Multimodal Analysis of Serious Games for Cognitive and Physiological Assessment

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ABSTRACT

Serious games usually refer to virtual games used for training, simulation, or education and can engage users in cognitive and physical tasks. The design of serious games may offer insights on users' cognitive and physical behaviors while they try to accomplish structured tasks. In this study, we concentrate on the design principles of serious games that can be used for assessment, which we employed for our own design. To test our prototype, we conducted an experiment with control participants. Results from surveys, our collected game features, and sensor outputs were compared and analyzed with hypotheses based on previous research studies. Finally, we interpret the results of our experiment, and we describe issues and real life uncertainties that associate with sensor errors.

CCS Concepts

•**Human-centered computing** → *HCI design and evaluation methods*; •**Applied computing** → *Psychology*; *Health informatics*;

Keywords

Cognitive Psychology; Serious Games; Rehabilitation;

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1. INTRODUCTION

Research into the use of virtual reality and haptic technologies has increased significantly over the past decade in terms of both quality and quantity [5]. Methods to utilize these technologies are becoming more integrated with currently existing techniques for assessing the user's performance and diagnosis of their impairments. Due to more commercially available equipment, there has been some success in the use of these methods for individuals who frequently need to be assessed, such as the elderly, workers in an assembly line, or individuals that suffer upper-limb disability commonly found in post-stroke patients [23]. Among these methods is the advent of serious games, which are computer games that have a purpose other than pure entertainment [28].

The functional practice of these serious games have contributed to many different goals, such as training military, e-learning education, and motivating individual patients that are in rehabilitative programs [28]. As these serious games continue to evolve, we achieve the capability to help numerous groups of people. Our contribution to this research is in creating principles for how to develop a set of serious games that combine both cognitive and physical interactions in one instrument. In this study we gather peoples' behavioral signatures by capturing their physiological and cognitive interaction through a set of defined features. These features include a score of correctness, reaction time, hand-eye coordination, working memory, and inhibitory control. More specifically, we try to interpret how the users behave in our experimental setup and publish accessible data along with a serious game application that will allow researchers from various fields to reproduce and modify the experiment.

The system collects the user's upper-limb physical effort as data for an analysis of behavioral interactions, arm co-

ordination, and smoothness. The cognitive functions that we are studying include user's engagement, concentration, inhibition control, and memory systems while they interact with the virtual game. In addition, we have incorporated the use of an eye-tracker device [34] and a Barrett WAM robotic arm [33] to aid in the rehabilitative process as well as collecting data of the individual user.

The following sections of the paper are dedicated to the thorough analysis and representation of the proposed system. In section 2, we address the related work of both serious game and eye tracking research. Furthermore, in section 3 we discuss the setup of both the serious game and the eye tracking device, and we discuss the data collected in each part of the experiment. To continue, in section 4 we provide our hypotheses along with a detailed description of how the experiment was carried out. In section 5 we provide an overview of the system results and analysis, and we discuss the theoretical expectation arising from our research and compared to the results. Finally, we discuss in Section 6 what other features can be incorporated to produce a more effective system.

2. RELATED WORK

2.1 Serious Games

2.1.1 Cognitive and physical therapy

Cognitive therapy is generally used to assess and retrain specific brain functions that may have been impaired due to physical injuries, congenital abnormalities, or degenerative diseases. Examples of such cases are strokes, traumatic brain injuries (TBI), cerebral palsy (CP), and Alzheimer's disease; all of which share similar symptoms of depression, cognitive impairment, social difficulties and often communication related issues [29][30][35]. Over the past few decades, computer-based cognitive therapy has been developed and employed to aid in the rehabilitation process [36]. In a previous experiment [36], a computer-aided program was implemented to alleviate symptoms of certain mental health issues, such as depression and anxiety. In addition to computer-aided cognitive therapy, there are many types of technology-assisted physical therapy. Recent examples include robot-aided rehabilitation, which is commonly used for the repair of upper-limb movement following a stroke [16]. Furthermore, extensive use of virtual reality games involve flight simulators or physical coordination tasks, such as grasping an object and placing it into a basket [26]. Traditionally, cognitive and physical therapy have been separated and often counterproductive [1]. Multiple doctors often disagree with the medical plan of action and the treatment centers are usually found in different locations, which causes more distress for the individual. As the literature concerning the use of serious games in rehabilitation develops, a consideration for the combination of both cognitive and physical therapy in the same session should be addressed [16].

