEDERHOLD, B. K. **Virtual reality and interactive simulation for pain distraction**, 2007.