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# A Virtual Environment to Motivate Children's Handgrip

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***ABSTRACT :*** *The objective is develop and test a device associated with a virtual environment to rehabilitate in a playful way the manual hand grip movement of children. For this, the Unity 3D and Maya graphics tools were used to design and to interact the characters with three-dimensional objects in the virtual environment. The virtual environment and the device were tested by 21 volunteers without motor impairment from 6 to 12 years old (9.0 ± 2.05) (Group A) and 12 volunteers with motor impairment from 5 to 18 years old (9.58 ± 3, 73) (Group B).As a result, all volunteers of Group A performed the 3 phases of the virtual environment with an average time of 56.48s in Phase 1, 66.52s in Phase 2 and 84.67s in Phase 3. Analyzing the data from the 3 phases of Group A, it was possible to observe that the result was statistically significant (p <0.0001). The volunteers of Group B performed only Phase 1 of the virtual environment in an average time of 90.17s. After performing the comparison between the results of Group A and B a p value less than 0.0001 was found, being statistically significant in phase 1. In addition, according to the evaluation of the system by the facial hedonic scale performed by the group B, 91.67% of the participants pointed out the "love it" facial expression and 8.33% the "liked it". Therefore, initial results demonstrate that the system has pleased by patients, showing to be efficient to playful rehabilitate children.*

***KEYWORDS*** *Game Therapy, Serious Game, Motivation, Cerebral Palsy.*

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## I. INTRODUCTION

The hand grip movement can be defined as the ability to grasp and manipulate an object while applying manual force on it [1]. This movement is essential for performing daily activities such as feeding and hygiene [2]. However, 60% of children with cerebral palsy indicated for physical therapy have a limited hand function [3].

In the rehabilitation context, evidence shows that therapy performed with repetitive exercises can substantially improve the manual function of patients with neurological impairment [4-6]. However, the monotony of this type of therapeutic approach has been the main cause of treatment quit by patients, who claim little motivation with traditional methods [7].

For Colombo et al. [8] motivation is a determining factor in the results of rehabilitation. Thus, identifying methods capable of encouraging individuals with cerebral palsy to perform exercises is critical to help them to improve their motor control and independence [9].

Thus, modern technologies using virtual environments appear as an alternative to optimize patients' adherence to treatment [10, 11]. With this in mind, several computerized tools have been developed for hand rehabilitation [12, 13]. In Colombo et al. [8] and Friedman et al. [14] games were designed for training hand gripping movements and pinch. However, these games are targeted to adult patients who have had a stroke.

Therefore, the objective of the present study is to develop and test a device associated to a virtual environment aimed to the children's audience, capable of rehabilitating, in a playful and interactive way, the hand grip movement.

## II. MATERIALS AND METHODS

The developed system consists of a device that gathers the palmar grip strength and reports the strength intensity to the virtual environment. Strength intensity is directly proportional to the speed of a character's movement in the virtual environment.

**Development of the Virtual Environment**

For developing the game, it was used a life cycle in the cascade model (Fig. 1), in which three phases of the game cycle are executed sequentially. However, this application can be interrupted at the end of each phase and a simple push of the device to be enough to the character starts to move again in the virtual environment. In addition, to motivate the volunteer, a trail of candy and sweets was pre-set in the path. The goal of the game is to reach the end in the shortest time and with the highest number of items collected.