2.1.2 Eye-hand coordination

Eye-hand coordination is a combined physical and cognitive behavior that is part of performing everyday tasks, and it has been studied in activities involving wooden block sets, archery, sporting performance, computing-games, and even tea-making [11]. In its absence most people would be unable to carry out even the simplest of actions like picking

up a book from a table or playing a video game. Clinical assessment tools employ this control mechanism to assess the sensorimotor impairment of stroke patients and to evaluate their recovery performance before and after rehabilitation treatment [16]. Additionally, in Alzheimer patients, the timing of eye-hand coordination tasks has been studied for its use of examining neuro-degeneration over time [8]. Hereby, the evaluation of the eye-hand coordination makes it important to identify user's behavior and agility.

2.1.3 Reaction and activity response time

Recent research has found that the combination of both cognitive and physical exercises significantly increased reaction time in elderly populations [15]. This suggests that the mind and body are connected through multiple facets. There are two important response times that can be measured while using virtual reality in rehabilitation. When combined together, these response times could aid in both cognitive and physical rehabilitation. The first time metric is the reaction time, which refers to the period that the user needs to respond to the stimulus once presented. This time is measured using the eye-tracker, and it is a measure of the user alertness. This kind of time information is important and can be used to monitor progress of users with cognitive impairment, especially when increasing the difficulty of a task. For example, people with closed head injury (CHI) show a decrease in vigilance while performing complex tasks [20]. The second time metric is the activity time, which is the time needed to complete the task once the visual cues are recognized. This activity time can be used in addition to the inertial measurement sensors embedded in the robotic manipulator to evaluate progress of a physically impaired user. This metric can be applied to people suffering from a stroke since they require longer time to accomplish active tasks [10]. When combined together, these response times could aid in both cognitive and physical rehabilitation.

2.2 Eye Tracking

Researchers have proposed that recording the detailed actions and changes that occur in the human eye can offer significant evidence. Eye-tracking of pupil dilation has introduced the claim that remote eye trackers can be used for a measurement of cognitive load [14]. Typically, as our cognitive demand rises, the pupils will dilate. Furthermore, researchers have shown that eye trackers can be used with an experimental technique that focuses on the detailed timing and magnitude of short-term pupillary responses, rather than a simple aggregated measurement over a long period of time [13]. As technology continues to develop and become more widely attainable, the ability to use eye-tracking software to gauge cognitive workload as well as attention and memory could potentially add additional metrics to grade and compare the subject's attention and focus. Related research has been conducted from [21][22], that examined physiological functions with the use of an inexpensive, commercial eye tracker [34][7]. They were able to effectively measure qualitative states of attention and memory. For this reason, our experiment will be carried out using this same affordable eye tracking device.

The inability to assess individual cognitive and emotional responses is one of the barriers toward successful evaluation of digital games [25]. There are many studies that have used different methods to evaluate player cognition and emo-

Figure 1: (A) Painting a Fence (L1) (B) Supermarket (L2) (C) Cooking a Meal (L3) (D) Painting a Fence (L4).

tions using either EEG [2], EMG [32], eye tracking [12][6], etc. Among these methods, eye tracking is one of most non-invasive approaches, since it does not require any attachment to the participant and can be set on a table or a screen at a distance from the user. The combination of serious games and eye tracking hardware/software has been recognized as being extremely beneficial across multiple disciplines. For instance, it has been used to evaluate the effectiveness of serious games in educational setups. In [12], the authors found that the average test score of a group of students increased after playing a serious game teaching them geography. The study also established that students who exhibited a larger number of fixations achieved higher scores on the exam. Furthermore, the development of serious games and eye trackers are expanding to health care application (i.e. social communication in children with autism) [6].

