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Development of a Virtual Reality-Based Game Approach for Supporting Sensory Processing Disorders Treatment †

Henrique Rossi [1], Raquel Prates [1], Sibele Santos [2] and Renato Ferreira [1,*]

[1] Department of Computer Science, Universidade Federal de Minas Gerais, Belo Horizonte 31270901, Brazil; henrique.sr@dcc.ufmg.br (H.R.); rprates@dcc.ufmg.br (R.P.)
[2] Occupational Therapist, Ampliar Pampulha, Belo Horizonte 31275080, Brazil; sibelemsantos@gmail.com
* Correspondence: renato@dcc.ufmg.br; Tel.: +55-313-409-5874

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Abstract: Serious games for health are those that are not aimed solely at entertainment, but rather at supporting health treatments. In this paper, we develop and assess the proposal of a Virtual Reality (VR) game aimed at supporting Sensory Processing Disorder (SPD) treatment. SPD is a condition which affects the integration and processing of the various stimuli coming from inside and outside of the body and its treatment involves providing patients with controlled sensory stimuli. Our goal is to investigate whether a Virtual Reality game that can stimulate different sensory systems could be useful in SPD treatment. In order to do so, we have designed and developed Imaginator, a VR Roller Coaster Game connected with a Head Mounted-Display (HMD) which can be customized by therapists to adjust its stimuli to different patients' needs in therapy. Imaginator was assessed by five occupational therapists through its use in their treatment sessions. Each therapist had the game available in their therapy environment for around 2–3 weeks. They were instructed to use the game whenever they thought it could be interesting to a patient's treatment. After the trial period, they were interviewed about their experience in using the game and their perception of its impact in therapy sessions. Our results show that therapists in general perceived Imaginator as having a positive effects in patients' treatment. They noticed that it was able to stimulate different senses, and they reported that in some cases it was able to help patients relax, increase their concentration and even work as an encouragement to explore similar activities in the physical world. There were a few patients who experienced some adverse reactions, such as nausea, but nothing that they felt was worrying or that could prevent the game from being used.

Keywords: Serious Games; Virtual Reality; Head Mounted Display; Sensory Processing Dysfunctions; SPD; HMD

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1. Introduction

Sensory processing (or sensory integration) is an activity that happens in the brain. This neurological process organizes the sensation inputs perceived by the body sensors [1]. Performing simple everyday activities (e.g., going for a walk, drinking a glass of water etc.) or rather complex ones (e.g., driving a car, performing Olympic gymnastic exercises etc.) requires constant integration and processing of different sensations. An example of such processing can be noticed when we eat an apple, our body sensors receive sensations of its texture, its flavor, its smell, as well as its shape. Although there are many different sensations, the integration and processing of the stimuli inform us that they all allude to a single apple [2].

The term 'Sensory Processing Disorders' (SPD) (sensory integration dysfunction) refers to any condition that is generated when an individual's brain cannot integrate or organize the stream of sensory impulses in order to provide an accurate and rich information about herself/himself or awareness of hers/his environment [2]. The consequences of such disorders can affect the modulation of the senses (e.g., one sense can be perceived with more or less intensity than the others), integration (executing tasks which require different stimuli can be difficult) and discrimination (ability to identify different stimuli within the same sense). As it can affect multiple senses, SPD may influence how a person perceives the environment around her/him, as well as how she/he interacts with it and with other people [3].

Current estimates [4,5] indicate that 16% (1 out of every 6) of the kids aged from 7 to 11 years in the US suffer from this condition. An earlier study [6] reported that considering children aged from 4 to 6 in the US, 5% (1 out of every 20) also suffered from the condition. SPD treatment is based on the principle that patients must be exposed to the various stimuli in the environment, causing the brain to naturally develop, and improve its processing and integration of the stimuli from the senses. By offering the necessary stimuli for a patient with modulation problems (e.g., vestibular or tactile hypersensitivity), the exposure will gradually let the brain learn how to modulate properly the sensations [2]. Therefore, treatment usually takes place in a therapeutic environment in which the therapist can provide different and controlled stimuli to all senses [7].

In this work, we present our research to develop an immersive VR game aimed specifically at SPD treatment. The first step was to elicit the main requirements based on the literature regarding SPD treatment, as well as input from experts in the field. To support treatment, our system allows for the control of the level of different stimuli to be provided to the patient, which is key for the therapy. It also allows therapist–patient interaction during its use.

The developed system, called Imaginator, offers a virtual roller coaster simulator experience, and requires the utilization of the Oculus Rift ™ DK2 [8], a Head Mounted Display (HMD) that provides a high level of immersion. Imaginator includes sound effects, for the auditory sense stimulation; a colorful and detailed scenario improved with graphic quality, for the visual sense stimulation; activities that instigate the user's constant rotation of the head improved with physics-based movements, for the vestibular (i.e., sense that processes stimuli related to our orientation and movement) and proprioceptive (i.e., sense that processes stimuli related to our posture) senses stimulation. As distinct SPD patients have different treatment needs, one of Imaginator's main features is to enable Occupational Therapists (OTs) to tailor the system's available activities to better suit every individual's treatment.

Once Imaginator was implemented and functional, we conducted a qualitative evaluation with the participation of five Occupational Therapists (OTs). In order to do so, we made the system available in the OTs own therapeutic environment for a period ranging from 14 to 21 days. They were instructed to use the system if and only when they believed the game could be beneficial to the therapy. After their period of experience with the Imaginator, we interviewed the OT about their use of the system as a therapeutic resource. Our results show that OTs believed the system was useful and had a positive impact in their patients.

A literature review indicated that Virtual Reality (VR) has been used to support treatment for various health conditions, including disorders that have SPD as a symptom, such as Vestibular Disorders [9–14], Autism Spectrum Disorder (ASD) [15–20], Attention Deficit Hyperactivity Disorder (ADHD) [21–25] and Speech Disorder [26,27]. All of these VR solutions have been used for rehabilitation and treatment of patients with different conditions, many of which are closely related to SPD. However, none of them focus on SPD per se. We have only identified two recently published works which are directly aimed at SPD children [28,29]. As our work, these works focus specifically on supporting SPD treatment. Nevertheless, their approach is different from ours. Their solution is for Kinect and Nintendo Wii to be used by the children at home, whereas ours focuses in supporting therapeutic treatment, allowing OTs to tailor the system to each patient's specific needs. Furthermore, our solution makes use of different technologies, presenting a novel immersive VR game aimed specifically at SPD treatment.

In the next section, we briefly describe a review of the various VR systems aimed at different health issues, and how they are related to our work. In Section 3, we present our system, describing the elicited requirements, the tools used in its development, the system's architecture and finally, the Imaginator system itself. Next, in Section 4, we explain how the evaluation was conducted, as well as its results. The findings related to the use of the Imaginator in SPD treatment and the opportunities for its improvement are discussed in Section 5. Finally, in Section 6 we present our conclusions, regarding the contributions of our work, as well as some directions for future work.

2. Related Works

In this section, we present works which address SPD either directly or as a common comorbidity, such as Vestibular Disorders, Autism Spectrum Disorders (ASD), Attention Deficit Hyperactivity Disorder (ADHD) and Speech Disorders. We briefly explain the focus of the works on each topic, and how they differ from our work being presented in this paper.

2.1. Sensory Processing Disorder (SPD)

In our literature review, we have only identified two works that are aimed specifically at SPD. Chuang and Kuo [29] chose two commercial games that offer aerobic exercises and balance. The games are VR systems and were used at home as part of children's SPD treatment. Parents were responsible for logging into a system and registering the data regarding their kids performance with the system. Later the same authors and other colleagues [28] developed a system connected with the kinect^{TM} offering 3 games which aimed at training children's visual-motor coordination, and improving their vestibular and proprioceptive systems. The participants were required to execute movement exercises with their hands in order to progress/complete tasks within the game. They applied the system with three SPD patients and analyzed the data before and after its use.

Although our work also developed a VR game for the treatment of SPD children, in our work we used an HMD device to provide a more immersive experience to the user. Furthermore, whereas the previous works were aimed at supporting home activities related to kids' SPD treatment, our work aims at supporting therapists in treating SPD. Therefore, a relevant feature in our system is to allow the OT to change, in real time, several settings related to the amount of stimulation offered by the system, as well as the challenge it poses to the patient during an activity.

2.2. Vestibular Disorders

We also identified a number of works which use VR as an alternative treatment for postural balance and peripheral vestibule diseases. Postural balance problems that affect vestibular, visual and proprioceptive senses may be caused by SPD [2]. Many works [9–12,14] used VR to help patients suffering from postural balance control. In these works, VR was used to stimulate vestibular and proprioceptive senses, through the use of games and virtual reality equipment for body movement capture.