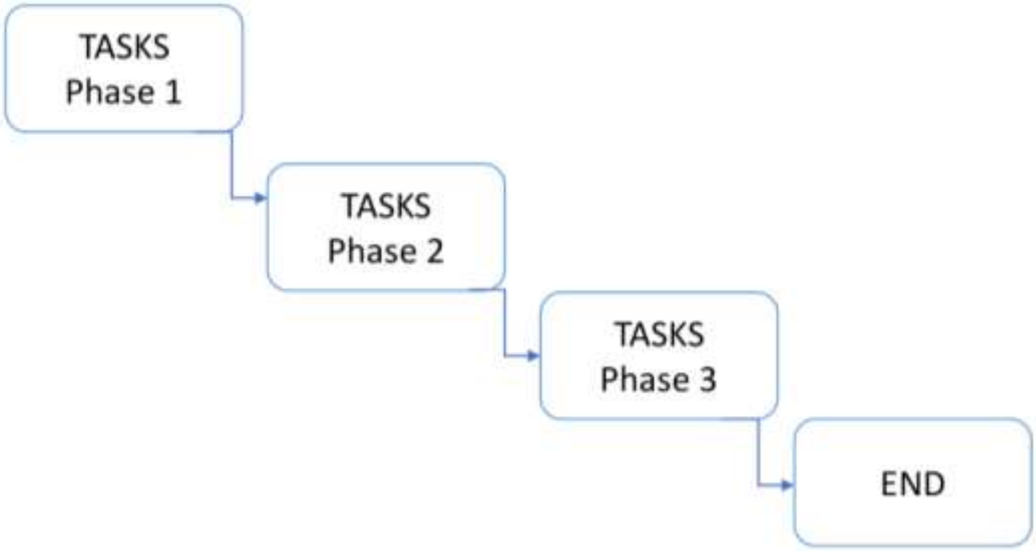


**Fig. 1. Life cycle in the cascade model.**

For children to assimilate the movements proposed to them in the virtual environment and in the device, the character reflects movement graduations according to the gripping force exerted on the device. Thus, in rest stage the character is immobile, when a slight change in range of movement is performed the character moves slowly and when performing the maximum displacement of the range of movement the character moves faster.

For modeling of the main character, the Maya®4 tool was used, implementing modeling techniques from a previously elaborated sketch with its main characteristics (Fig. 2A). The process of mapping textures using any 3D tool makes the modeling process more realistic (Fig. 2B). The textures applied on the character were solid and vibrant colors (orange, brown and black) to look like a plush toy (Fig. 2C).

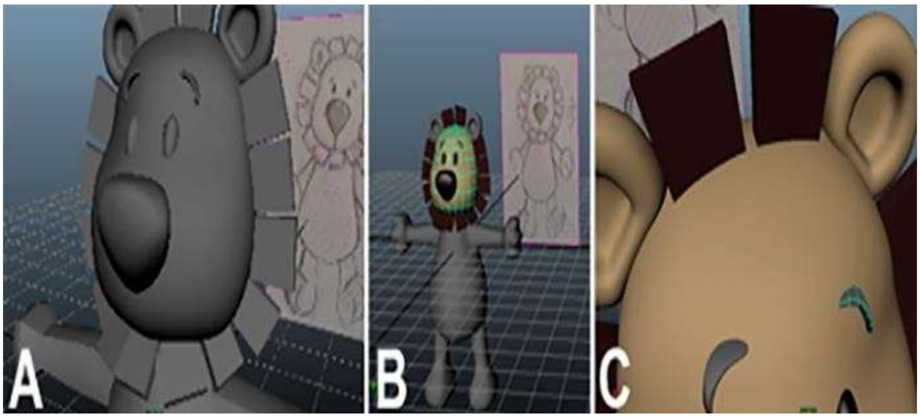


**Fig. 2. Modeling techniques: A: Sketch with the main characteristics of the character; B: Character modeling process; C: Textures applied to the character.**

After the modeling and texturing process, the models must allow deformations in their meshes naturally. Thus, the entire process of moving the joints of the character was also developed using the Maya® tool, allowing a more realistic movement (Fig. 3).

