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Design and Usability of a Medical Computing System for Diagnosis of Mild Traumatic Brain Injury

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Abstract— **In this paper, we present a prototype design of POCTENA (Point-Of-Care Testing Environment for Neurological Assessment), a medical computing system that will be used to assist with diagnosis of mild traumatic brain injury. The design includes an initial set of neurological tests that are built into the system. Component-based usability testing was conducted to examine the effectiveness of the user interface. Results from usability testing are then used to suggest possible system design revisions.**

I. Introduction

Traumatic brain injury (TBI) is one of the leading causes of mortality in the United States. Approximately 1.7 million people suffer from TBI, each year [1]. TBI or intracranial injury involves an external force that traumatically injures or disrupts the brain. TBI can be classified based on severity (mild, moderate or severe), mechanism (closed or penetrating head injury), or location (localized or widespread). One of the traditional and standardized methods of classification of brain trauma is the Glasgow Coma Scale (GCS). This classification system involves three factors: eye opening, verbal responses and motor responses. The scale ranges from 15 to 3 (13-15 being mild, 9-12 being moderate and 3-8 being severe TBI).

Mild TBI, often referred to as a concussion, is one of the most common neurologic disorders, accounting for a significant portion of TBI cases [2]. It is widely reported amidst soldiers in war zones [3], in athletic settings [4], and even among children [5]. Patients with mild TBI may have minimal or no externally visible injury. Moreover, symptoms or characteristics associated with mild TBI are often hidden or very subtle, leaving patients or even clinicians unaware of any brain-related problems. This makes mild TBI, especially in subjects without penetrating head injury, difficult to diagnose. Undiagnosed mild TBI may lead to several physical and mental complications like cognitive disturbances, depression, behavioral disturbances, sleep difficulties, and many other postconcussive complaints [6]. Therefore, early and quick diagnosis is critical for patients with mild TBI. This challenge has motivated the development of a Point-Of-Care Testing Environment for Neurological Assessment (POCTENA).

The major goals of this work are (1) to design a low-cost, non-invasive, point-of-care, system that allows sensory, motor and cognitive assessment (2) to incorporate mild TBI-sensitive neurological tests that involve upper-limb motor function and, (3) to enable extraction and analysis of reliable information to quantify motor control attributes specifically, reaction time.

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II. Prototype Design

Hardware: The initial set-up of the system is made up of three basic hardware components: A laptop, a pair of motor response input devices, and a headphone (see Fig. 1).

- A Dell XPS (L502X) laptop with 15.6'' widescreen LCD display and two operating systems (Windows 7 and Ubuntu 10.04) is used to run the software.
- A pair of identical input devices, placed on either side of the laptop, is used to capture the subject's motor response. Subjects can hold and move the handle of the input devices to respond to tasks that are presented by the software. Two different devices were experimented – (1) Genius Metal Strike Forced Feedback (FF) joysticks: a 4-axis control joystick with 13 programmable buttons and a USB interface (2) 3M™ Ergonomic mouse: a joystick-shaped vertical mouse with 2 programmable buttons and a USB interface. Unlike a conventional palm-down mouse, the vertical design allows use of larger muscles for movement to reduce strain and discomfort.
- Sony® MDR NC7 headphones are used to present audio instructions and reduce ambient noise.

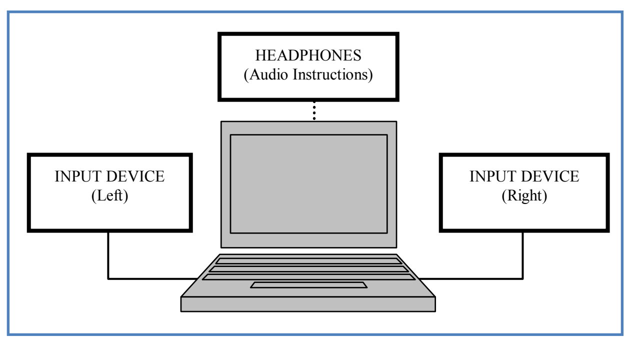

Figure 1. Hardware set-up of POCTENA system

Software: Four neurological tests [7-10] that allow assessment of sensorimotor and cognitive performance were adapted and implemented using Python programming language. From this point, the term *device* refers to the input device (FF joystick or vertical mouse) on the either side of the laptop and the term *paddle* refers to the corresponding interaction component on the display screen.

A. *Bimanual Visuomotor Task*

In this task [7], the system presents two paddles that can be moved in the y-direction using the devices on the either side. The subject should use the paddles to hit objects (circles) dropping from the top of the screen. This task is represented in Fig. 2. At first, the speed of the falling objects is slow, but it gradually increases over time.

B. *Modified Bimanual Visuomotor Task*

The bimanual visuomotor task is modified to present two differently shaped objects: circle, and triangle. The subject is instructed to hit only one kind of objects (circle), using the paddle and avoid triangle-shaped objects.