Rausch et al. [10] used low cost VR solution (smartphone with Google cardboard), to asses whether such technologies can induce greater postural instability than traditional testing. Lubetzky et al. [11] used the Oculus Rift^{TM} to capture head position and orientation of patients while executing postural control exercises. Later on, Lubetzky et al. [9] applied a similar VR approach to test different parameter choices (embedding dimension and radius similarity) for the analyses of sample entropy, a measure used to study postural control. Rodrigues et al. [12] used force feedback devices with Xbox Kinect^{TM} so that patients could position themselves in a correct posture (either sitting or standing) by visualizing their body virtually and feeling force feedback in their hands. McConville and Milosevic [14] assessed the feasibility of using VR technologies (using PlayStation EyeToy^{TM}) for postural balances, by measuring the amount of head movements. Bergeron et al. [13] present a review of several works which use VR to stimulate the vestibular sense, as an alternative for treating peripheral vestibule diseases (e.g., benign paroxysmal positional vertigo, Ménière unilateral or bilateral, vertigo and chronic vestibular dysfunction).

Even though our work focuses on stimulating senses related to SPD therapy and these papers focus on supporting postural balance treatment, some of the senses stimulated in both cases are the same: visual, vestibular and proprioceptive. Nonetheless, how these senses are stimulated and to what degree, and even the how the stimuli are combined may be different for distinct treatments. Moreover, in our game auditory stimuli was also included. Furthermore, different from other systems mentioned the stimuli in our game could be tailored by therapists for each patient at a given moment.

2.3. Autism Spectrum Disorder (ASD)

Autism Spectrum Disorder (ASD) treatment is also one that has employed VR systems broadly [15–20]. Barajas et al. [16] applied a mixture of a tangible device connected to a VR game on a computer screen, in order to help patients improve their conceptual, practical and social skills. Sturm et al. [17] developed a customizable system which aims at generating different types of face expressions. The goal is to request the ASD patient to recognize expressions that depict the same emotions among the generated options, and as a result help them to improve at emotion recognition. Hughes et al. [18] created a game to train empathy and perspective in autistic patients by requiring them to take care of a living creature. Silva et al. [19] use VR as a tool to instigate the collaboration between autistic children with the goal of improving their social interaction skills. To do so, the authors developed a multi-touch application that requires two people to work together to complete challenges. Ribeiro and Raposo [20] developed a customizable system to help ASD patients improve their communication with other autistic patients or/and a tutor. Following the same research line, Silva-Capa et al. [15] developed a game for ASD patients aimed at performing three strategies to support collaborative work. Kandalaft et al. [30] use VR in improving the social, cognitive and functional abilities of young adults through similar real life experiences using Second Life ^{TM}. Finally, Herrera et al. [31] developed a supermarket simulator, installed on a tablet, to teach children symbolic play.

These works focus on supporting ASD patients' improvement of different skills. The relevance to our work is because often ASD patients also have SPD (e.g., lack of attention, tactile defensiveness, gravitational insecurity) [1]. Nonetheless, these works focused more on the social aspects of ASD, whereas our focus is on providing multisensorial stimulation in a controlled way. Therefore, our work is aimed at supporting SPD treatment, independent of is associon with other disorders.

2.4. Attention Deficit Hyperactivity Disorder (ADHD)

VR has also been used as an alternative treatment for ADHD [21–24]. These works used Electroencephalogram (EEG) connected to a VR game application on the computer, to read users' brain activity. Alchalcabi et al. [22] use an EEG signal device on ADHD patients as an input device to perform game tasks while keeping concentration. Rohani et al. [23] analyzed the P300 wave (from an EEG) during a VR experience, to determine whether or not the user was concentrated. Mandryk et al. [24] use EEG data to alter the computer screen, by obfuscating it based on the user's concentration. Santos et al. [25] collected attributes from patients' gaming experiences to classify the presence or absence of ADHD (using machine learning). More recently Avila-Pensantez et al. [21] developed an Augmented Reality (AR) focus game with the support of kinect, to increase players attention and decrease their frustration.

These works have a different focus from ours, as their goal is to manipulate users' concentration, either by analyzing their brain activity or through an AR solution. In other words, their goal is not to treat patients, but rather diagnose whether they have ADHD [25].

2.5. Speech Disorder

SPD may also be a symptom of speech disorder, if the person affected has modulation and/or discrimination problems related to the auditory stimulus [1]. We identified works that use VR as an alternative treatment for speech sound disorders (SSD) and hearing problems, [26,27]. Nasiri et al. [26] developed a game to help children with hearing and speech disorders to learn how to speak basic words which should be known before the age of 7. The player interacts with the game by voice commands allowing him/her to control his/her own avatar (by saying words to make it move within the scenario) and complete game tasks (listening and repeating basic words). Grossinho et al. [27] developed a system which has phoneme recognition. The system which has gaming activities, requires the player to speak linguistic phonemes (from the Portuguese language). The closer the sound of the spoken phoneme to the correct sound, the higher the score the player gets.

As in our work, these works focus on treatment. However, their treatment is specific for SSD, as they support users in learning how to say or pronounce phonemes or words. In our system, although we stimulate the auditory sense, there is no speech input.

2.6. Summary

In this section we presented a broad set of VR systems related to sensorial health aspects. Although some of the solutions found were closely associated with SPD, their focus was on more specific aspects such as postural balance or speech abilities. We only found two recent works that were specifically aimed at SPD [28,29], as is ours. Nonetheless, their approach is different from ours in two main aspects: the level of immersion provided to patients (ours uses the HMD Oculus Rift and allows for a higher immersion), and also the context that they are aimed at (ours is aimed at supporting therapists treatment activities, whereas theirs is to be used at home by patients). Furthermore, different than most of the works discussed our work allows for customization of the amount of stimuli associated to an activity and its difficulty level, so that therapists can tailor the activity to each individual patient and his/her treatment. In the next section we present Imaginator, the system developed to support SPD treatment.

3. Developing an SPD Treatment Support System

The main goal of our research was to propose a new VR solution aimed at SPD treatments. In this section we present the requirements identified for the system; the decisions regarding the development tools to be used; the architecture of the proposed solution; and finally the system developed.

3.1. Requirements

In order to elicit the relevant requirements for a system to support SPD treatment, we resorted to our literature review. Based on some relevant works regarding the SPD field (namely [1–3,32]), we identified two main requirements that were relevant for a system supporting SPD treatment: generating multisensorial stimuli and allowing for real-time customization.

As explained, SPD affects one or more of a person's sensory systems and the treatment involves exposing patients to natural stimuli they need to learn to process. Thus, the first requirement we identified was that the system should be able to generate multisensorial stimuli, so that it could be used to stimulate one or more of the patients' senses.

The next requirement we identified was the need for the system to be highly customizable. The reason for this is because SPD patients' individual characteristics can be highly variable. Therefore, during treatment OTs propose activities that take into consideration an individual patient's limitations and needs [1]. Thus, the system should allow the OT to not only define which senses will be stimulated at a given moment, but also the level of stimulation. The customization should involve not only the level of the activity per se (which should not be too difficult nor to easy) so the patient will feel stimulated and interested in performing it [3]. Also, OTs should be able to adjust the activity as the patient is performing if they deem necessary (and not only beforehand).

Considering these requirements, we decided to develop a highly customizable roller coaster simulator, in which the patient views the VR environment from the inside of a virtual cart. It should allow OTs to manipulate, in real time, several predefined parameters, which would alter the experience for the patient, such as game activities, level of stimulation generated by the tracks, visual stimulation fostered by objects present in the scenes, speed of the cart, among others. Thus, the therapist could tailor the experience to each patient, taking into consideration what would be an appropriate level of stimulation for that individual that would foster the engagement, tuning the system to the specificities of that patient's treatment.

3.2. Development Tools

The VR hardware chosen for this research was the Oculus Rift (see Figure 1), DK2 (Development Kit 2) the only version available at the time. This HMD is classified in the group of headsets that blocks the external visualization of the environment, creating an inside only experience [33]. It is accompanied by an external camera which tracks translation movements in three dimensions (forward, horizontal and vertical movements) in a small area in front of it. The DK2 has a seven-inch screen with resolution of 960 $\times$ 1080 pixels for each eye.

Figure 1. Oculus Rift version DK2 with movement capture camera. Source: [8].

The motivation for using this technology in the SPD treatment is based on how typical treatments are performed. OTs specialized in this treatment, offer a number of different stimuli at once to the patients during sessions considering their needs. The vestibular system is particularly important, since its processing contributes to modulate the others senses [2]. We considered using the HMD because it would naturally instigate the movement of the head which, in turn, would stimulate the vestibular sense as well as the visual and proprioceptive senses [34].

In addition, the vestibular sense is also stimulated by the input from visual stimuli, known as visuo-vestibular connection observed by Riccelli et al. [35]. They analyzed neural activity in the left parieto-insular vestibular cortex (PIVC) region, while users watched a simulated roller coaster video on an HMD. This connection would be beneficial for stimulating both senses. The vestibular-vision interaction has been used before [11,13,14], and thus was also explored in our work.

