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Assessment of Manual Dexterity in VR: Towards a Fully Automated Version of the Box and Blocks Test

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Abstract. In recent years, the possibility of using serious gaming technology for the automation of clinical procedures for assessment of motor function have captured the interest of the research community. In this paper, a virtual version of the Box and Blocks Test (BBT) for manual dexterity assessment is presented. This game-like system combines the classical BBT mechanics with a play-centric approach to accomplish a fully automated test for assessing hand motor function, making it more accessible and easier to administer. Additionally, some variants of the traditional mechanics are proposed in order to fully exploit the advantages of the chosen technology. This ongoing research aims to provide the clinical practitioners with a customisable, intuitive, and reliable tool for the assessment and rehabilitation of hand motor function.

Keywords. Automatic, Assessment, Manual dexterity, Virtual reality

Introduction

In neurological rehabilitation, assessment requires specialised workers and adequate space and material [1]. Therefore, factors such as optimising clinicians time, the appropriate management of workspace and equipment, and proper management of results are quite important. In this way, the development of systems to support the clinicians and contribute to the management of previously mentioned factors are valuable in healthcare settings. One way of supporting the assessment procedure can be via the automation of traditional tests commonly used for evaluation and diagnosis. For that purpose, the use of gaming technology seems promising [2,3,4].

In general, current systems for automatic assessment of motor function have been mainly focused on objective outcome generation using different methods for rating the performance-based data gathered by sensors [5]. However, good data acquisition not only depends on sensor's reliability, but also the method of administering the test. An incorrect way of giving the instructions to the patient could lead to incorrect movement execution caused by trouble understanding the instructions instead of a real impairment, and thereby causing an incorrect assessment. Proper integration of these aspects could lead to fully-automated assessment systems.

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In this paper, we present the design and development of a game-like system that focuses on the automatic assessment of manual dexterity based on the conventional Box and Blocks Test (BBT). This ongoing research aims to provide a virtual tool for the assessment of hand motor function. In addition to proper data acquisition, the test administration and careful score validation (rating) were considered in order to move towards a fully-automated assessment tool. Additionally, variants on the traditional assessment procedure are included to explore the possible advantage of a VR BBT. The remainder of this paper is structured as follows. Section 1 presents a brief description of the BBT and a summary of related work towards the automation of the BBT. In Section 2, the design considerations for automating the BBT are presented. Section 3 describes the functionality of the proposed virtual tool. Finally, the conclusions can be found in Section 4.

1. Background

The Box and Blocks Test (BBT) is a clinically validated system for measurement of gross manual dexterity and coordination [6]. The test is made up of a wooden box with two 290mm wide square compartments, and 150 wooden 25mm cubes. A 100mm high partition is located between the two compartments. The objective of the test is to transport as many cubes, one at a time, from one compartment to the other in one minute. For scoring, the therapist must manually count the number of transported cubes when the time is over. However, the clinician must pay attention during the test performing in order to detect invalid attempts, which must be subtracted from the total score. For the test administration, the wooden box should be placed on a desk and the subject should be seated on a chair facing the box. The examiner faces the subject and reads the instructions before the test begins.

While this test is widely used in the clinical domain, there are some limitations with this approach. The test performance must be observed by the therapist in order to assess the user performance, which can significantly affect its reliability. While this estimation tends to be reliable (intra-operator) and objective (inter-operator), the nature of visual inspection includes some degree of uncertainty (subjectivity). Some of these drawbacks can be reduced via automation of the test.

One automation strategy of the BBT is using a conventional depth-sensing camera, as in the case of the Digital Box and Blocks Test (DBBT) [7]. In such work, a Kinect V1 sensor was used for monitoring the test development and detecting the cubes displacement via a computer vision approach. The success rate of the DBBT in cube counting was of 90% for 80 cubes. However, the test administration was not addressed. This issue was considered by the Automated Box and Blocks Test (ABBT) [8] that provides visual and audio feedback via a Graphical User Interface (GUI) to give the tests instructions to the patients. This GUI also displays and stores the results of the test for better management of patient record. The lowest average success rate in cube counting for the ABBT using the Kinect V2 sensor was 92% in clinical trials [9].