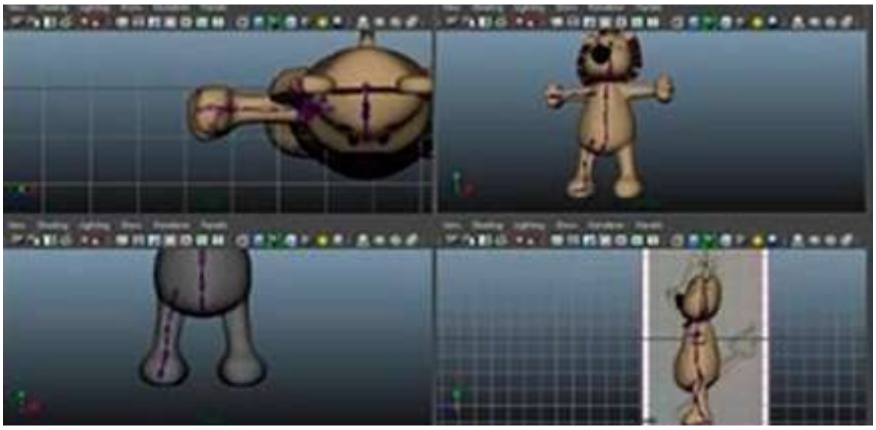

**Fig. 3. Process of elaborating the articular movement of the character.**

With the help of the animation editor Maya®, it was possible to apply more details about the movements of the feet, ankles, knees, hips, shoulders, elbows, and head of the character, allowing a biomechanical aspect closer to reality. After that, the character was exported as a rendered (texture-mapping process) and animated model to the Unity 3D game management tool.

The Unity 3D three-dimensional content modeler features were used to model the mountains of the scenario with distinctive characteristics in each phase of the game (Fig. 4A and B). This allows a better interaction of the player with the virtual landscapes environment.

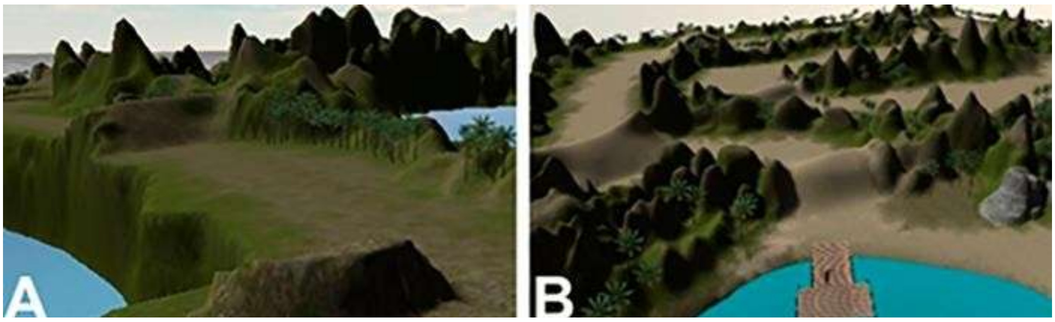


**Fig. 4. A: Scenery with small hills; B: Scenario with intermediate hills.**

The phases of the game have obstacles such as different elevations that allow a gradual increase of its difficulty, visually stimulating the volunteer to perform a more intense hand grip movement in the device to reach the top of the hills as the phases progress.

**Device Development**

To stimulate the child to perform the hand grip movement properly, the Pivot Hand Grip device (DR-HG005 from Brand New) was selected. It has two handles hinged to a pin, containing inside it a spring that provides difficulty during the hand grip movement. Seeking the suitability of the device for children, the spring inside the device was replaced by two springs with lower elastic force. With this, some tests were carried out to verify how much force would be required for the total displacement of these springs.

For this, a Dynamometer - Portable Electronic Scale (Weiheng), and calibrated weights of 50g and 100g were used. The tests were performed for the 4 levels of difficulty present in the device, being repeated 3 times and so the mean value was calculated.

The choice of thewas based on was based on the studies made by Moura [15], that evaluated the hand grip strength in different age groups of children, reaching a mean of 6.93 kgf for pre-schollschildren, in school age 14.18 kgf for middle school children and 34.37 kgf for adolecents.

Analyzing this information, a spring with a force of 1,120 Kgf was drawn. This spring enables the required displacement to the difficulty level 1 of the device to be achieved. In this way, as the child must keep the device pressed to activate the virtual environment, this spring will generate less effort to the child during the movement, thus avoiding muscle fatigue during the rehabilitation process.