The software was developed using the game engine Unreal Engine 4 (UE4) [36]. The choice of this tool was due to its ease for developing games. Although the system has a purpose that goes beyond entertainment, most of the development is similar to a game, such as designing a scene with 3D objects. In addition, UE4 has native support for communication with Rift, as well as networking programming support, facilitating development. We built the whole simulator using the internal engine script language called Blueprint.

3.3. System's Architecture

In order to allow for therapists to customize the system at real time, that is during a patient's use of the system, it was necessary to create an architecture for the system that provided two different interfaces, one for the patient and one for the therapist that could be accessed at the same time. To do so, we decided to create an architecture that connected two computers using a local server setup with TCP/IP network protocols. This enables the two interfaces to connect into the same session, (e.g., an online game, with multiple players playing in the same map) constantly synchronized by the server application. The OT sees every action patients' perform in their own interface, and any adjustments in the activity made by the therapist will immediately take effect in the patient's interface.

Although the ideal would be to have two computers available to run the system, the solution might be too expensive or not viable to be included in OT practices. Thus, we have also proposed a solution in which it would be possible to run the system, using one computer and two screens. Figure 2 illustrates the two possible system setups. Figure 2a depicts the configuration with two computers. In this case, Computer 1 runs the patient application, which sends the images to the Oculus Rift, receives its inputs, and generates images on Screen 1. This application connects to the server application that is also on the same computer. Computer 2 runs the therapist's application (presenting the interface on Screen 2), which has all the system's customization parameters, and communicates with the server (that is on the Computer 1) through the local network. In this configuration, Computer 1 must have high performance hardware to run the Oculus Rift application at 75+ frames per second.

In contrast, Figure 2b depicts the configuration with only one computer. In this case, Computer 1 runs all the applications: the patient's, the therapist's and the server's. In order to allow the therapist to make changes during patient's use time, it is necessary to present the patient's interface and the therapist's interface in different screens. Just as in the first setup, Computer 1 needs to support adding multiple video devices and having high-performance hardware to run the 3 applications simultaneously.

The system was developed in our lab using the Configuration 1 architecture proposed. However, the system setup for the evaluation at the therapists office, used the Configuration 2 architecture. Our motivation for this decision was that by using only one computer per therapist, it was possible for us to provide the system to different therapists at the same time, which was interesting due to the time involved in each evaluation.

3.4. Imaginator

The system consists of a VR roller coaster that runs through a track, while different possible activities are presented to the user to perform during the ride. There are two possible scenarios, four possible tracks, various sound effects scattered in VR environment, and three different activities (or games) that require the patients to move their head in order to interact.

The two scenarios present two very different levels of simuli. One is a very bare scenario (very little visual simulus), containing only the track (denominated The Box). Whereas the other is a medieval scenario containing a number of different elements depicting nature and houses. Figure 3 shows the two existing scenarios. The four tracks vary in relation to the ascents and descents they contain, going from soft slopes to steep ones.

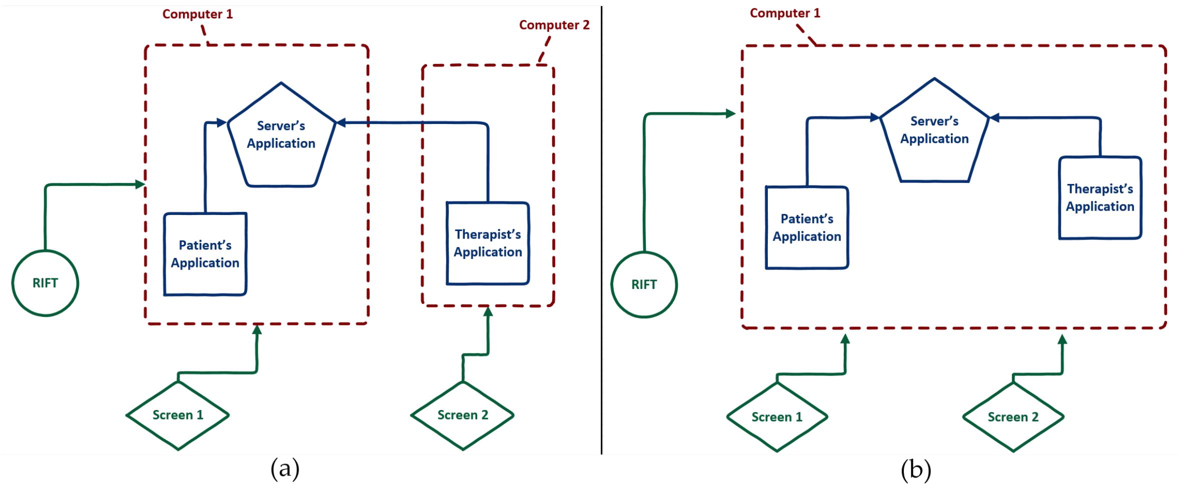

Figure 2. The images represent the two possible setups the system can accept, to be used in the OTs office. They differ in the number of computers (one or two). Configuration 1 (**a**) with two computers. Configuration 2 (**b**) with one computer and two screens.

Figure 3 also depicts the patient and therapists view of the virtual environment. The patient's view is always from a first person perspective from inside the cart. Figure 3b,d depicts the image shown to each of the patient's eyes through the Oculus Rift. However, the patient views a 3D virtual reality environment as depicted in the therapist's overall view of Figure 3a,c.

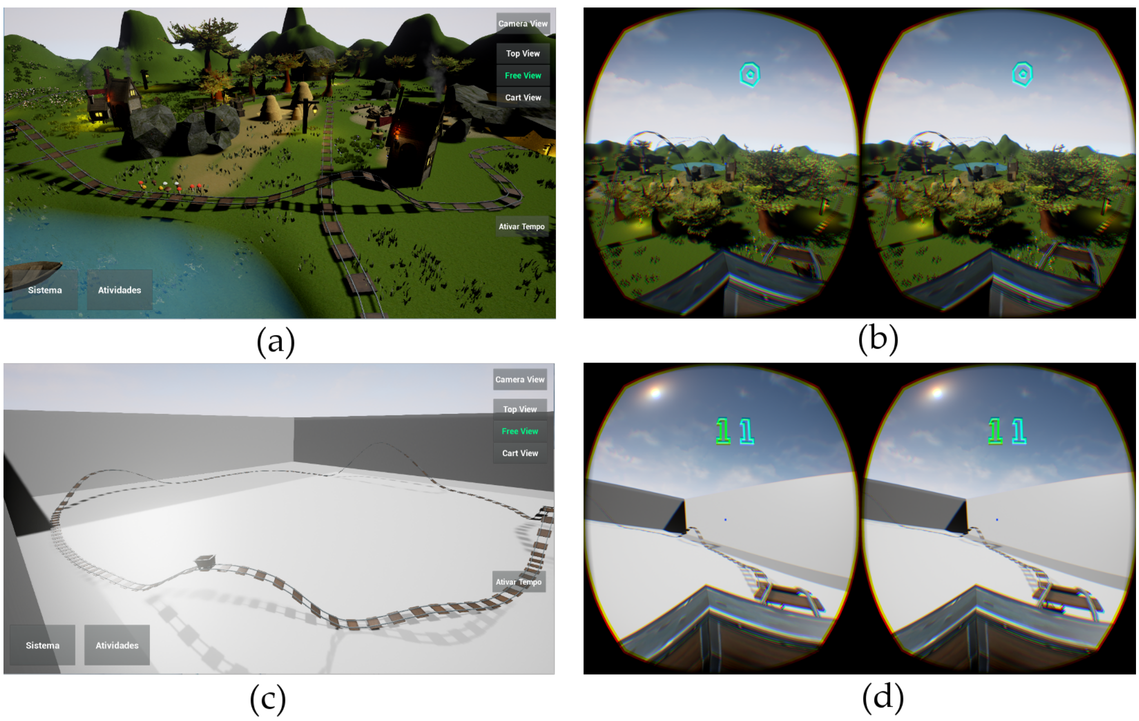

Figure 3. The top and lower images depict the two scenarios, the images on the left are the therapist's views, whereas the ones on the right are the patient's views through the Oculus Rift. (**a**) Therapist's view of Medieval scenario; (**b**) Patient's view of Medieval scenario; (**c**) Therapist's view of Thebox scenario; (**d**) Patient's view of Thebox scenario. While the Medieval scenario is a very colorful and detailed environment, to stimulate vision, Thebox has almost no details, to reduce visual stimulation.

The therapists' view depicts an overall view of the environment as well as a menu that allows them to customize the settings that control the patient's experience (note the menu on the top right hand corner and options on bottom left corner of Figure 3a,c). The therapists' configuration options are organized into different sets of options: *View, System, and Activity*.

