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Grip and pinch capability assessment system for children

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ABSTRACT

The grip movement is essential for performing daily activities. However, the assessment of this movement is currently made subjectively, due to the lack of appropriate quantification equipment. The objective of this study was to develop, validate and test a virtual environment controlled by five trigger devices used to analyse cylindrical, spherical and hook grips as well as tip-to-tip pinch and pulp-to-side movements. Sensors and electronic circuits that detect the correct grip, the threshold of grip strength and the range of motion were inserted into the devices. To validate this system, tests were conducted with 20 children while being evaluated by three physical therapists, all specialists in neurology. The results from the evaluators and the system agreed to an extent of 86.6%. Following validation, the system was used by 35 children with no motor impairment and by 10 children with mild motor abnormalities in an upper limb; these assessments provided efficient and reliable results. The developments presented in this study may help to assess grip and pinch movements and facilitate the choice of strategies in therapeutic processes.

1. Introduction

The grip movement is achieved through the functional application of forces made by the hand around an object to perform a certain function [1]. In humans, such movement, which is essential for performing daily activities [2], is initiated voluntarily from the age of 4 months and resembles the movement of an adult by the age of 7 years. However, tone changes, muscle weakness, sensory deficits and motor coordination failures can affect grip and pinch movements [3].

The evaluation of upper limbs has several purposes, including tracing the goals of treatment, guiding treatment planning, checking the effectiveness of therapeutic intervention programs, readjusting the therapeutic approach and obtaining data to assess the progress of the patient [1,4]. Thus, the development of reliable instruments to adequately quantify the movements to be rehabilitated is necessary.

Functional evaluations of the hand are performed in most rehabilitation centres through interviews, questionnaires, observations of the functionality of the movements executed in daily activities [5–7] and tests requiring the manipulation of objects. These tests include fitting and lifting blocks, picking up small objects such as beans, using a pencil closing bottle caps and other similar manipulations [8]. Unfortunately, the subjective nature of these functional assessments may result in variations in the interpretation by the observer.

Cutting-edge technologies have been used by several authors to develop objective assessment tools, including kinesiology, which is often used to analyse movements. However, kinesiology laboratories are primarily focused on assisting with the rehabilitation of the walking process; the evaluation of the upper limbs in these laboratories remains at a primitive stage [9]. Thus, some authors have developed kinematic systems to assess the reaching and cylindrical gripping movements of the hand during object manipulation [1,10], yielding good results; however, these systems are not available for use in the daily clinical routine or in outpatient rehabilitation. Other technologies have been studied for use in electromechanical systems for the assessment of grip force [11–13] and to control the grip strength of patients undergoing rehabilitation [14]. Nevertheless, the elaboration of efficient therapeutic approaches for hand rehabilitation necessitates the quantitative assessment of other types of grip and pinch movements.

Technological advancements in computer systems and virtual environments are particularly applicable for assessments of children, as compared to conventional technologies, because they provide function, motivation, discovery and autonomy [15,16].

Thus, the objective of this research was to take advantage of the new developments and motivation provided by computer systems to develop, validate and test a system composed of a virtual environment associated with a sensor-enhanced peripheral device for the evaluation of the grip and pinch capacity in children in a interactive and attractive way that can be easily applied in clinics and rehabilitation centres.

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2. Methods

2.1. Subjects

To demonstrate the need for an evaluation system that does not depend on therapist experience, 7 physical therapists who were not neurology specialists (Group F1) with an average of 3.26 years of experience were selected to participate in this study.

To define the device specifications, 20 children ranging from 3 to 9 years old (6.25 ± 1.92) without motor impairment were selected (10 females and 10 males, development group; Group A); 10 of the children were 3–6 years old, and 10 children were 7–9 years old. All children had normal physical characteristics for this age group. To validate the evaluation system, the children in Group A used the devices and were analysed by 3 experienced physical therapists (F2) (Golden standard) with an average of 22.6 years of experience in neurology.

To demonstrate that the system can be easily applied to children in this age group, 35 children ranging from 3 to 9 years old (6.06 ± 1.77) without motor impairment were randomly selected (19 females and 16 males, test group; Group B). Group B was divided into two subgroups B1 with 10 children 3–6 years old; and B2 with 10 children 7–9 years old and booth evaluated by seven physical therapists (Group F1).

To demonstrate that the system can be used to evaluate children with motor impairments, we selected 10 children with mild to moderate motor impairment and normal cognitive function (3 males and 7 females; Group C) treated at the Physical Therapy Clinic at the University of Mogi das Cruzes (state of Sao Paulo, Brazil), and they were accompanied by a physical therapist with 23 years of experience in neurology. The selected children ranged from 4 to 13 years old (8.7 ± 2.65); however, those over 9 years old had a body habitus compatible with a younger age, which often occurs in cases of motor impairment.