3. SYSTEM ARCHITECTURE

3.1 Game Setup

In this section we will describe how we incorporate these design principles in a four level serious game. In the first level (L1) we have incorporated and slightly altered the design from the original Stroop effect experiments in order to facilitate cognitive assessment in a virtual environment [31]. The task consists of painting a fence consistent with the presented words on the game’s screen. The user will play this level twice (L1, L4) throughout the entire game in order to test inhibitory control. The first attempt (L1) will be used to determine a control reaction time for later comparison with the secondary test (L4). For example, when the word RED with white font color appears on screen, the individual should choose the red paint bucket for the particular section of the fence (Figure 1A). As the level continues, the user must bring the virtual paint brush back to the circle in the

center of the screen, in order to receive the next stimulus. In the second level (L2) the user has to interact with virtual items in a supermarket environment. Based on a model from Baddeley [4], this game tests the use of an individual’s working memory. At the beginning of the level (L2), a shopping list is presented on screen; it is then removed after fifteen seconds and the participants must remember all of the items (Figure 1B). The user must internally or externally rehearse the items in order to recognize all the ingredients later on the store’s shelves. As the user moves through the aisle, he should control the robotic arm in the correct 3D position in order to grab the ingredients. There will be three iterations to collect all of them. If any of the ingredients are not collected at the current iteration, then the shopping list will be presented again for five seconds showing only the remaining items. At the second iteration the navigation speed is slower relative to the first, and at the third iteration visual cues will be presented to help find the missing items. We surmise that the amount of iterations needed, exemplifies an individual’s working memory workload and their ability to remember all of the items.

Following the market environment (L2), we ask the user to insert the items (virtual ingredients) into a virtual pot as if they were cooking a meal (L3). The user must collect each item from the kitchen table and follow a 3D trajectory to transfer it inside the pot (Figure 1C). The 3D trajectory will help challenge the user and integrate a more direct physical rehabilitative process to the game. As the user follows the predetermined and changing trajectories, the system estimates their hand-eye coordination, hand’s smoothness and trajectory deviation [19][27]. In the final level (L4), we return the user to the first scene of painting the fence. As previously stated, the first attempt will be used to determine a control pattern, whereas the second attempt engages their inhibitory control [9]. For example,

during this attempt, the word RED would appear on the screen, but it would have a brown font color (Figure 1D). In order to be correct, the participant must choose the brown color of the word rather than the semantic meaning of the word RED. With the modification of color for each presented word, the user must resist the urge to choose the incorrect choice, which would delay the activity response time and slow their cognitive and physical reaction. We should mention the game does not have time constraints as the participants navigate through the game. An example of our serious games interface is illustrated in this link: https://www.youtube.com/watch?v=8TPn_aqfVi8. Moreover, access to the source code of the games can be found at the following website <http://heracleia.uta.edu>¹. This can be the basic infrastructure for conducting further experiments with the same or alternative monitoring devices [18].

3.2 Collected features

Each level assesses different features, such as physical and cognitive abilities. As described above, we investigate the design principles in order to develop an assessment virtual reality tool that provides individuals' behavioral signatures. These features are:

1. Correctness of task/Inhibitory Control: this represent the correct choice of color by the participant in levels (L1) and (L4) as explained in the section (3.1 Game Setup). Additionally, we measure inhibitory control by the participants' ability to correctly differentiate the color of the word and the actual word in L4. This score is captured to determine a possible variance of difficulty between the levels.
2. Reaction and Activity response time: more information regarding reaction and activity response time can be found in the subsection (2.1.3). A simple definition would be the elapsed time that it takes to detect the visual cues as well as the time needed to complete the task once the visual cues are recognized. In L1 and L4 we have recorded metric data with the eye tracking device and robotic manipulator, which we have labeled as: eye delay and move delay.
 - (a) Eye Delay: the reaction response time of the eyes as they react to the illustrated message on the top of the screen. We were able to measure this delay using the x and y coordinates of the eye's point of gaze (see Average Eye Delay Figure 4).
 - (b) Move Delay: the hand activity response time of the user once their hand moves inside the center circle, and the time it takes them to complete the task. This parameter could provide insight on how long it takes the user to process and decode the messages once they have received the visual stimuli. This parameter offers both cognitive and physiological information about the user's performance during the gameplay, as the mind and body are connected. We should note that we did not set a time limit for any participant, which could have introduced individual bias as their motivation levels were dissimilar.