The *View* options (top right hand corner in Figure 3a) allows therapists to change the perspective of their view of the 3D world. The change does not impact the patient's view and can be performed during patients' activities. This feature is important for viewing patients' actions during activities. Each option is presented as a button on the interface, and by clicking on the desired option, the view is immediately changed. Figure 4 depicts the three available perspective options, which are are:

- **Top View**: The therapist views the world from above. It is possible to move the view window using the directional arrow keys that move left/right/front/back. In addition, it is also possible to zoom in or out of the scene by changing a slide control.
- **Free View**: It positions the therapist's perspective in the center of the map. From this position, therapists can rotate their view using the mouse, turning left/right or up/down. Using the directional arrows on the keyboard, it is possible to move around following the orientation set by the mouse. For example, if the therapists position their visual field upwards (looking at the sky) and press the Up/Down directional arrow it will move towards the sky/ground.
- **Kart View**: It positions the therapists view within the cart, as a first person perspective. It is the same perspective that is being seen by patients. Notice that in this view, the therapist does not have any control of how the view changes, it moves along with the cart.

Regarding the view option, there is also the possibility to activate a picture-in-picture view depicting the patients' view. This option is available at the **Camera View** top button on the right hand corner of the screen and can be activated with any of the available views.

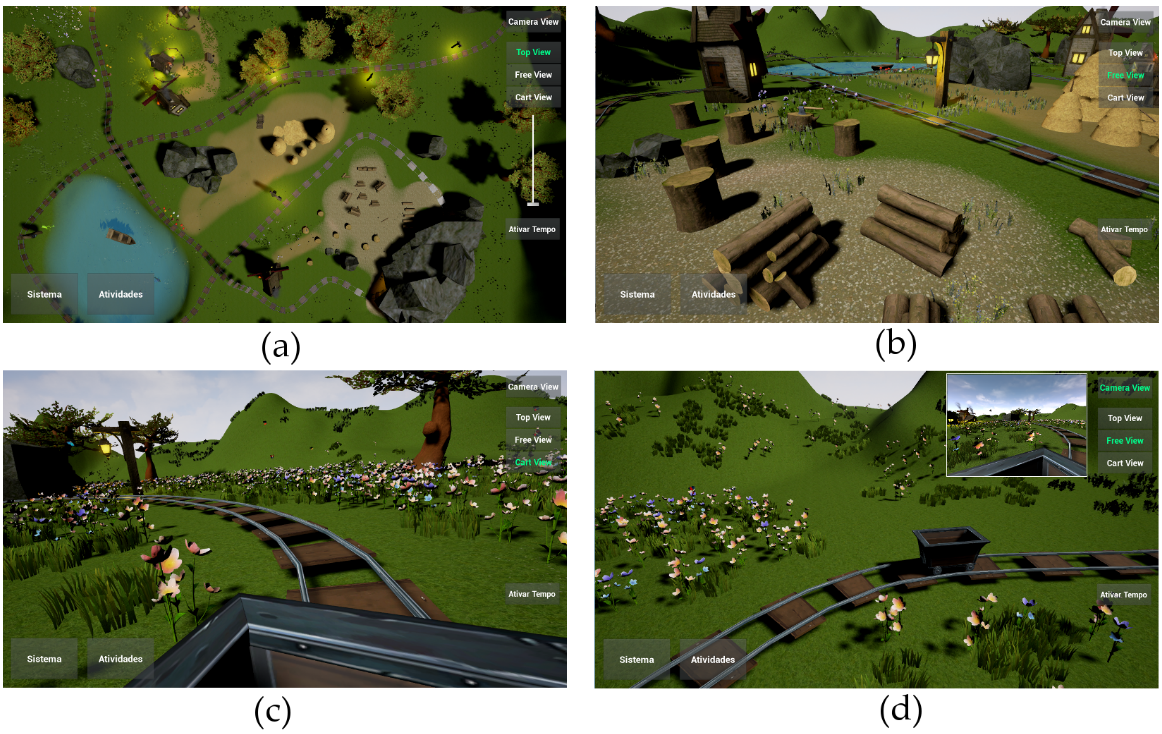

Figure 4. The images show the environment perspectives available at the therapis's interface. The perspective selected is depicted by the green text of the selected button (top right hand corner). Image (**a**): Top view perspective. Notice that a slider is shown on the right to allow the therapist to zoom in or out. Image (**b**) Free view perspective. Image (**c**) Cart View perspective (same as the patient's). Image (**d**) shows the Free view perspective, with the Camera view option activated. The smaller window show the patients view from within the cart.

System settings allow for the customization of the general options regarding the overall environment, such as: changing kart speed parameters (minimum/maximum speed and motion activation), promoting changes in the environment (scenario selection, difficulty of the tracks and which groups of objects are visible in the map), sound control (allows/blocks playback of various system sounds) and player information (which shows patient's performance during sessions).

The *Activity settings* contain the options for choosing among the three available activities—Playing Ball, Forming Words and Summation (these activities were proposed by the author S. dos Santos based on her experience as an OT). In general, in every one of the three activities available to patients, they need to focus their gaze on a virtual moving object. Hence, in order for the patient to perceive where the Oculus Rift ™ is fixated, our team added a blue square that moves along with every movement of the HMD (see Figure 5d). It indicates the focal point of the view and is positioned in the center of the patient's screen accordingly. Imaginator only considers that the patient has looked at an object (a hit) if he/she keeps the blue square on top of the moving target for a specific period of time (that can be adjusted by the therapist). Therefore, when patients have to interact with a moving object, they must move their head to focus the blue square on top of that object. When the system identifies a hit, a victory sound is played. Otherwise, the loosing sound (a car horn) is played. All of these activities intend to lead patients to move their heads, as they present them with a challenging, but playful, task.

Next we describe the rules of each one of the three activities.

- **Playing Ball**: In this game, the goal is to hit a moving ball of a specific color defined by the OT (see Figure 5a). At each hit the player's score increases and another ball automatically appears next to the player's cart. The therapist may define if all balls should be the same color, or if the balls should be of different colors (increasing the difficulty for the patient to hit balls). If the patient looks long enough for a ball of a different color the system will count it as an error.
- **Forming Words**: In this activity, the goal is to hit moving letters in the correct order to form the word shown (see Figure 5b). The OT is responsible for choosing the word in each turn of the game. Each letter is represented in the game by a virtual cube which depicts the letter in its six sides. The word inserted into the system is displayed on the patient's interface (see Figure 6a) and remains available until it is completed. Whenever the player hits a cube with the correct letter, it is instantly colored at the interface, and the next letter is highlighted. During the activity the system also generates and drops random letters that are not part of the word being formed. Imaginator also allows the OT to increase the level of difficulty of the game, by choosing the option to present the letters of the word out of order. In this case, whenever a letter present in the word is shown, the player will need to hit it. If the player hits a letter which in not present in the word it will be considered an error.
- **Summation**: In this activity the goal is to choose numbers that will add up to a predefined value (see Figure 5c). As in the Forming Words game, the numbers will be represented in moving cubes which the player will select by looking at them. The patients' interface shows the final value to be achieved, but not the resulting partial sum (see Figure 6b). Whenever players believe they have reached the intended sum, they should look at a cube that has the letter "X" stamped which is always available in the scenario so players can indicate the end of the game. If the player achieved the intended sum he/she scores, otherwise Imaginator counts it as an error. The OTs are responsible for choosing the final sum intended. They also have the choice to define a range of numbers and let Imaginator randomly choose a number within this range. The final intended sum can be changed by the OT at any moment. Furthermore, the system allows OTs to control which numbers will be used in the activity. The numbers range from (1–9), but a summation activity can be set up to spawn only the number 5, or only even numbers, or any other combinations.