In [10], an approach based on gaming technology was considered to create the Virtual BBT (VBBT). This system uses a Kinect V1 sensor for hand, finger, and grasping assessments in a virtual environment based on the BBT. While this system had good results in clinical trials [10], it has some drawbacks. Firstly, the system was implemented in a virtual reality mode (desktop mode) making it difficult for users to perceive depth. Additionally, the BBT requires fine manual capabilities and, therefore, it requires of accurate hand gesture recognition, which is a limitation of the Kinect

sensor. Finally, the automatic administration of the test was not considered. Accuracy in hand gesture recognition was improved in the virtual version of the BBT proposed in [11], by using the leap motion controller (LMC) as the main hand motion capture sensor. However, this system was still running on a flat screen monitor and the automatic test administration was not investigated.

On account of the above, we present a game-like system for automatic assessment of manual dexterity based on the BBT. This system includes: (1) a reliable data acquisition of hand movements by using the LMC sensor, (2) an automatic test administration which is embedded in the gameplay, (3) an automatic outcome generation according to the traditional test mechanics, and (4) a higher level of immersion with a 3D workspace in VR. The integration of such aspects makes this system potentially useful in a clinical setting as it combines clinical knowledge with more refined capabilities of biomechanical capture systems. The following section sets out the methodology used for conceiving this system and the most relevant aspects that were considered in the design process.

2. Design Considerations

The BBT study is considered in this paper due to: (1) it is widely used in neurological rehabilitation, (2) the outcome is simple (total cubes transferred), (3) the test administration (rules and instructions) is systematic and clear, and (4) the test mechanics are well defined. These features made the BBT suitable for automation, but they must also be properly considered during the design and development of an automatic, objective, and friendly assessment tool. The following requirements have been set out in order to make this system as autonomous as possible and suitable in neurological rehabilitation.

a) *Game dynamics* that are similar to the traditional BBT test, being more intuitive and straightforward but keeping the clinical knowledge.
b) *Assessment-oriented gameplay* that allows the user to perform the assessment stages with minimal difficulty. The instructions and game (test) rules should be provided in a clear and simple way.
c) *Game-User interface* that allows patients to run the video game easily and to navigate through the game options in a natural and entertaining manner.
d) *Outcome generation* in the same terms as the traditional test (number of cubes) but providing additional objective metrics that can be used as indicators of exercise performance and improvement. These metrics include different periods of time, trajectories of hand joints, and movement ranges.
e) *Automatic data storage* of the information obtained in each session, such that it is possible to get an updated report for each patient, allowing the physician to monitor the recovery progress remotely.

Notice that the automatic administration of the test has been emphasised as a design requirement. Following section describes the system functionality.

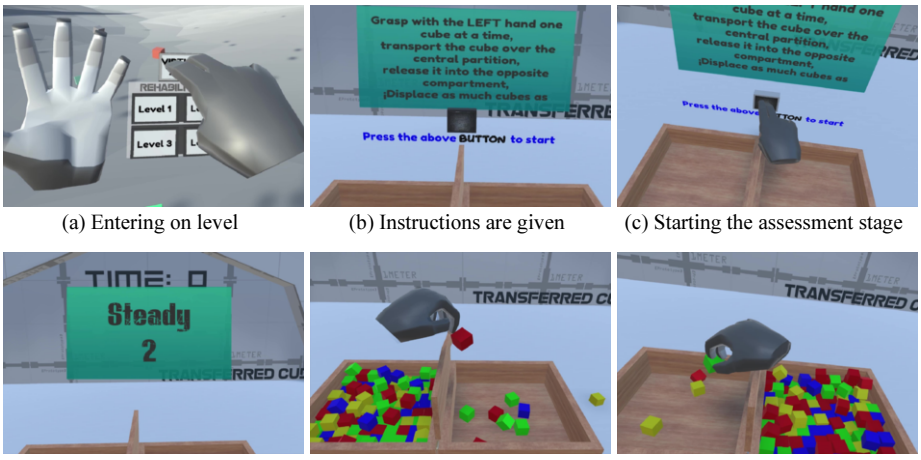
3. Game Description

In this system, two scenarios were implemented: standby and assessment. The standby scenario represents a forest where 2-inch size cubes are moving close to the user for interacting. The user is free to move and can grasp any cube. This standby scenario can

be useful for the user to become familiar with grasping virtual objects. The main scenario focused on the assessment stage is made up of the BBT box, a black button, various panels to display information (time, score, instructions, etc.), and a clear-grey table (as a reference plane to support the previous components).

3.1. Automatic Test Administration and Outcome Measure

The automatic test administration is addressed via pre-programmed gameplay and an interactive navigation menu. A gesture similar to looking at the palm of the left hand will deploy the navigation panel and the user must use the right hand to activate the options.