3. Working Memory/iterations: this feature was collected in the second level (L2) and it estimates the users' ability to memorize the items on the shopping list and successfully manipulate that information. For a basic analysis, the number of iterations needed to complete the task was documented. As described earlier in section (3.1 Game Setup), the participants were allowed three opportunities (iterations) to complete the task.
4. Eye-hand coordination: this represents the level of accuracy to the 3D trajectory presented in the third level (L3). With the employment of the robotic manipulator, we gather the users' behavioral and physical agility so we can visualize the trajectory deviation and create a scored feature.

3.3 Eye Tracking Setup

Figure 2: Calibration Process with 9 Points.

We used the eye tracking EyeTribe device [34][7] to monitor reaction response time. Before starting the experiments, the participants were asked to orient their head towards the monitor and look at nine points (targets) appearing on the computer's display to calibrate the eye tracker (Figure 2). The calibration process was offered directly from the EyeTribe API to create a model that maps the user's eyes to the display (x and y coordinates). Also, EyeTribe API provides 6 ratings (perfect, good, moderate, poor, recalibrate and uncalibrated) as an indication of the quality of the calibration. We used this rating as a measure to decide which of the data to include in our analysis as explained in section 5.

4. HYPOTHESES AND EXPERIMENTAL PROCEDURE

4.1 Hypothesis

For our experiments we plan to examine the serious game in a control setting of healthy individuals. These following three hypotheses are based on the assumption that we will compare them with a future clinical population (individuals with disabilities CP, stroke, TBI). We believe that the

¹http://heracleia.uta.edu/~lioulemes/serious_games.html

marginal difference would be greater in a clinical setting because of reduced inhibitory control, working memory, and issues with eye-hand coordination, that are found among individuals with disabilities.

- H_1 : For the comparison of L1 to L4, we expect the subject to have more mistakes and a slower move delay time for L4. The eye and move delay will be recorded in order to compare the two populations, and we anticipate that the control population would exhibit faster reaction and activity response times.
- H_2 : In L2, we predict that the number of iterations needed for the control population would be lower (≤ 2 , no need for the visual cues) when compared to a clinical population because we expect them to exhibit stronger working memory abilities.
- H_3 : We hypothesize that the overall scores for L3 would be higher (≥ 75 , on a scale $[0 - 100]$) in a control population as the participants do not suffer from any physical impairments, nor issues with hand-eye coordination.

4.2 Experimental Procedure

Figure 3: Experimental Setup and a participant.

In order to test our hypotheses, we conducted an IRB approved experiment (*IRB No.: 2016-0121*) using human participants. After the process of informed consent, each participant received verbal instructions that described each level. Then, they were given the opportunity to ask questions or voice concerns. Next, the calibration process for the eye tracker occurred, which was followed by an interactive tutorial phase allowing each participant to play the serious games. The tutorial was a condensed version of the actual gameplay and the participants were given another opportunity to ask questions. An example of our experimental setup can be seen in Figure 3.

Table 1: Participants Demographics

Participant Demographics - N = 12 Participants
Age Range: 18-29
Gender: 6 Males, 6 Females
Handedness: 12 Right, 0 Left

For our study, there were twelve total participants recruited. All participants were students and staff from the University of Texas at Arlington. Each participant was asked, after the experiment, to answer a questionnaire in order to gather demographic and self-report data (Table 1 shows their demographic information). The demographic information included age, gender, and hand dominance (which was useful because every participant had to interact with the robotic manipulator using their left hand). The rest of the survey was used to compare and analyze self-report responses to their physiological reactions throughout the game. For example, it collected the participants' perceptions about the individual level difficulty and their overall enjoyment.

Figure 4: Eye Delay Average for L1 and L4.

5. RESULTS AND DISCUSSION

Overall, we examined the results from four out of twelve participants in our analysis. Those four participants had either perfect or good eye tracker calibration. We have tried to re-do the eye tracker calibration for the other eight participants multiple times, but we were only able to achieve either moderate or poor calibration, which we believe it is not sufficient to produce accurate results. We should explain that this was due to the lack of data collected and hardware errors from the eye-tracking device. Moreover, we observed that the participants' facial feature deviations caused a discrepancy on the eye-tracking data. We also found that the experimental environment should be more controlled when the Eye-Tribe device is used for recording pupil dilation. The eye tracker did not consistently measure the eyes due to exaggerated movements from the participants and their distance from the device (over 60cm). In order to reduce ex-