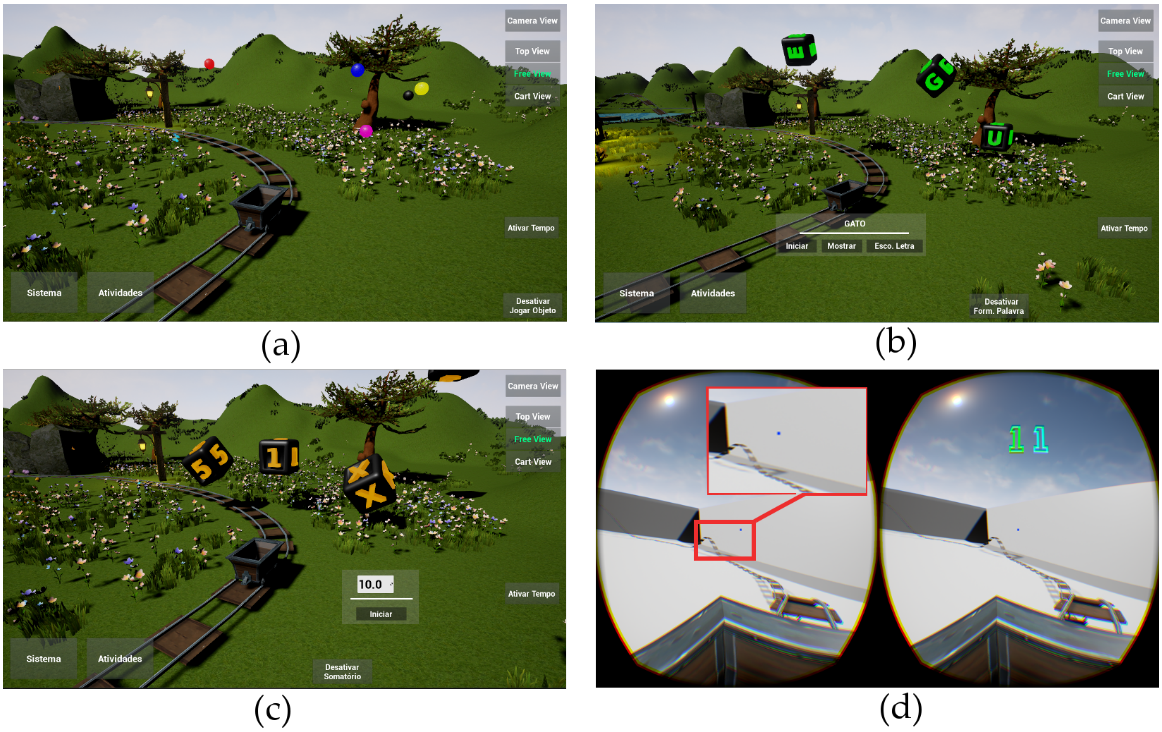

Figure 5. Images (**a**–**c**) depict the screenshots for the 3 games available in Imaginator as seen from the OT's interface. Image (**a**): Playing Ball—The goal in the example is to look at the red ball. Image (**b**) Forming Word—The goal in the example is to look at the each letter which composes the word "Gato" (cat). Image (**c**) Summation—The goal in the example is to look at the numbers until they add up to 10. Image (**d**) shows the blue squared dot present in the patient's interface to indicate the focus of the gaze being considered.

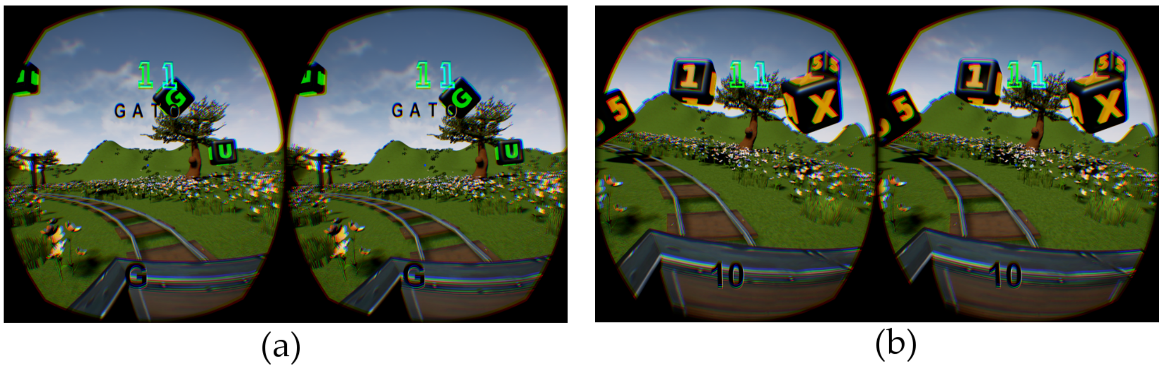

Figure 6. The images show the patients' view while executing activities. (**a**) The Forming Word activity shows in the patient's interface the word—so the patient will know the letters necessary to complete the task. (**b**) The Summation activity shows in the patient's interface the final value to be achieved.

In this section we have described the Imaginator system, as well as the possible customization choices available to the therapist. Next we present a summary of the customization possibilities available regarding the overall environment and the activities.

In regards to the overall environment:

1. Select one of the two available scenarios (The Box or Medieval).
2. Add or remove predefined groups of virtual objects available in the medieval scenario (houses, ornaments, trees and stones).

3. Turn on or off audio effects from the virtual environment (e.g., water noise, tree leafs noise, insects' noise, wind noise, etc.) or from the system (e.g., cart movement noise, the background music, ball/cube bouncing noise, hit ball/cube noise, etc.)
4. Choose among the different roller-coaster tracks, which have different amounts of ascents and descents.
5. Modify the speed of the patient's cart (i.e., the minimum or maximum velocity) or change it to an idle state.

In regards to the activities (or games) to be performed:

1. Change the color (Imaginator offers 10 different color options) of the goal object (e.g., ball, letter/number, edges or background of the cubes).
2. Modify the size of the goal object (e.g., ball, cube).
3. Change the period of time the user is required to focus on the goal object for it be considered a hit by the system (in seconds).
4. Change the period of time (in seconds) that the goal object stays in the virtual environment.
5. Change activity specific option settings (e.g., generating or not additional balls in the Playing Ball game that could confuse the patient, or shuffling the letters in Forming Word game).

In short, the options described allow OTs to be in control during patient's interaction with the system of a number of different aspects available in Imaginator. As a result, they can control the stimuli presented to a patient at a given moment, tuning it to the patient's individual needs and treatment. In the next section we present the Imaginator evaluation conducted based on OTs use of the system.

4. Evaluation

In order to validate Imaginator's performance in a real life scenario, we performed an evaluation with occupational therapists. In this section we present the methodology adopted and the results generated by the OTs experience with the system.

4.1. Methodology

The assessment of whether Imaginator would be a useful resource for SPD treatment, was performed through an initial evaluation with occupational therapists. The reason to asses the developed system with OTs was first of all, because they were a major stakeholder of the system, and would be the ones making the decision to use the system or not. Furthermore, collecting their perception and views of the experience with the system was essential, as they were the technical experts that could decide with which patients they should use Imaginator, which activities and level of stimuli should be explored, as well as to make an assessment of its impact on patients and their treatment.

Allowing OTs to evaluate the Imaginator, required them to actually use the system in their own therapy setting. Thus, in order for that to be possible, our first step was to take the system and install it at their therapeutical environment. Then we presented the system to the OT, taught them how to install and use it, and did a quick interview about their experience with technology. The system was left with them for approximately 2 to 3 weeks so they could use whenever they thought it would be appropriate. Finally, we conducted a semi-structured interview about their experience in using the system with (some of) their patients [37]. We next describe in more detail each step of our evaluation process:

- **Presentation and initial interview**: First, Imaginator was installed at the OTs workplace. The equipment was comprised of one computer (with processing level suitable to run the simulator at 75+ frames per second), two monitors and the Oculus Rift. Then we presented the system to the therapists, including its settings and features. We also, handed and explained to them a short step-by-step manual on how to initialize Imaginator. The OTs could interrupt and ask any questions or clear doubts they had. This presentation took about 1 h.

  Next, we conducted a short interview containing 8 open questions that aimed at collecting data about their profile and experience in SPD, as well as their previous experience in using technologies in treatments. Then we asked questions about their first impressions regarding Imaginator (the design and graphics of the simulator, the realism of the movements, about their feeling of being inside the virtual environment, and the sound effects). These first interviews took from 10 to 15 min.

- **Usage period**: Imaginator stayed at the therapists workplace for a period of 2 to 3 weeks. During this time, OTs should decide whether they would the system with any patient, and in case they did, with which patients, how often and how it would fit into their therapy plan.
- **Final interview**: After the 2 to 3 weeks usage period, we scheduled a time to collect the system and conduct a second interview with the OTs. The goal of this second interview was to collect data on the OTs' experience in using Imaginator in their treatments, their insights and attitudes towards the system.

  This interview's script contained 12 open questions, divided into 2 main thematic blocks: the first one was about their use of the system in therapy, and the second their views about the system itself. For the first block, we addressed questions regarding what stimuli they believe were affected by the simulator, their thoughts about applying the VR solution to SPD treatments, how they selected patients to use the system and if they perceived any benefits or costs associated to the use of the system in their treatments. For the second block, we addressed questions related to the system, such as its interface, configuration of activities and possible improvements. In average the interviews had a duration of 25 to 35 min.

4.2. Execution

We defined three requirements that should be met by participants of our study: have a formal degree as a licensed occupational therapist; have at least 4 years of experience in therapy, and have experience with SPD treatment. The recruitment was done through snowball sampling, the first participant was indicated by a member of our team, and the others through the indication of the other participants themselves.