**Device Characterization**

A potentiometer was added to the device to detect the force of the handgrip movement exerted by the volunteer by means of the angular variation, and to reproduce in the virtual environment a movement with a velocity proportional to that force (Fig. 5).

**Fig. 5. Sensor arrangement (potentiometer) installed in the device.**

Pressing the device handles automatically activates the potentiometer stem, generating a variation in the electrical signal through a GAMEPORT - LeaderShip USB converter. In this way, the data generated by the device is sent to a computer, and the character's activity in the virtual environment is executed.

**Application of the Functionality Test and Usability of the Virtual Environment and Device**

This study was approved by the Research Ethics Committee of the University of Mogi das Cruzes (CAAE: 41250915.0.0000.5497). The sample consisted of 33 volunteers, divided into group A (evaluation and usability) and group B (functional test). Only the volunteers whose parents or guardians signed the free informed consent term and the consent term were part of this research.

Group A consisted of 21 male and female individuals, from 5 to 12 years old, without musculoskeletal and neurological alterations, able to understand the guidelines for performing the game tasks. The group B was formed by 12 volunteers, patients from the physiotherapy school of the University of Mogi das Cruzes, female and male, aged between 5 and 18 years, able to understand the guidelines to perform the game tasks, and to be able to perform the handgrip on the device.

In addition, to evaluate the developed system, an opinion consultation was carried out with four specialists, two physiotherapists and two software engineers. For this, they answered a Usability questionnaire based on the SUS (System Usability Scale) form [16], composed by 10 usability related statements, where each question receives a score from 1 to 5, ranging from strongly agreeing to strongly disagreeing.

To perform the tests with group A and B, the subjects were instructed to remain seated with their feet flat on the floor, with their trunk erect and supported on the back of a chair, and in front of a table containing the computer and the device . Initially, a demonstration was performed regarding the manipulation and actuation of the device, and latter on the instructions about the phases of the virtual environment.

The volunteers from group A performed the tests in their own residence in the presence of the researcher and the person in charge. As the purpose of the tests with this group was to verify the effectiveness of the gradual increase of difficulty between the three phases of the game, all the volunteers started the game in Phase 1, and they evolved to the other phases, adopting an interval of 1 minute rest between them.

The volunteers from group B underwent the test in a room of the Polyclinic of the University of Mogi das Cruzes, after finishing their rehab session, in the company of its person in charge. As the objective of the test with this group was to verify if they could use the device and the virtual environment, and to identify their satisfaction with the proposed system, they performed only Phase 1 of the game, and a sensory analysis evaluation was made using Graduated facial hedonic scale from 1 to 5, where facial expression 1 refers to detested, 2 did not like, 3 indifferent, 4 liked and 5 loved.

**Statistical analysis**

To verify the normality of the sample, D'Agostino's statistical test was applied. The analysis of the variance between the phases of group A was performed through the Kruskal-Wallis test. The Wilcoxon-Mann-Whitney test was used to compare groups A and B in phase 1. For all analyzes, $p < 0.05$ was considered.

## III. RESULTS

**Computerized Virtual Environment**

To motivate and arouse the volunteer interest, the beginning of each phase of the game shows a different scenario (Fig. 6). As you move the character along the path, the player will encounter caramels and candy that can be collected. A sign that counts the number of collected candies is shown in the upper left margin of the screen.


**Fig. 6. Scenario with initial screen of Phases 1, 2 and 3.**

When approaching the end of each phase the character finds a table with several goodies, and at the end of phase 3 the volunteer comes across a screen that displays the word "Won", with the purpose of congratulating him for the performed task. (Fig. 7A and B).