Table 2: Results of the Serious Games

Participant	Correctness(L1)	Iterations(L2)	Eye-Hand Coordination (Average)(L3)	Correctness(L4)
1	90%	2	83%	100%
2	100%	2	76%	90%
3	100%	3	78%	100%
4	100%	2	72.5%	90%

perimental bias, we allowed a more natural setting that was unfavorable to the collection of pupillary data. In our experiment, the combination of cognitive and physical activities required autonomous control from the users. Previous work [21][22] controlled the participants' movement by limiting physical activity, which allowed for better eye pupil recordings. In the rest of this section, we will discuss results from the collected data and we will indicate some inconsistencies with our hypotheses.

Figure 5: Average Move Delay for L1 and L4.

The conducted experiments partially verified our first hypothesis (H_1) as we found slightly more mistakes made in L4 instead of L1. However, move delay was not significantly different among the two levels. As seen in Figure 5, participants 1 and 4 showed a slower move delay for L4, but participant 2 and 3 were slower in L1. It was possible that they became more familiarized with the gameplay as they reached L4. This could have contributed to the faster move delay times found among participants 2 and 3. A possible solution could be a variation of the game-play parameters, such as color choices, playtime or game-level reordering and combination.

Following, the second hypothesis (H_2) suggests that a control population does not need visual cues. From Table 2, only one participant exceeded our predicted number of iterations (> 2) needed to collect all the items. Based on participant's survey responses, L2 was the most difficult level to accomplish due to the navigation speed at the first iteration. Additionally, the participants found it challenging to recognize the items in the virtual environment as they had different perceptions for the shape and characteristics of each item. To solve this issue, we can modify their size

Figure 6: Pearson's correlation between Move & Eye Delay.

or the game perspective view.

Lastly, for the third hypothesis (H_3), most of the participants met our expectations (≥ 75) as seen in Table 2. The outcomes for L3 show the average score for the five different 3D trajectories. Participant 4 showed a lower score, but this could be attributed to communication errors between the robotic arm and the game platform (Unity) software. A better computer gaming architecture could eliminate these errors, such as using *wxPython* implemented in *C++* instead of using Unity which is based on *C#* programming language.

One unexpected outcome that we found was that eye delay ($M = 2.13$, $SD = 1.08$) and move delay ($M = 3.83$, $SD = 1.54$) were positively correlated as seen in Figure 6. Using a Pearson's r correlation, we found a strong correlation $r(78) = 0.89$, $p \leq 0.001$. For the four participants with working data, we discovered that as their eyes reacted slower to the stimulus, so did their physical response to choose the correct answer.

6. CONCLUSIONS AND FUTURE WORK

In this work, we have designed a working battery of serious games using two external sensors, and we have analyzed the collected data for higher level interpretation that will bring strong support to our design prototype. In addition, we have completed our first round of collecting data from

participants to test our research hypotheses and to understand participants' behavioral physical and cognitive signature through their interactions and the survey responses. The results and analysis suggest that the four serious games have the potential to assess the users' conditions based on collected features. The incorporation of eye pupil dilation could provide a measurement of cognitive load as the user performs challenging tasks using more accurate remote eye-tracking sensors such as the next generation (*EyeTribePro*) or head-mounted eye-trackers [18].

In the near future, we plan to present our system to clinicians and medical professionals through surveys that will indicate their professional opinions. Their feedback will help us upgrade our assessment tool and will integrate the serious game into a training instrument for cognitive and physical rehabilitation. Also, we plan to add haptic cues, so when the user deviates from the path, the robotic manipulator would apply counteracting forces to assist with task completion [17][3][22]. Furthermore, we will add an EEG sensor, like the MUSETM [24] in order to extract enjoyment and concentration rates for each of our serious game levels. This engagement feature will provide personalizable training to the users based on their preferences. In our lab, we have already conducted experiments in order to identify users' enjoyment rates using the brain signal waves extracted from the head-mounted device [2]. All in all, we believe that applying this type of multi-data sensing collection and advanced data fusion and analysis will produce a robust, reproducible and adaptable rehabilitation instrument that can be used for clinical and assistive-home environments.

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