At the end, 5 therapists were selected to participate in our study The therapists (we will use 'T' to refer to each OT to preserve their identity) were all female; their ages varied from 28 to 46, and their experience with SPD treatment varied from 6 to 10 years. All the selected therapists worked in the same city, yet in distinct neighborhoods. Its worth mentioning that all OTs reported having previous experience using technology (personally and at work). They also mentioned they had used game devices, such as tablets and Xbox Kinect, in their SPD treatments.

The interviews were conducted in Portuguese (the OTs first language) with each OT individually at their working environment between May and June of 2017. All the participants were informed beforehand of the goal of the research, how it would be conducted and agreed to participate – a formal consent form was presented and signed by each participant. The interviews were recorded, and later transcribed. The analysis of the transcript involved an iterative inter-participant and intra-participant analysis, in order to identify recurrences and categories that emerged from the participants' discourse [38,39].

4.3. Results

All of the OTs who participated in our study reported having used Imaginator with SPD patients. The patients were aged between 4–15 years, and some of them presented other comorbidities (e.g., asperger syndrome, difficulty in motor coordination, language disorder, hyperactivity, learning disorder and autism). As a result of our analysis, 9 thematic categories that emerged from therapists discourse were identified. Next we will present each one of the categories, as well as some excerpts that led to the identification of the category (the quotes presented in the paper were translated from Portuguese to English by authors).

4.3.1. Category 1: The Simulator Generates the Sense of Presence in the Virtual Space

The sense of presence in VR is when psychologically a person believes that an experience in the virtual world feels like it was experienced in the physical world [33,40]. About their initial use of the system, some of the therapists reported having the sense of presence. Therapist T1, for example, refers to the terms "rise" and "descent" as if these motions were actually occurring while she was using the simulator: *"[...] especially when we are climbing up, right? and down. Then our head goes together."*. This same sensation is repeated in the speeches of therapist T3, who felt even insecure in the face of these virtual movements: *"I felt a strong sensation at the descent [...] at some point I even had to hold on to the chair."*. Therapist T4 attempted to seek, in the real world, the existing safety support on roller coaster carts: *"[...] I put my arm on the table, thinking I had the restraint in the cart."*.

In addition, when analyzing the therapists' reports regarding their patients, it was noticed they also expressed the feeling of being in the virtual world. T3 reported that one of her patients, who had cerebral palsy, believed that he could move freely through the virtual world: *"He does not walk independently. It meant to him something surreal and he said: 'it gave me a sense of movement, of being able to control the movement alone.'"*. T1 also observed reactions of her patients to the artificial movements of the simulator: *"[...] some children held on to the chair [...] especially when they were going up and down."*. Therapist T4 reported that several patients, believing that everything they visualized was real, wanted to interact with the virtual environment: *"They asked me: 'is there any way I can go there and get the house?'—they kept asking it even after the first session: 'can I put my hand in the fire? pick up the flowers?'"*.

4.3.2. Category 2: The System Generated Stimuli in More than One Sense

All of the therapists considered that the vestibular, visual and auditory senses were being stimulated. Three of them reported having noticed stimulus in the proprioceptive sense, and two said they noticed a little stimulus to the tactile sense.

Regarding the vestibular, some therapists relate the stimuli to the head movements made by the patients. This was notorious in the speech of the therapist T5: *"[...] we move our heads the whole time with the game right? And we know the head movement stimulates the vestibular system."*. Other therapists relate vestibular stimuli to patients' reactions. T3 for example mentions one of these reactions: *"The main system is the vestibular, because there are children who felt discomfort and motion sickness, resulting from this stimulus."*.

About the visual sense, some therapists related their stimulation to the movement made by the eyes in order to focus and look for objects. Therapist T2, for example, expresses this idea: *"[...] since the child is there looking, searching, it is necessary to adjust his acuity to score points. Because it's his/her eye that will direct the point."*. Others relate the stimuli to the images generated by the system. Therapist T1, for instance, mentioned this relationship: *"The visual because it is stimulated all the time, from the trees the rocks and the lake [...]."*.

In relation to the auditory sense, most of the therapists related its stimuli to the sounds and effects existing in the simulator. Therapist T4 mentioned the need to control the sound's volume: *"[...] some patients asked me to lower the volume. The noise of the balls irritated them."*. Therapist T5, however, said sounds were important as a spatial information about the environment: *"So, for instance, I know we are getting close to the lake when we hear its sound. I know we're distancing from the lake because many of the sounds fade way [...]."*.

Regarding the proprioceptive sense, the therapists related the stimulus to the movements patients made while playing the game. Therapist T5, for example, mentioned the posture adjustment, while the patient uses the simulator: *"[...] all the time I have to rethink my posture, right? I have to adjust my posture. When I move my head backwards to look at a ball that is behind me, I have to activate muscles which rotate the trunk and to support this posture."*.

Some OTs felt the need to represent a virtual body within the game. Therapist T4 related this lack of a virtual body with the patients reactions to always want to walk within the scenario: *"I explained to them [patients]: 'look this is a computer, a game, and you are inside and outside at the same time'. But they* *didn't know where their bodies were [...]. Maybe if there was a virtual body this need to know 'where am I?' would decrease."*.

4.3.3. Category 3: Patients Felt Motivated to Use the System

OTs reported that motivation was a decisive factor in patients' acceptance of the system. This information was clear in Therapist T4's report, referring to an autistic patient with tactile hypersensitivity: *"I believed this child was not going to use the goggles as they are heavy and block vision. The first time, I let him look without putting it on his face. Then he would take it off, I would try to gradually put it on, until he accepted it. [...] He only accepted it because he noticed it was something different and liked it. It took a while to put the goggles on him. At the end he loved it, enjoyed, used it and even cried when I took them off, because he still wanted to use it."*. T2 reported that a patient did not want to stop playing, even though he felt nauseated: *"As it caused a reaction on him, we had to say you'll use the system and it will be for this long. And, when he was there he would get motivated. He was feeling nausea, but did not want to stop."*.

Therapist T1 used this motivation and patients' interest as a reward for their good behavior during the therapy sessions: *"[...] then it was even a bargain sometimes [...] look if you [patient] do not do everything right you will not have the goggles at the end."*. For some therapists, this motivation comes from patients' interest in technologies and games. Therapist T5 makes this link in her discourse: *"So they were very motivated, for children nowadays if you say the word 'technology' they already get excited."*.

4.3.4. Category 4: The System Caused Positive Changes in Patients' Behavior or Attitude

OTs perceived that, in general, the system had an effect to increase patients relaxation and helped their concentration, improving their session. Therapist T1 observed some relaxation in a very agitated patient: *"[...] she is a girl who is very agitated and every time I let her use it [the system] from 10 to 20 min [...] and when we started the session, she was calmer, and followed all my commands [...]. I noticed a big difference in terms of her organization within the therapy room. She would take much longer [without the system] to get to this point."*.

Therapist T3 describes that after the use of the system, a patient felt relaxed and sought a deeper tactile stimulus: *"After using it [the system], this boy would seek a session with a deeper use of tactile sense, he would go under the cushions, right after using it. He also does that after using the swing and after he twirled."*. Therapist T5, on her turn, observed increased concentration, which was beneficial to a patient's memory: *"With one of the patients we put some objects under cushions, but he couldn't remember which objects we had hidden, nor where they were. He went to the system and used it for about 15 min. When he came back, he was able to concentrate, and immediately remembered everything."*.

About the behavior, some therapists reported a behaviour change in patients towards real life situations. Therapist T2 mentioned a patient who, after using the system, was more willing to accept her activities and equipment that stimulated the vestibular sense: *"[...] he would go to the equipment and use it randomly. The stimulus was taking place, but he was generating it. To let us guide him, this child resisted. After he starting using the goggles, his stimulus threshold increased, he proceeded to accept our guidance on the real [physical] equipment."*. Finally, therapist T1 observed changes in relation to a patient's increased interest in experiencing similar stimuli, as well as an increase in his concentration sessions with the speech therapist: *"[...] his mother told me that they went to the park, and he asked to go into the simulator and ride the kid's roller coaster, which he had never done before [...] his speech therapist also thought that he was different that day in terms of attention and concentration."*.

4.3.5. Category 5: The System Caused Adverse Reactions in Some Patients

OTs reported that some of the patients had some negative reaction to the use of the system (e.g., headache, nausea, dizziness, sweating, euphoria, agitation and exhaustion). These reactions, according to therapists, lasted 3 to 5 min after the system was used.

Therapist T4 stated that these bad sensations also happen in the physical equipment used to stimulate the vestibular system: *"Well, it was nothing very extreme. It was expected, just as it is in other* *motion equipment. Then I would try to organize, calm down the child and bring him/her back to the session."*. There was only one report of a patient feeling nausea that lasted more then 30 min. Therapist T5 mentioned that as the patient continued to use the system, the nausea symptoms gradually diminished: *"[...] we [therapist] noticed that there was one child that complained for about 1 h. After the second time, she spent much less time complaining and more time playing. The third time, she spent even more time playing than complaining about the side effects of the game. So we think over time, it was favorable."*.