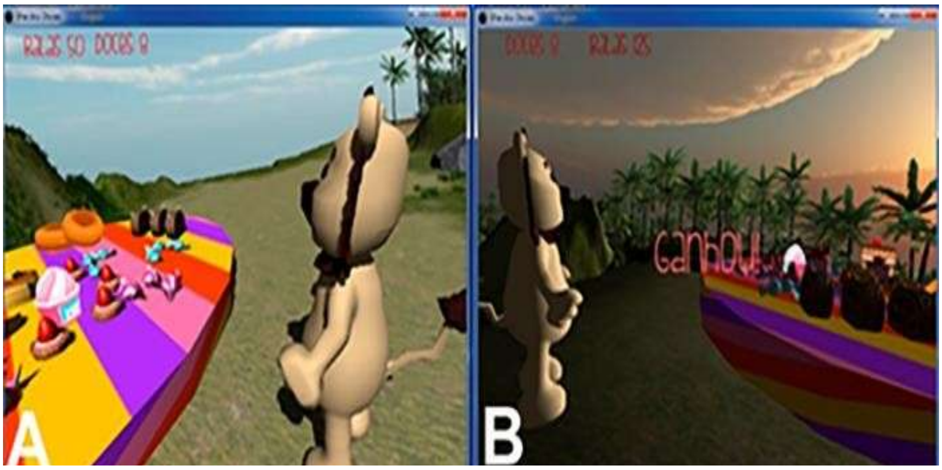


**Fig. 7. A: Final screen of Phases 1 and 2 containing a table with the delicacies marking the end of them. B: Phase 3 final screen with a motivational incentive.**

**Device**

To connect the device to the computer a DB15 connector, an analog / digital signal converter and the USB output were used, making the computer recognize it as joystick Thus, when the game is triggered through the device, the computer recognizes and performs the functions that are determined. That way, when there is no pressure the character stands still, when there is a small pressure on the device the character walks slowly, and when a movement is made in the total amplitude of the device the character accelerates his steps.

**Virtual Environment and Device Usability Testing**

Although only four experts have evaluated the virtual environment and the device, according to Nielsen et al. [17], this number of participants makes possible to identify 80% of the usability problems of the system, which satisfies our purposes. Table 1 shows the results of expert assessment.

| Table 1. Evaluation of specialists by the SUS | |
|---|---|
| **Experts'** | **Score** |
| 1 | 85 |
| 2 | 100 |
| 3 | 85 |
| 4 | 97,5 |
| average | 91,8 |

In the System Usability Scale (SUS), scores below 60 points represent systems with relatively poor experiences and user dissatisfaction, and scores above 80 points represent very good experiences, with an elevated level of satisfaction among those involved. Thus, it is observed that all the specialists evaluated the developed system as very satisfactory.

After the experts' evaluation, the evaluations of groups A and B were started. Group A consisted of 21 volunteers aged between 6 and 12 years ($9.0 \pm 2.05$), 61.9% were male and 38.1% female. The Table 2 shows the data referring to the mean execution time in each phase of the game according to the age groups.

| Table 2. Time of Play of group A in the different phases | | | |
|---|---|---|---|
| **Age group** | **Phase 1 (s)** | **Phase 2 (s)** | **Phase 3 (s)** |
| 6 years | 70,33 | 84,33 | 145,33 |
| 7 years | 53,33 | 57,67 | 64,67 |
| 8 years | 82 | 77 | 86,33 |
| 9 years | 53,67 | 60,67 | 73 |
| 10 years | 43 | 67,33 | 74,33 |
| 11 years | 47,33 | 59,67 | 78,67 |
| 12 years | 45,67 | 59 | 70,33 |

Phase 1 was traveled by the volunteers in a mean time of 56.48 seconds, Phase 2 in 66.52 seconds and Phase 3 in 84.67 seconds. As the data in Table 2 are non-parametric, the comparison between the data obtained in the three phases of the game by group A was performed by the Kruskal-Wallis test, being statistically significant ($p < 0.0001$).

Based on these results, it is noted that the individuals took a longer time to walk through the phases as they advanced, demonstrating that the goal of gradually making the phases more difficult was achieved.

