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Development of an Interactive Motivating Tool for Rehabilitation Movements

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Abstract—**In this paper, an interactive tool, including three computer games controlled via the *center of foot pressure* (COP) trajectory biofeedback, was designed to aid in pressure balance for rehabilitating persons with balance disorders. The games interact in real-time with the Vista Medical Force Sensitive Applications software and pressure mat. The main goal of this research was to employ attractive and motivational learning techniques, using equipment that is available to a large population, to increase volume of exercise practice and to retain the patient's attention. Questionnaires regarding the motivational aspects of the games were administered to 15 subjects (7 patients). The results indicate that the tools were indeed attractive, motivational and an improvement to conventional exercise regimes.**

Keywords—**biofeedback, center of foot pressure (COP), motivational, pressure mat, rehabilitative games**

I. Introduction

Rehabilitative exercises are an essential part of the recovery program for individuals with diminished motor skills. A reduction in a person's balance and mobility impacts their quality of life and health and can lead to an individual being unable to carry out activities of daily living. Standard rehabilitative exercises generally include standing activities, steppers and over-ground and treadmill walking with and without support from a cane or body harness unloading system, at a given rate for a specified duration; this is dependent on the type of disorder [1].

Biofeedback has been used to augment training and awareness of movement, weight bearing status or balance. One parameter that is often used as biofeedback and as an outcome measure in rehabilitation is the *center of foot pressure* (COP). Instabilities will be manifested in the resulting COP signal as a reflection of the effect of a balance disturbance and reaction [2]. Thus, the amount of COP displacement and its trajectory are important as they provide a measure of stability and can be used when evaluating the human postural control system. However, biofeedback is one-dimensional and simplistic, with limited motivational value.

The main goal of this research was to develop a tool which uses a computer-based gaming system, in order to motivate and promote active goal-directed movement. In turn, this will facilitate the rehabilitation process for restoration of weight bearing and balance control for persons with neurological or musculo-skeletal disorders. This was done through the creation of three biofeedback interactive tools, namely Tic-tac-toe, Memory Match and Under Pressure. The link to computer games engages the patient in the process of practice, in order to make it attractive and prevent boredom; i.e., the idea of *motivated use* to increase volume of practice and retain the patient's attention. Computer games are also an important form of augmentative biofeedback, promoting goal-directed movements through full active range. In addition, a set of objective performance measures based on COP trajectories can be developed while the patient is playing the games [3]. Lastly, we sought to employ equipment that is easy to use and portable, while minimizing the cost, such that the tool would be available to a larger range of clinicians in their daily practice.

II. Methodology

A. *Biofeedback Signal Selection and Delivery Method*

Several research groups are currently investigating biofeedback for use in rehabilitation exercises [4,5]. The criteria the biofeedback signal must meet for this research is that it must represent a global balance variable and the acquisition of the signal must be done through equipment that is easily available to a large population base. Thus, the COP trajectory and load values were selected as they are global variables, representing full body performance, and they can be easily acquired using a pressure mat.

One way in which to alert the patient of the biological signal is to incorporate it into a game. The use of games in rehabilitation has been studied as a method to provide a motivational atmosphere; to accomplish this they must provide fun and satisfaction from reaching a goal or completing a task [6,7]. It can then be inferred that, if the game provides the patient with motivation and is fun for them to use, they will practice their exercises more. For example, NeuroCom NeuroGames [4] provides three games that are used to enhance practice and motivation. In addition, they have a screen where circles appear and the patient has to move the marker into the circle. The *center of gravity* (COG) is used as the control variable and is measured via a custom strain-gauge force plate. NeuroCom suggests that these motivational rehabilitation exercises increase recovery [4].

Using these ideas and results, an interactive tool with three games was created in this research using the COP signal for game control. The inclusion of biofeedback that is not only functional but also motivational should increase the patient's desire to perform their rehabilitative exercises. The games developed in this research offer several advantages and new features, which will be elaborated upon in the following sections.

B. System Integration

The COP signal is acquired with a thin, flexible pressure mat and the *Force Sensitive Applications* (FSA) software (Vista Medical Ltd, Wpg, MB, Can). Unlike force plates, the pressure mat can be made to any size (including insoles) and may be used on many different surfaces; in particular, a compliant foam surface of varying density or thickness. The use of foam is an inexpensive and convenient way to change the balance requirements in a graded and controlled fashion.