4.3.6. Category 6: Importance of Customization in the System

The system's interface was praised by all therapists. They said that it was easy to navigate between menus, as well as between the settings for the system (configuration of the environment, cart and sounds) and for the three activities. The therapists also claimed to have enjoyed the quality and graphic effects of the system.

A common positive point mentioned by therapists regarding the system is its flexibility for change and customization. Therapist T1 relates the control of the number of objects that appear in the scene with the amount of stimuli generated: *"Yes, regarding the scenario I thought it was very good, I think it is great to be able to control if we want more or less stimuli."*. Therapist T4 changed the size of the cubes to decrease the challenge: *"[...] when the activity was the one of the cubes or letters, we would change the size of the cubes that were falling, that makes it easier for them to win."*. Therapist T5 used this flexibility to aid in the auditory discrimination of patients: *"I thought it was great, because there were 2 possibilities again: lower the sound or having all those sounds in the back. Or even turn off the sounds in the back. [...] I tell them [the patients]: 'Now when you go by the lake you will hear the sound of a frog' then I would remove all the sounds but the frog's for the child that had difficulties in discriminating sounds."*.

4.3.7. Category 7: Content Diversity Is Necessary in order to Maintain Patients' Interest in the System

In general, all therapists suggested the addition of new games and activities to increase the possibilities of using the system. The point made by the OTs was that it would be necessary a more diverse set of scenarios and activities for the system to continue to be interesting in the long run.

OTs also reported that some patients lost interest in using the system after exploring all the possibilities. Therapist T3 reinforces the need for more content when reporting the requests that her patients made: *"At first they [patients] were highly motivated, then they would not even look in the direction of the computer [...]. They always asked me: 'I want something different, I want to go inside a castle, I want a vampire, I want Mickey'. Maybe if there were more options it would increase their interest."*. Therapist T5 also realized this need when asked if she would consider investing in the purchase of this equipment: *"I would have to consider, what I can do and what games the system can offer, so it wouldn't be all the same. If it had more games I would consider [buying] it."*.

4.3.8. Category 8: Suggestions for Improving the System

Besides the diversity of content, OTs had other suggestions to improve the system, such as including animated beings that users may interact with. Therapist T2 indicated in her speech that a character would make the child feel more confident to perform the activities: *"It would be interesting to have a 'little person', a character who would be waving and seeking this interaction [with the child] as well. Because, it could happen, that a child that has difficulties looking at the ball, would see the character, then the sensor that hits the ball, would hit that little person and it could even change its expression."*.

Regarding the system, the therapists reported having difficulties in turning it on to the point where the simulator was ready to be used. Therapist T5 mentioned this difficulty, and to initiate both interfaces (the therapist's and the patient's): *"I thought it takes too long to start and I have to go to one screen, to another screen, then I have to go from one place and pull it [the interface window] to the other place."*. Therapist T1 had difficulties with dealing with the two screens: *"The only thing I found harder, is that sometimes I forgot where the mouse was [because of having two screens]. [...] these two screens, one is the continuation of the other."*.

4.3.9. Category 9: Therapists Would Consider Using the System as a Resource for Treatments

All therapists stated that they would use the system to improve symptoms of SPD. However, this use is not limited to SPD only. Therapist T3 states that she would use the system for the treatment of autism, movement limitations, difficulties in literacy and learning: *"I would mainly use for autistic treatments, for patients who are poorly motivated towards getting alphabetized. [...] I would use it with children with learning difficulties in the phonic method. [...] I also found it a very nice resource to use with patients with limited movement. But I would have to experiment more to confirm."*.

Therapist T1 mentions that she would use the system to improve patients' cognition: *"Yes, I would use it, even as another stimulation resource in Sensory Integration Therapy, in regards to the vestibular, visual and all stimulation part, as well as in the cognitive side."*. Therapist T5 would use the system to support the modulation of the vestibular, and also because it is an attractive technology for children: *"I would use it a lot with children who have vestibular hypersensitivity, to see if we can achieve what we call modulation [...]. And I would use it even more, because this technology is part of the daily life of these children, and will be increasingly more so."*.

The above categories describe the topics that emerged from the interviews. Next a broader discussion of these findings is presented.

5. Discussion

In this section we discuss the results from our evaluation. To do so, we have organized our discussion in two main topics: the perceptions of the OTs regarding the use of Imaginator in SPD treatment, and their comments (criticism and suggestions) about the system itself.

5.1. Use of Imaginator in SPD Treatment

One of the topics investigated through the interview was the OTs perception of the immersion generated by the system. Overall they believed that the Imaginator provided a sense of presence, both for the patients and the OTs, and they mentioned that they believed that the Oculus Rift was the main reason for it. As a result, we can classify the Imaginator as an immersive system. Providing immersion in SPD treatments is a relevant contribution, as it can support the sense of presence and create real sensations for the patient. The higher the sense of presence and immersion, the greater the probability that patients will behave in the virtual world, as they would in the physical world [40]. Thus, because of the immersion it provides, the Imaginator allows OTs to explore with patients how they process the different senses, while interacting with the VR environment.

With respect to the senses' stimulation, OTs reported that the system was able to stimulate five senses: Proprioceptive, Tactile, Visual, Vestibular and Auditory, but more intensely the last three. This multisensorial feature of Imaginator is a positive aspect for SPD therapy, as one of the issues that OTs may need to work with SPD patients is improving their ability to integrate the processing associated with one or more senses being stimulated at once.

Imaginator presents players with images, sounds and requires them to move their heads to play the games. Therefore, we knew it would stimulate the visual, auditory and vestibular senses. However, it is interesting to note that the vestibular sense was stimulated not only by the required head movements, but also through the other senses, mainly the visual sense. This conclusion was associated to the fact that some players presented reactions such as nausea, sweating and dizziness which are commonly associated with cybersickness [41].

Cybersickness associated to the use of VR is a concern not only in the VR industry [42], but specifically in relation to its use in therapy and rehabilitation [43,44]. Although there is no consensus on the cause for cybersickness [41,45], sensory conflict theory which attributes it to the discrepancies between the senses causing a perceptual conflict in the sensory processing [41] is the most accepted explanation [41,43,45]. Studies indicate that cybersickness after-effects are common, and that its occurrence is associated to a combination of different variables ranging from individual characteristics to technical aspects of the system [44]. However, to the best of our knowledge, there are no studies that indicate that VR systems and cybersickness can be harmful to SPD patients or children.

Furthermore, SPD typical treatments involve stimulating the vestibular sense, in addition to other senses, so that the brain will naturally reorganize, and better modulate the incoming stimuli [1]. Thus, it is common for patients to experience gravitational insecurity, motion sickness, intolerance/increased tolerance for physical movement when using physical equipment, as mentioned by one of the OTs. In the Imaginator system, the users' vestibular sense is stimulated through head movements necessary to play the games. However, this stimuli might still be in conflict with stimuli being sent to the visual sense, as it is not associated with the movement of a roller coaster. Therefore, the conflicting stimuli which is probably not natural in the physical world, could represent a problem of using such a system as part of SPD treatment. This issue needs to be further investigated. In this direction, one aspect that could be considered is the impact of proposed solutions to diminish cybersickness, by controlling the visual stimuli presented to users (e.g., [46,47]).

In our study, exposure to stimuli in the VR environment also caused some positive behavioral changes in patients, such as the willingness to accept other vestibular stimuli equipment used during therapy or even to experience it through other activities (e.g., going in rides in an amusement park). It is worth noting that the vestibular sense is the one that unifies all other types of sensations that are processed in reference to this basic vestibular information [2]. Therefore, stimulating the vestibular sense is an important aspect to be worked on in therapy.

Our analysis also indicates that the system motivated patients to use it. In some cases, the OTs even used the system to reward patients' for their good behavior during therapy. Hence, we concluded that patients enjoyed and wanted to use Imaginator, at least for the brief period during which it was available to them. Keeping patients motivated is important in SPD's treatment, as it will keep patients engaged in the activity proposed by the OT, allowing them to achieve the goal of the treatment [3].

None of the OTs mentioned any of the patients not being interested in using the Imaginator. Nonetheless, currently, the system only offers to players 3 games and 2 scenarios. Thus, OTs mentioned that some of the patients lost interest after they had played all the games. The fact that the mechanics involved in the different games were the same, may also have contributed to patients' loss of interest. These results indicate that for the system to be used for a longer period of time it would be necessary to make a broader range of activities available to players.

One of the effects that a few of the patients experimented was relaxation. OTs considered it a positive effect during sessions, as it allowed for an increase in concentration and helped memory related activities. Albeit beneficial, it is not clear what (aspect of the game) caused the relaxation and during the interview we did not explore OTs views on possible causes. Also, as the system was only used for a short period of time, it is not possible to know whether it would be a persistent effect (or not) in a long-term use of the Imaginator.