Group B was composed of 12 patients, aged between 5 and 18 years ($9.58 \pm 3.73$), being 66.67% male and 33.33% female, where 66.67% were diagnosed with Encephalopathy Non-evolutionary chronic and 33.33% were diagnosed with other neurological diseases.

According to Table 3, it can be observed that all the volunteers were able to use the device and evaluated the virtual environment in a positive way, with 91.67% of the participants pointing to the facial expression I loved and 8.33% I liked.

| Table 3. Time to go through phase 1 by group B and classification by graded facial hedonic scale | | |
|---|---|---|
| **Volunteers** | **Phase 1 (s)** | **Facial expression** |
| 1 | 70 | I loved |
| 2 | 66 | I loved |
| 3 | 88 | I loved |
| 4 | 104 | I loved |
| 5 | 81 | I loved |
| 6 | 126 | I loved |
| 7 | 71 | I liked |
| 8 | 78 | I loved |
| 9 | 72 | I loved |
| 10 | 147 | I loved |
| 11 | 103 | I loved |
| 12 | 76 | I loved |

When comparing the results obtained in Phase 1 of group A and B, it was observed that group A had a mean execution time of 56.48 seconds and group B of 90.17 seconds. Thus, the Wilcoxon-Mann-Whitney test found a significant difference ($p < 0.0001$) between the time in the execution of the tasks proposed by groups A and B, showing that group A had greater ease to perform the Phase 1.

Thus, these findings corroborate the hypothesis that the present device may contribute substantially to the motor recovery of patients with neurological impairment. If, in order to go through the phase of the virtual environment, the individual needs to be performing the handgrip movement, the longer is the time to excute the phase, the longer the volunteers will be performing the proposed task, thus contributing to patient-specific task, which is positive for recovery.

## IV. DISCUSSION

According to the findings of this study, based on the SUS scale [16], the specialists evaluated the device and the virtual environment as a satisfactory system capable of bringing great experiences to the user. Thus, these findings corroborate the hypothesis that individuals with motor impairment of the hands can benefit from the use of this tool, since no usability problems were identified in the developed system.

One of the major difficulties in the rehabilitation of children with cerebral palsy is to keep them focused on the tasks, especially in the case of repetitive exercises, which have the most scientific evidence for functional recovery [18]. However, this virtual environment study allowed the therapist to take the volunteer's focus from the handgrip movement, and to establish his interest in going through the phases of the game, since the obstacles created in the scenario were able to stimulate the handgrip movement in a playful way.

The patient motivation is fundamental within the process of rehabilitation, favoring the individual´s adherence to the treatment. Thus, similarly to this study, Colombo et al. [8] developed a device that detects the force exerted by the volunteer and produces in the virtual environment a movement with a velocity proportional to the intensity of that force. However, the game design by Colombo et al. [8] is composed of only three circles with different colors, which is not enough to catch the children's attention. In contrast, the virtual scenario of the present study consists of candys, sweets and stuffed animal, being more appropriate for the children's audience.

According to the evaluation of the system by the facial hedonic scale performed by group B, 91.67% of the participants pointed out the facial expression of love it and 8.33% liked it. This shows that the device associated with the virtual environment developed in this study is pleasant to the patient with cerebral palsy, motivating him to adhere to the treatment.

In a recent study, Friedman et al. [14] developed sensitized gloves for the rehabilitation of handgrip movements in a virtual environment. However, children with neurological injuries usually present muscle contractures [19], adversely affecting the motor function of the hands [20], which makes it difficult to use these gloves, since they can cause discomfort to the user.

Thus, in the game developed in this study, the interaction of the player with the virtual environment occurs through a easy handling device, which allows children with different degrees of motor impairment enjoy this tool with greater convenience.

## V. CONCLUSION

In this study, a device associated to a virtual environment was developed and tested to recreationally rehabilitate the handgrip movement of children. Initial results demonstrate that the system has pleased both experts and patients. However, in future studies it is necessary to apply the system developed in a larger number of children to prove their effects.

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