(a) Entering on level (b) Instructions are given (c) Starting the assessment stage

(d) Regressive counting panel (e) Dominant hand assessment (f) Non-dominant hand assessment

Figure 1. Process for automatic test administration and outcome measure

The assessment procedure is described as follows. From the standby scenario, the user can launch the assessment game using the navigation menu (Figure 1-(a)). Then, the system automatically leads the user through the test phases (training, dominant hand, and non-dominant hand). Prior to test execution in every test phase, the system provides the user the corresponding instructions through text and audio messages (Figure 1-(b)). The user must confirm he/she is ready to start by pressing a virtual button. (Figure 1(c)). After pushing the button, a regressive counting (Ready, Steady, Go) is activated and displayed on a frontal panel (Figure 1-(d)). According to the more affected arm, the virtual cubes will appear at the corresponding left or right compartment (Figure 1-(e) or Figure 1-(f), respectively). Similarly to the original BBT test [6], the user must transfer as many cubes as possible. The grasping action can be performed in a natural way. That is, the user can use a pinching grasp (thumb and index fingers), three fingers (thumb, index and middle fingers), or a fist action. When the 60 seconds are over, the results are displayed through the score panel.

The above procedure is repeated by the non-dominant hand. At the end of all test stages, a farewell message is displayed, and the video game closes the assessment level and goes back to the standby scenario.

3.2. Score Validation

Validation of the attempts when cubes are transferred is a key point in automatic cube counting. According to the BBT rules, the user's hand must overcome the central partition, the cube must fall inside the opposite compartment, and one cube at a time. Our system detects whether the previous conditions were accomplished to mark an attempt as valid. Contrary, cubes falling out the compartment, cubes falling inside but the user's hand did not overcome the central partition (throwing the cube) or transporting more than one cube at a time are registered as invalid attempts.

3.3. Adaptive Assessment

The flexible modelling of VR-based systems allows for enhanced or adapted functionality of automated clinical tests. In the case of our system, four assessment levels have been implemented. These levels are slight variants of the main assessment mode where the 150 coloured cubes appear, and they are summarised in Table 1.

Table 1. New assessment modalities included in the system

Complexity	Modality	Rationale
Level 1	Fixed-Location Single Target	This is to allow for an easier grasping as participants always pick a single cube from a fixed location
Level 2	Randomly Located Single Target	This is to increase the cognitive load of the test requiring participants to quickly scan and aim for the cube to be transferred
Level 3	Fixed-Location Multiple Targets	This is to allow for easier grasping, but it reduces the complexity of having to pick a single cube by presenting patients with more options
Level 4	Randomly Located Multiple Targets	This is the most challenging configuration as it combines an increased cognitive load with the dynamic placement of multiple targets

All levels are available with neutral (grey) or coloured (red, green, blue, yellow) cubes. Notice the physical BBT is commercially available with coloured cubes or wood colour ones. In our case, the use of coloured cubes helps to better distinguish the virtual cubes from each other when they are clustered together. However, it also can allow the therapist to design new assessment strategies that include cognitive colour-based components, as in the case of the Stroop Colour and Word Test [12].

To the best of our knowledge, this is the first study that proposes new assessment modes based on the BBT to seek new ways of assessing performance making better use of state-of-art VR technology. The needs of patients with a neurological disorder are usually multi-dimensional (e.g. physical, cognitive, psychological) and may be very complex. Therefore, the development of customisable tools could extend the diagnosis and treatment options of clinicians to suit individual patient needs.

4. Conclusions and Future Work

This paper describes a game-like system that automates the BBT by using the LMC as a hand motion capture device and VR for immersive visualisation of the task. This system aims to reduce the subjectivity during the examination, to avoid using marker-based motion capture, and to provide additional information about the user performance. Regarding the current literature, not only the outcome generation, which

includes data acquisition and task rating, have been addressed but also the automatic test administration. Similar work has not emphasised such aspects as it is performed here towards full automation of the BBT. Several levels have also been implemented making available the therapist with a powerful tool to explore new assessment strategies.

The future work includes the exploration of new ways of reinforcement the visual stimuli in order to reduce the loss of tangible feedback when grasping virtual cubes. Automatic storing of outcome data in a web-based system for ease of access for physicians is also considered. The next stage of this study will involve the clinical validation of the virtual tool via including this system as an assessment tool in a rehabilitation treatment. Thus, a comparison between the physical and the virtual BBT can be achieved using a dataset built from real patients' scores.

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