On the negative side of effects, OTs reported that some patients experienced agitation, euphoria and exhaustion. Different patients had distinct reactions. OTs report did not suggest that there were any patterns in their occurrence. Some of the reactions occurred in isolation, whereas others took place at the same time. On all accounts, their duration was short—3 to 5 min (except for one case in which it was longer) and OTs considered them to be temporary. Furthermore, OTs considered these reactions ordinary, as they also can be observed during other regular therapeutic activities.

At any rate, these different reactions, positive and negative, reinforce the need for future long-term investigation regarding the use of the system. Among the aspects that should be considered in such an investigation, would be to try to identify what are the factors that could be coming into play in triggering each one of these reactions. Being able to understand the contexts in which each reaction could take place would be a relevant piece of information for OTs when deciding how to use the system and how to integrate it with other activities.

Overall, OTs were unanimous in stating that they believed Imaginator was an interesting resource for sense stimulation in SPD treatment, and even for other comorbidities. Their interest is a positive indicator of the usefulness of the system in the context of SPD treatment. It also would justify investing in broadening the range of activities available, as well as creating a more complete and robust product. The OTs main concern in regards to the use of Imaginator would be the financial cost entailed in acquiring such a system.

5.2. Comments on the Imaginator, Criticism and Suggestions

In regards to the therapist's interface in the system, OTs considered it simple and easy to use, including the customization related actions. They considered the customization a relevant and positive feature of the system, as they mentioned the need to tailor activities to each patients' specific treatment needs. Their explanation confirmed the results found in the literature that allowed us to identify customization as a system requirement in the first place.

Participants also considered that the patients interface was easy for them to interact. Nonetheless, they pointed out that the limited amount of activities available caused some of the patients to lose interest after having interacted with them. As mentioned before, in order to consider the use of Imaginator as part of long-term treatments (and a worthy investment for OTs) it would be essential to broaden the set of games and activities, as well as scenarios and interaction options.

In addition, OTs identified and suggested new features for the system that could be useful in SPD treatment. In that direction, two of the OTs mentioned that including the possibility of the patient having a virtual body within the system would be interesting (currently users only have a first person view of the environment). A virtual body could allow them to explore different aspects in relation to the proprioceptive sense, as a movement in the physical world, would also cause changes in the virtual world [2]. Although a virtual body had not been considered in the initial plans for the system, we can see how this suggestion is relevant. This possibility could even increase the sense of embodiment, the feeling of being inside and owning the virtual body [48], which can also increase the feeling of presence [40].

Another interesting suggestion was to include animated agents (e.g., people, animals or characters) in the virtual world. These agents could open a new set of aspects that could be tackled during therapy with the system. For instance, if the agents would interact with the patient, and better yet, the level of interaction could be customized, OTs might be able work on social interaction issues that often are associated to SPD or other common comorbidities.

In Imaginator, customization allows existing sounds to be turned on or off at any moment. Nonetheless, one OT reported that the sound associated to the bouncing objects was very irritating. As working with sounds can be relevant in SPD treatment, even when they may be uncomfortable for patients (e.g., hyperacusis patients) [49], it might be interesting to include in the system more customization options, such as changing its volume or allowing OTs to choose the sound associated to different events (e.g., hit/error sound or bouncing object sound).

Finally, some of the OTs mentioned they experienced difficulties in setting up the system before using it (i.e., initializing the system and its initial settings). The initialization process can be described in four steps:

1. Turn on the computer (using the two monitors setup), and wait for it to initialize the operating system.
2. Log into the computer through one of the monitors (one of them had password) and wait for the interface of the Oculus Rift to be initialized.
3. Initialize the OT's interface by clicking on the specific icon, and then dragging its window to the second computer monitor.
4. Initialize the patients' interface, by clicking on the specific icon, and once it was running, disable the security message that appears within the HMD.

Although the initialization procedure involves four steps, which could be considered fairly simple, it can still be challenging for the OTs. The operating system can have impediments, and in the current version, the patients and OTs interfaces are overlapped on the same screen when they first open. Thus, the OTs must realize they are both there (even if they cannot see both at the same time) and drag one of them to another position. Thus, even though a step-by-step script was given and explained to each OT when the system was installed, it was still a negative aspect in their experience with the system. Therefore, it would be interesting to automatize the entire procedure, making it simpler for the therapist to get it started.

6. Conclusions

In this paper we investigated the use of virtual reality games in the context of sensory processing disorders treatment. The first step in our investigation was to identify through a literature review the main requirements for such games. The two most important requirements identified were: (i) for it to be a multisensorial system, as it would be used to stimulate patients' senses (diverse sensory systems and more than one at a time); (ii) for it to allow OTs to tailor the stimuli a patient would be exposed to at any given moment.

In light of these requirements, we developed the Imaginator system which is a very adaptable roller coaster simulator, with game activities connected to the Oculus Rift HMD. Although the technology involved in building the system is not a novel contribution of this paper, the fact that is aimed at supporting SPD treatment is a relevant and original contribution of this research.

In order to analyze the usefulness of our system, we conducted a qualitative assessment with occupational therapists. The process included 5 therapists using the system as they found appropriate with their patients over a two to three week period, followed by an interview about their experience. The results indicate that therapists found that the Imaginator system was an interesting resource to be used in the treatment of SPD. Mainly their reports indicated that besides being able to stimulate five different senses, it was very motivating to patients, which is a factor of great importance in the treatment. They also mentioned that they considered the possibility for them to customize the activities essential to its use. Therapists also contributed by suggesting improvements that should be made to the system to allow it to be used for a longer period of time (before patients lost interest), or even broaden the therapeutic activities it supported. They all stated that they would be interested in having such a system available as a therapeutic resource, but they all expressed concern with how much it would cost and if it the cost would be feasible.

As described in our Related Works section, virtual reality systems have been used in a broad range of health related therapies. Nonetheless, to the best of our knowledge, our work is the first to develop an immersive, highly customizable system aimed at supporting SPD treatment. Thus, it contributes to the research on the field of games applied to health by identifying the main requirements for such systems; developing a functional game that can be used (albeit its current limitations); and also identifying other relevant aspects that could improve its usefulness, based on the OT's experience with the system. Moreover, as SPD frequently co-occurs with different disorders (e.g., autism and ADHD), the Imaginator system itself, as well as our findings can be useful to other researchers interested in technological applications for health therapy or developers that would like to turn our system (or similar ones) into a product that could be more widely available.

While the analysis of the therapist experience with the system yielded interesting and promising results, it can be considered a preliminary evaluation. Although the OTs are not the primary end user of the system, they are the stakeholders who will make decisions if and how the system should be used. Therefore, collecting their opinion is essential to direct the development of such systems. Our assessment only involved five participants, thus it would be interesting to conduct a longer term study in a controlled clinical trial. In order to do so, it would be necessary to further investigate the potential implications of the cybersickness experience, and whether its cause, probably the conflicting sensory inputs, is a problem or not.

In order to perform more detailed and long-term evaluations of the system, it would be necessary to review the existing version of the system, taking into consideration the main points that emerged from our initial evaluation. The first step would be to include more scenarios and games, as well as allow for a more fine tuned tailoring of some of the stimuli (e.g., auditory senses). Also the system should be better instrumented to collect relevant data about players performance that could help not only in defining the next steps in their therapy, but also be used to evaluate the impact of the system. We also plan to include more VR technology that would allow for hand and body movements to be considered in the system, and in the therapy with Imaginator.

Finally, there are a number of new investigation possibilities that would be interesting as future direction for the research presented in this paper. One possibility would be to investigate the other suggestions that would broaden the system's application, such as the inclusion of a virtual body and the introduction of animated agents within the scenarios that would be able to interact with users. In the direction of broadening the system's application, we could consider extending it to include support for other therapies, such as speech therapy, by adding new games and activities that would require the user to speak. The introduction of animated characters could include an investigation towards the development of intelligent agents that could foster patients' participation in the activities or interaction with them. It might also be interesting if an end-user programming environment was created to support Imaginator, allowing therapists themselves to create new activities to be added to the system. In addition, one possible future direction would be to include machine learning algorithms to understand the patient's movements within the system. This could open possibilities related to more precise ways of measuring patients' performance or to defining the next steps in the activities or therapy. It would be interesting to investigate if, based on players previous interactions and achievements, the system could automatically adapt some aspects of the activity for that player, or suggest to the therapists possible changes in the activities or levels to be explored with the patients or even next steps in the therapy plan.

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Abbreviations

The following abbreviations are used in this manuscript:

ADHD	Attention Deficit Hyperactivity Disorder
ASD	Autism Spectrum Disorder
HMD	Head Mount Display
OT	Occupational Therapist
SPD	Sensory Processing Disorders
SSD	Speech Sound Disorders
VR	Virtual Reality

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