C. *Unimanual Visuomotor Task*

In this task [8-9], the subject is presented with a circular arrangement as shown in Fig. 3a. One of the outer circles and the inner center circle lights up (in red) alternatively. The subject is instructed to move the paddle on screen using the input device on the right side to touch the circle that lights up. In case of a normal subject, if the path taken by the subject is plotted, it should result in star-like pattern as shown in Fig. 3b. This task is repeated using the input device on the left side.

D. *Trail Making Test-A*

Trail Making Test (TMT) is widely used as a measure of frontal lobe function of the brain [10]. It is usually administered in two parts, A and B. In Part-A, the subject is required to connect in ascending order, the numbers 1-25 that are distributed randomly in space. For usability testing purposes, a modified version of TMT-A (see Fig. 4) which requires the subject to connect the numbers 1-8, is built into the POCTENA system.

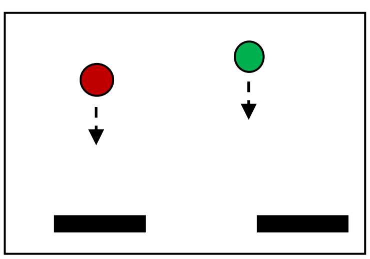

Figure 2. Bimanual visuomotor task

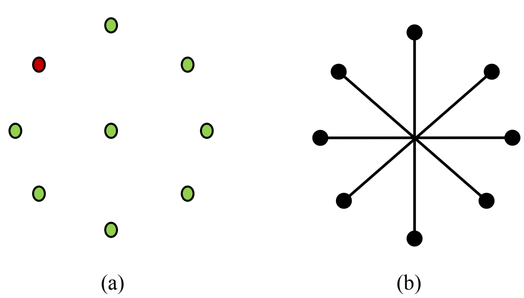

Figure 3. (a) Unimanual visuomotor task (b) Ideal pattern that represents the path taken by a subject in unimanual visuomotor task

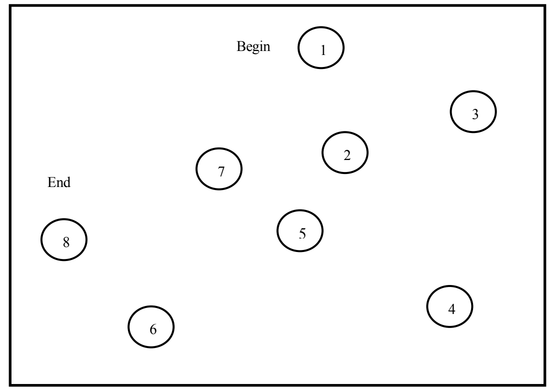

Figure 4. Modified Trail Making Test A

III. DESIGN PLAN AND METHODS

Three key design process concepts are involved in the development of POCTENA system – an iterative and incremental design (IID) model, user-centered design (UCD) and component-based software engineering.

Iterative and incremental design model: The idea behind the design model of the POCTENA system, shown in Fig. 5, is to create a basic version of the system to which a user can interact. This subset of the entire system is built using an initial set of design inputs and it goes through a series of iterations until the full system is implemented. Updated and/or new functional capabilities and design revisions are added at each iteration. One of the key strengths of this model is that learning comes from both system development and use of the system. User feedback paths are required between each stage in the model, constituting an iterative and incremental product development model. The feedback paths are not shown in Fig. 5 to make various stages in the model more distinct.

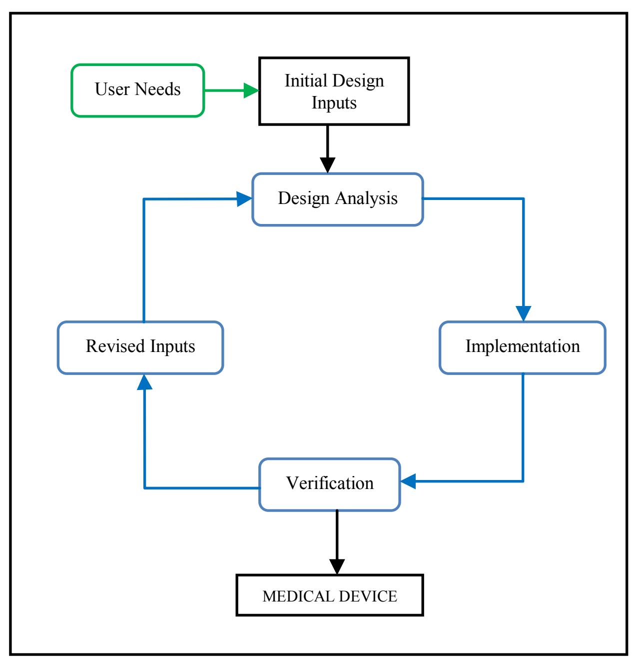

Figure 5. POCTENA's iterative and incremental design model

User-centered design: This requires users to be involved throughout the design process. Two groups of users have been defined: subjects and physicians. The first iteration of usability testing was conducted with a small group of peers and colleagues as subjects, to obtain feedback on user interface of the prototype. Subsequent iterations of testing will involve formal recruitment of subjects and active involvement of physicians from the department of neurology and/or emergency medicine at the University of Cincinnati, to review the neurological tests that are built into the system and critique the entire system.

