Motivating Motion

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ABSTRACT

In this paper, three biofeedback games that use the *center of pressure* (COP) trajectory as the control input, namely Tic-tac-toe, Memory Match and Under Pressure, were 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 UltraThin Orthotest Mat. The UltraThin Orthotest Mat's flexibility and size affords its use on many different surfaces, for example, treadmills and over-ground walking; it also allows for portable clinics. Thus, the system can be of benefit to a larger population. The trajectory of the COP is important as it provides us with a measure of stability and can be used when evaluating the human postural control system, as it reflects the effect of a balance disturbance and reaction [3,21]. The main goal of this research was to employ fun and motivational learning techniques, using clinically available equipment, to encourage patients to practice their rehabilitation exercises and to retain the patient's attention [5]. Questionnaires regarding the motivational aspects of the games were administered to 15 subjects (7 patients). The results indicate that the games were indeed fun, motivational and an improvement to conventional exercise regimes.

Keywords

Biofeedback, center of foot pressure (COP), motivational, pressure mat, rehabilitative games.

1. 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 every day tasks that are instrumental to living [8,9]. This is especially prevalent amongst chronic disabled individuals (diabetic peripheral neuropathy, stroke, osteoarthritis and joint replacement) and older adults. With the aging of our current population, an increased burden will be placed on our health care system [17].

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Balance disorders can result from loss or deterioration of sensory information that the human postural control system uses to maintain stability [9]. Somatosensory cues comprise one of the three primary sensory inputs to this system. Somatosensation encompasses two different types of spatial information: 1) an internal reference frame or proprioception, in which muscle spindles and joint afferents provide information indicating where one body segment is in relation to adjacent body segments; and 2) an external reference frame or exteroception, which provides information relating where the foot is with respect to the support surface. Of particular interest are the cutaneous exteroceptors, located on the bottom of the feet, which also provide information about the ground reaction forces of the support surface [16,19].

Patients with the neurological disorder diabetic peripheral neuropathy experience loss of touch sensation in the feet (numbness), muscle atrophy/weakness and various atypical perceptions such as tingling, burning or tickling. This results in diminished reception of ground reaction forces. Ergo, diminished somatosensory information is provided, hindering the person's ability to maintain and restore balance during standing and walking activities; this is especially prevalent when outdoors. In addition, persons with prosthetic devices receive limited information about ground contact forces and characteristics. Similarly, many people who suffer a stroke will lose perception of foot sensation and weight-bearing. In these cases, rehabilitation exercises are used in order to re-teach the patients proper loading and dynamic balance techniques.

One parameter that is often used as biofeedback and as an outcome measure in these exercises 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 [3,21]. Thus, the trajectory of the COP is important as it provides us with a measure of stability and can be used when evaluating the human postural control system. The COP can be calculated from the load values as measured by a force sensing array mat; as such, the loading of the feet also provides us with stability information required for mobility.

Conventional rehabilitative exercises depend on the type of injury an individual has sustained. In general, they include standing activities, steppers and over-ground and treadmill walking with and without support from a cane or body harness unloading system [4]. These conventional exercises are now being augmented with biofeedback signals, including *center of mass* (COM), *electromyogram* (EMG), load and COP. The biofeedback signals attempt to realize the biological signal in a visual and/or auditory form, in real-time. This realization can aid the patient in their balance task, as well as the therapist in their evaluation, by providing immediate performance feedback for the exercise/task being performed.

In order to increase practice of the rehabilitative exercises and retain the patient's attention, the exercises should employ fun and motivational learning techniques for the patient to perform [5]. In addition, the lowering of equipment costs increases the range of clinics the system is available to; thus, the system can be of benefit to a larger population. Similarly, if the system is easy to use and portable, then it can be taken to where the patients are, rather than requiring them to come to the clinic. Thus, the main goal of this research was to employ fun and motivational learning techniques, using clinically available equipment, to encourage patients to practice their rehabilitation exercises and to retain the patient's attention [5]. This was done through the creation of three biofeedback games, namely Tic-tac-toe, Memory Match and Under Pressure, which aid in pressure balance for rehabilitating persons with balance disorders. The games were developed to interact, in real-time, with the Vista Medical *Force Sensitive Applications* (FSA) software and UltraThin Orthotest Mat (Vista Medical Ltd, Wpg, MB, Can).

2. METHODOLOGY

2.1 Selecting Biofeedback Signal

There are numerous research groups currently investigating biofeedback for use in rehabilitation exercises. 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.

In [23] the *center of gravity* (COG) with respect to the feet is provided as feedback to the patient. The COG provides a good feedback measure as it represents the overall equilibrium of the system. However, the COM/COG displacement was not considered in this research as the equipment required to reliably determine the COM/COG trajectory (video motion analysis) is not portable, has an increased cost for low to moderately funded clinics and is ergo not readily available for a routine clinical assessment.

In [12], EMG feedback is employed. This is a good procedure to regain muscle coordination, however when relating it to overall postural control, one must consider the EMG signal with regards to motor control outcome or performance. Specifically, in multi-joint systems, different movements (including movements in different directions) can produce the same EMG signal. Due to this, when comparing a stationary task with a walking task, the EMG signal alone could not predict proper movement of the specified task, as it could not predict what task was occurring. In other words, the EMG signal represents a local variable to a given movement and thus can have many different meanings.