The pressure mat used in this study was of dimension 53 cm x 53 cm x 0.036 cm and contains a 16 x 16 grid of piezo resistive sensors spaced 2.8575 cm apart. It comes with an RJ-45 interface box, which captures the data for display on a PC with the FSA Software. The unit is portable, easy to use and has a reduced cost when compared with NeuroCom's system [4], making it an ideal system for use in routine clinical applications.

Each game was created as a separate *dynamic linked library* (.dll) file. The game is loaded by selecting the desired game from the device Configurations Dialog. The game is then displayed in the main FSA window; thus the scan, record, save and new functions of the main FSA toolbar all apply. In addition, the load values per cell and pressure map may also be displayed.

C. System Design

It is important that the games fully exercise the range of movement the patient currently has available, with the goal of increasing this range and the rate of the movement. Thus, each game has parameters that can be configured for different levels of difficulty and introduces cognitive distractions. Furthermore, using the flexible pressure mat, the games may be performed on solid fixed surfaces or tilted and compliant surfaces, thus adding increased balance requirements as appropriate. In addition, prior to beginning a game, the patient's limits of stability bounds are calculated. The following subsections describe the bound initialization and game play for each of the three games, Tic-Tac-Toe, Memory Match and Under Pressure.

1) *Initializing Bounds*: The steps for determining the bounds are as follows, as indicated in an instruction box displayed to the user: 1) center point coordinate determination; 2) peak detection of self-induced oscillatory movement; and 3) bound indication. As the users increase their movement capabilities, the stability bounds should increase to their optimal levels. As the determined bounds are average values and as the speed of the oscillations play a role in their determination, the bounds can be scaled by a percentage value. In cases where the patient's weight distribution between his/her legs is asymmetric, the COP will be biased towards the weight-bearing leg. Similarly, this can be true with improper balance between toes and heels. Thus, another feature offered is the ability to offset the center value. In addition, the COP movements can be smoothed over a given number of samples to reduce jerkiness.

2) *Tic-Tac-Toe*: A simple 9 square version of Tic-Tac-Toe was created, with the computer serving as the opponent. This game attempts to provide an increased range and speed of movement in the *anterior-posterior* (AP) and *medial-lateral* (ML) directions concurrently. This is accomplished by having the user stand on the mat and shift their weight to move the cursor on the screen, which is the COP indicator.

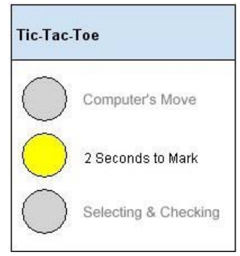

Fig. 1. Tic-Tac-Toe display: currently, the user has 2 more seconds to select their square, as indicated by the yellow light.

The Tic-Tac-Toe display (Fig. 1) shows light indicators for what stage the game is at: Red) signifies that it is the computer's turn; Yellow) signifies that the user may move the COP marker to the square they would like to mark. The number of seconds they have left to move the marker is also indicated. A sound is played for each elapsed second while the user is selecting a square to mark; and Green) if it is the user's turn, the square that the COP marker is on is selected and an X is placed. If the user selects a square that has previously been marked, the game returns to the Yellow state. The game then checks if a line has been formed or if there are no squares available. If the user forms a line, the statement "You Win!" appears in large letters on the screen and a red line is drawn through the winning squares. Performance is then measured by completion of the game.

The number of seconds the user has to move the COP marker is configurable. This allows for the addition of difficulty in two ways: 1) needing to get the cursor to a specific square in a short period of time, thus testing out quick movements; and 2) having a long period of time to get to a specific square and having to sustain the position in the square.

3) *Memory Match*: In Memory Match, the patient must select cards in order to find all of the pairs. This game attempts to provide an increased range and speed of movement in the AP and ML directions concurrently. This is accomplished by having the user stand on the mat and shift their weight to move the cursor on the screen, which is the COP indicator.

The Memory Match display is similar to that for Tic-Tac-Toe, showing the number of pairs found and the light indicators for what stage the game is at: Red) signifies that the game is checking if a pair has been found. When a pair is found, a sound plays and the score is updated; Yellow) signifies that the user may move the COP marker to the square they would like to mark. The number of seconds they have left to move the marker is also indicated. A sound is played for each elapsed second while the user is selecting a square to mark; and Green) the card that the COP marker is on is selected and the object on the card is displayed. If the user selects a card that has previously been selected, the game returns to the Yellow state. The game is over when all the pairs have been found. Performance is then measured by successful completion of the game.