Component-based software engineering and testing: An interaction component can be defined as a basic unit of a human-computer interaction system on which a usability assessment is possible. Component-Based Usability Testing (CBUT) can be classified based on the testing paradigm as Single-Version Testing Paradigm (SVTP) and Multiple-Version Testing Paradigm (MVTP). SVTP involves testing a single version of each component in the system and aims at identifying components that have negative impact on the overall system usability. MVTP uses multiple implementations of a single component while all other components in the system remain the same. The focus of MVTP is to determine the version with highest usability. CBUT can be more effective than overall usability assessment of the system, when comparing different versions of a part of the system [11]. In the POCTENA system, each neurological task is built as an independent software module. This provides an easy way to perform CBUT on each neurological task module and on smaller interaction components within each module (like *paddles*), as well.

IV. Usability Testing

The primary focus of the first iteration of CBUT was to assess the usability of input devices that drive the paddles on the screen through a Multiple-Version Testing Paradigm (MVTP). Two versions of the paddle (one for FF joysticks and another for vertical mouse) were created.

The usability test objectives are,

- To determine design inconsistencies within the user interface, specifically navigation concerns.
- To identify presentation errors and places within the user interface where users fail to properly act upon a certain given task.
- To establish baseline user performance levels for future iterations of usability assessment.

Sixteen volunteers (20 years of age or older) were asked to perform the four tasks listed in Sec. II, first using the vertical mouse and then, using the FF joystick. A 'Think Aloud' protocol was encouraged throughout the session and all user comments and behavior were entered in a log file. Also, the responses for six perceived ease of use questions based on the Perceived Usefulness and Ease of Use (PUEU) questionnaire [12] were collected for both the input devices. A 7-point Likert scale (with 1 = Strongly Disagree and 7 = Strongly Agree) was used. The Cronbach's alpha values were calculated to measure the reliability of the ease of use questions. The alpha values, shown in Table I, indicate an acceptable level of internal consistency of the questionnaire.

TABLE I. Results from the First Iteration of Usability Testing

Input Device	Cronbach's α	Mean
Vertical Mouse	0.81	6.56
FF Joystick	0.87	2.25

a. Average of aggregate mean of responses

The following are reflections from the first iteration of usability testing with the paddle on the screen as the interaction component.

- *Vertical Mouse:* It was observed that users were extremely comfortable with using this device to navigate the paddles on the screen and were able to complete all the tasks with very little upper-limb movement.
- *FF Joysticks:* Contrary to the vertical mouse, the FF joysticks were found to be sensitive to small movements and the users found it difficult to steer the paddles using the joysticks.

V. Proposed Design Revisions

Due to navigation difficulties, it was concluded that FF joysticks were not an appropriate choice for the POCTENA system. While the vertical mouse was efficient in navigating the paddles on the screen, it did not allow sufficient upper-limb movement that is needed for sensorimotor assessment.

The usability study in Sec. IV revealed the need to define a new set of input device requirements and identify alternative input devices. A revised set of critical requirements for the input device are listed below.

- The input device should support dual configuration i.e., the ability to connect two identical devices that can drive two paddles on the display and be identified as separate devices in the software.
- The device should provide easy and efficient navigation of their corresponding paddle on the display.
- When the subject holds the handle and just let their arm hang limp, the device should be able to support the weight of the subject's arm and support programming that would provide sufficient robotic motion to move the subject's arm. This requirement is included to allow addition of more powerful neurological tests for sensorimotor assessment.

Recommendations from the usability testing enabled an elaborate exploration of several commercially-available forced-feedback and haptic devices. Haptic devices provide tactile feedback or in other words, a sense of touch by applying force or motion to the user. Currently, three haptic devices are being considered – the Novint Falcon® gaming controller (Novint Technologies Inc., USA), the delta.3 haptic device (Force Dimension, Switzerland), and the PHANTOM Omni® haptic device (Sensable Technologies

Inc., USA). With a haptic interface and a powerful set of neurological tests, the POCTENA system is targeting to provide a point-of-care platform for effective diagnosis of mild TBI.

VI. Discussion

The usefulness and strength of an IID model, UCD and CBUT can be clearly perceived from the POCTENA system development. It was seen that both versions of the interaction component did not meet the usability requirements. When new versions of the interaction component are being replaced, all the other software components can remain the same and if necessary, new components can be added, as well. Besides design revisions that were mentioned in Sec. V, additional neurological tests will be included in the next iteration of development.

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