2.2. Evaluation system specifications

We developed a system consisting of a device and virtual environment designed to assess 3 gripping types and 2 functional pinching types: gripping a cylinder with all fingers wrapped around the object; gripping a ball with all fingers wrapped around the object; gripping a handle in which four fingers are flexed around the object; pinching with the tip of the thumb to press an object against the tip of the forefinger; and pinching with the fleshy side of the thumb to press the object against the tip of the index finger.

The system was designed to evaluate whether the hold is correct, whether the movements of the individual fingers are suitable to perform a functional movement and whether the gripping force reaches the threshold value of 2 N and remains above that threshold level throughout the movement.

For the present study, we implemented the peripheral devices as components of toys with little resistance to movement. Thus, it was possible to evaluate the functional range of motion of small children or children with physical limitations even when they did not have sufficient strength to handle everyday objects. However, to assess whether some children had the strength necessary to handle the objects used in daily routines, limit switches were placed on the toys that required 2 N of force to be activated.

The peripherals consisted of five devices (Fig. 1) that were selected from those used in traditional tests applied by physical therapists to perform functional assessments: a knob for the evaluation of a cylindrical grip; a switch to evaluate a tip-to-tip pinch; a spinning button to evaluate spherical grip; a key to evaluate a flesh-side pinch; and a handle to evaluate a hooked grip.

The devices were placed on an easily handled single platform, transported and adapted to the computer interface. A specifically developed software program recorded and processed the collected data.

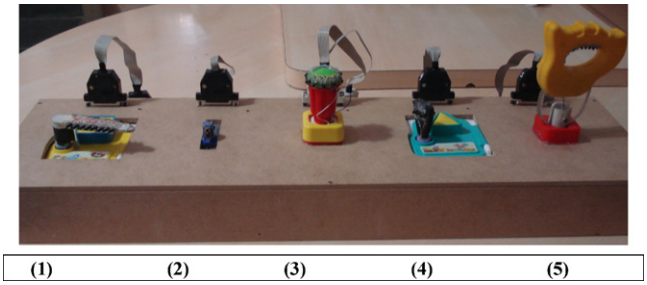

Fig. 1. Peripheral devices: (1) device to assess cylindrical grip, (2) device to assess tip-to-tip pinch, (3) device to assess spherical grip, (4) device to assess pulp-to-side pinch, and (5) device to assess hook grip.

To motivate the children to perform the movements required for evaluation, we developed a virtual environment that simulated an amusement park with 5 toys: bumper cars, a carousel, a Ferris wheel, a roller coaster and a spinning cup. Next to each virtual toy, an animated representation shows which device should be activated. When the first peripheral device is pressed and moved, the character approaches and enters the ride. The virtual ride proceeds through two cycles, and then the character goes to the next ride activated by the device. In the final scene, fireworks indicate that the game is completed successfully. If the device is not pressed after 15 s, the software moves to the next phase. If a grip is attempted but the child cannot move the device, the ride moves normally to avoid discouraging the child. The data related to the hold, range of motion and force threshold were recorded by a software program developed for this task. This recorded information was then processed and made available to the therapist.

2.3. Grip position detector

To verify that the position of the children's phalanges was correct, we placed limit switches on the five devices. The limit switches (Microrutor model MM2E1N1S and MM2E3N1S) were positioned to ensure that they could only be activated with the correct grip. The limit switches function in series and parallel in an electronic circuit composed of logic gates, amplifiers and adapters that activate the output signal and send the information to the computer.

The location of the limit switches was determined using clay moulds that simulated each device. Under the supervision of 3 experienced physical therapists, the 20 volunteers in Group A pressed moulds with various forms of grips and pinches. The limit switches were placed on each device activated by all of the positions adopted by the children deemed to be correct by the physical therapists.

Fig. 2a shows the first device, a knob to evaluate a cylindrical grip. Four limit switches were placed on the top, and a small limit switch with a long shaft was placed on the bottom of the device. When all of the limit switches are pressed, the output of the electronic circuit records that the grip is correct.

For the second device, designed to evaluate a tip-to-tip pinch, 2 small limit switches were placed on the right and 1 on the left side of the switch. When the tips of 2 fingers press the 2 upper limit switches without triggering the third, the pinch is recorded as correct (Fig. 2b).

For the third device, which is a spinning button to evaluate a spherical hold, we added 4 limit switches in the back and a long-shafted limit switch in front (Fig. 2c). When the 4 fingers and thumb are wrapped around the object, the 5 limit switches are pressed, and the computer receives the information that the grip is correct.