As with Tic-Tac-Toe, the number of seconds to mark parameter is configurable. In addition, Memory Match has two different difficulty levels: 9 cards and 16 cards. A cognitive difficulty is added when 9 squares is selected, as 1 card will be without a pair. Then, when the number of cards is increased to 16, the area the COP must be in to select the card is smaller and thus the COP movement must be more precise.

4) *Under Pressure*: Under Pressure is comprised of two games: 1) Apple Drop: movement in horizontal (ML mode) plane (Fig. 2.); and 2) Target Practice: movement in vertical (AP mode) plane. The goal is to catch objects with a receptacle controlled by COP movement. For ML mode, the user shifts their weight side-to-side to control the COP indicator; similarly, for AP mode, the user shifts their weight front-to-back to control the COP indicator. When an object is caught, a sound is played. These games attempt to provide an increased range and speed of movement in the AP and ML directions.

A display shows the user how many objects they have caught and the total number of objects that have appeared. The game is over when the number of objects reaches a pre-specified maximum number. Performance is then measured by how many objects are caught; ideally the user wants to catch all of the objects. At the end of the game, the total movement range in the ML and AP directions is reported in the game display.

The user can choose from 5 different receptacle sizes and 5 different object speeds. This game becomes difficult when the object speed increases and the receptacle size decreases. However, movement has only one degree of freedom. Thus, as their abilities increase, so should their performance.

D. User Testing

1) *Subjects*: Fifteen subjects volunteered to participate and gave informed consent. Eight subjects were healthy individuals consisting of School of Medical Rehabilitation students and faculty members, with no history of postural problems. Seven subjects were patients with the following demographics: 1) female, age 72, with a right stroke; 2) female, age 62, with a right stroke; 3) female, age 52, with balance impairment indirectly due to chronic low-back pain; 4) male, age 52, with left side stroke (second stroke); 5) male, age 52, with bilateral head injury due to a motor vehicle accident; 6) male, age 15, with left side head injury due to a motor vehicle accident; and 7) male, age 62, with balance impairment etiology unknown. Ethics approval was granted prior to recruiting subjects by The University of Manitoba, Faculty of Medicine, Ethics Committee.

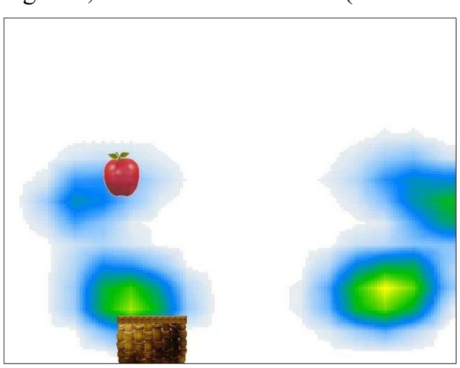

Fig. 2. Screenshot of Under Pressure: Apple Drop, horizontal (ML mode) game.

2) *Experimental Setup*: The forces from each sensor were sampled at 3072 sensors per second, in the AP and ML planes, utilizing an FSA Seat Pressure Mat, from which the vertical COP was calculated. The mat was connected to a PC running the FSA software via the FSA interface module. The monitor of the PC was setup so it was facing the user, so the user could see the game while standing on the mat.

3) *Protocol*: Each subject participated in a 10 minute session for each game. Afterwards, they were administered a questionnaire to be filled out for each game. The questions of the questionnaire were ranked according to: a) I strongly agree; b) I agree; c) neutral; d) I disagree; and e) I strongly disagree. Questionnaires have been shown to provide imperative information regarding game enjoyment, effectiveness and ways in which improvements could be made [6].

The questionnaire for the patients consisted of 9 questions: 1) the game was fun to play; 2) the game increased my motivation to perform my exercises; 3) the game was more fun than my traditional program; 4) I would practice the game more than my traditional program; 5) the game's difficulty levels enhanced the exercise; 6) I felt that the game was too difficult; 7) I felt that the game was too easy; 8) I felt that the game helped me more than my traditional exercises; and 9) I felt that my game performance is something that I can improve over time.

The questionnaire for the healthy subjects consisted of 2 questions: 1) the game was fun to play; and 2) would you incorporate these games into your exercise regime.

III. Results

The results for the patient and normal questionnaires are given in Table 1. Every single subject strongly agreed that the games were fun, motivational and an improvement to their current exercise regime. Subjects also commented that the games offer lots of flexibility with regards to difficulty levels and being able to scale and offset bound values. Another method used to increase the difficulty of the game was the placement of the mat on top of a heterogeneous surface, thus distorting the ground reaction forces. The normal subjects also unanimously agreed that the games would be a welcome addition to their current treatment regimes.

IV. Discussion

In order for a game to be appealing it must offer a challenge [6]. The survey results show that the game offers sufficient difficulty levels and is therefore challenging. In addition, they also felt that game performance was something that they could improve, indicating that the game has a goal which is achievable but not too easy. Positive reinforcement is also important when providing an

TABLE I
Questionnaire results for patient and normal subjects.

Patient Subjects	
Questions	Response
1 – 5, 8, 9	All patients: a) I strongly agree
6,7	All patients: e) I strongly disagree
Normal Subjects	
1	All subjects: a) I strongly agree
2	All subjects: a) I strongly agree

environment that is fun and motivational [6]. When the user finds a pair in Memory Match or catches the object in Under Pressure, their success is reinforced through use of sound. When the user forms a line in Tic-Tac-Toe, a red line is drawn on the screen and "You Win!" appears in large letters. The idea that these features make the games more fun is reinforced by the questionnaire results.

The games developed in this research offer several advantages over the NeruoCom NeuroGames [4]. Firstly, in Tic-Tac-Toe and Memory match, item selection is done independently of aid through use of the 'number of seconds to mark' parameter. In the NeruoGames Puzzle Master and Solitaire, the mouse button must be clicked when the COG marker is on top of the desired item. The mouse button must then be held down while the item is dragged to the desired location. Thus, in order for the patient to independently play the game, they must use the mouse. The use of a mouse in therapeutic games is not desired as: 1) in cases where the patient must hold on to an object to maintain stance, they would not be able to simultaneously operate the mouse; noting that eventually the subject should learn to bear the weight entirely in their legs, as support removes some of the balance task dynamics [3]; 2) in cases where the patient is able to maintain stance on their own, the mouse would provide an unwanted additional tactile input, which has been shown to reduce sway variance [8]. In addition, the patient could offset some of their weight through the use of their hands [3]; and 3) some patients hands and/or arms are paretic and they would therefore not be able to operate the mouse. Secondly, as our games interact directly with the FSA software, the session data can be saved, whereas the NeruoCom and NeuroGames software operate independently and thus data cannot be saved. Load data and pressure maps may also be viewed when playing the games and with Under Pressure, the movement range in both the ML and AP directions is reported. Thirdly, the NeuroCom system has an increased cost compared to the seat pressure mat. Therefore, the seat pressure mat will be available to a wider range of clinics and will thus benefit a larger population. Lastly, the seat pressure mat is easily portable and can therefore be taken to where the patients are, rather than requiring them to come to the clinic; this also makes our system available to a larger population. In addition, the Neurocom system assumes that the COG and COP are equivalent for single-segment inverted pendulum dynamics; however, this is not always true as demonstrated in [9].

V. CONCLUSION AND FUTURE WORK

In this work, an interactive tool, including three biofeedback games that use the COP trajectory as the control input, were designed to aid in pressure balance for rehabilitating persons with balance disorders: Tic-tac-toe, Memory Match and Under Pressure. The tool interacts in real-time with the FSA software and pressure mat. The unit is portable, easy to use and has a reduced cost when compared with NeuroCom's system, making it an ideal system for use in routine clinical applications. The questionnaire results indicated that all patients found the games to be challenging, attractive and more appealing than their traditional exercises. In addition, the normal subjects also agreed that the game was attractive and would enhance their rehabilitation programs.

As the results also indicate that functional and motivational biofeedback will increase the practice time, it is hypothesized that the amount of recovery should increase. Thus as future work, evaluation of the tool will be done by quantifying the amount of recovery, pre-treatment versus post-treatment, for this biofeedback treatment regime; the results will then be compared to the amount of recovery for either no treatment or a more conventional treatment. Another way to increase motivation and fun would be the addition of music and more sounds. Also, the shapes in Memory Match could be replaced with pictures of the user's choice in order to increase emotional appeal [7]. Finally, for increased portability, the code could be exported for use in with a PDA and the games could be developed for use with Vista Medical's pressure mapping insoles.

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