In [11], the amount of load for each leg was displayed on an LED. A line also indicated if the weight was equally balanced or towards which leg the balance was skewed. In [6], a visual display of the footprint sensors was given, with a sound being played if the amount of pressure exceeded a predefined threshold. Similarly, in [22] the force at the heels was displayed on an LCD, with an audio tone indicating if the correct force is being applied. In [18], *anterior-posterior* (AP) and *medial-lateral* (ML) displacements of the COP were displayed; different delays were also added to the display to determine their effects on balance. The COP trajectory and load values are commonly used as biofeedback signals, as they are variables that are more global, representing full body performance. These signals can be acquired using the UltraThin Orthotest Mat from Vista Medical. The UltraThin Orthotest Mat's flexibility and size affords its use on many different surfaces, for example, treadmills and over-ground walking; it also allows for portable clinics. Therefore, the system can be of benefit to a larger population. Thus, the COP trajectory was selected to be used as the biofeedback signal in this research.

2.2 COP Biofeedback Delivery Method

The COP and load signals can be acquired using force plates and pressure mapping systems (mats and insoles). Currently, some systems employ visual and audio biofeedback with their pressure mapping technologies to alert the patient to correct and incorrect loading practices [7,14]. The most common visual feedback provided being pressure maps and COP location; the most common audio feedback provided being tones indicating if the minimum or maximum pressure loading is ceded or exceeded.

Another 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 [10, 13]. 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 [14] provides three games that are used to enhance practice and motivation: a puzzle, NeuroPong and Solitaire. In addition, they have a screen where circles appear and the patient has to move the marker into the circle. However in these cases, the 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.

Using these ideas and results, three games (Tic-Tac-Toe, Memory Match and Under Pressure) were 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.

2.3 System Integration

The COP signal will be acquired with the FSA software and flexible UltraThin OrthoTest Mat. Unlike force plates, the UltraThin OrthoTest Mat can be used on many different surfaces, for example, treadmills and over-ground walking. It is 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, making it an ideal system for use in routine clinical applications.

Currently, the FSA system provides visual loading and COP information in real-time; the data can also be saved for offline analysis. Loading is provided via percent value of maximum load

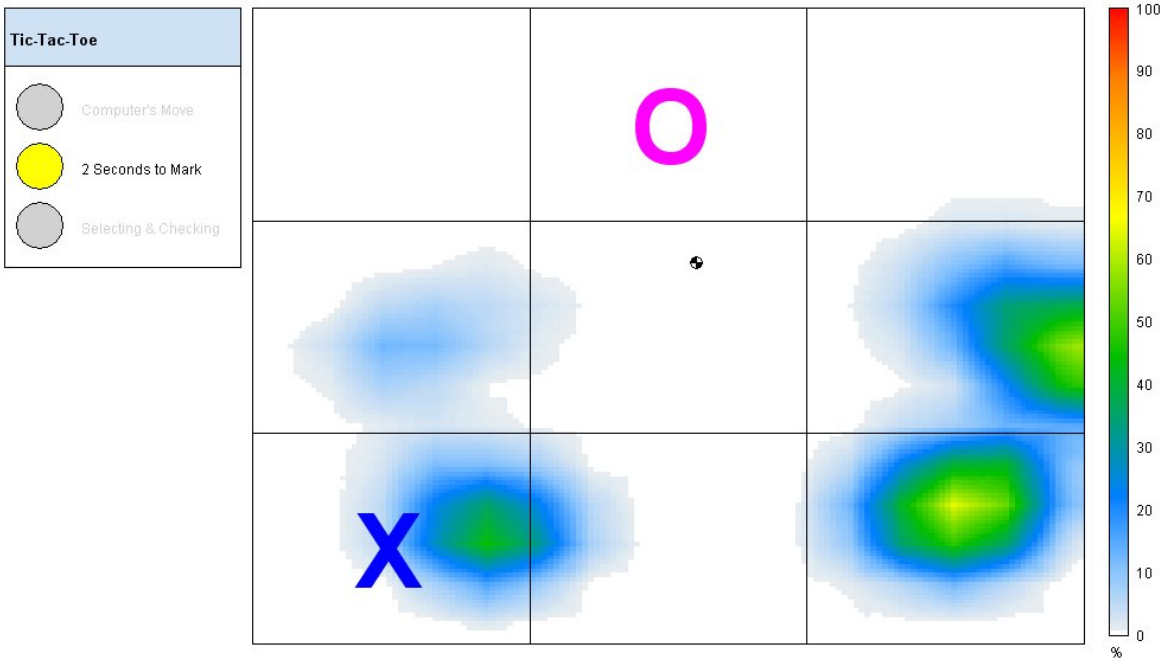

Figure 1. Screenshot of Tic-Tac-Toe: 'X' marks the user's square and 'O' marks the computer's square. Currently, the user has 2 more seconds to select their square, as indicated by the yellow light in the Tic-Tac-Toe display.

per piezo-resistor and given in the form of a gradated scale (0-100%) and pressure graph. The trajectory of the COP is indicated by a black and white dot.

Each game is 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.

2.4 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. Thus, each game has parameters that can be configured in the game's Configuration Dialog, launched from the Options menu on the main FSA screen. Each game offers different levels of difficulty and introduces cognitive distractions. 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.

2.4.1 Initializing Bounds

To determine the patient's limits of stability bounds, Initialize Bounds must be selected in Game Play panel of the game Configuration Dialog. The patient then follows the instructions indicated in the instruction box, located in the upper left corner of the screen. The steps for determining the bounds are as follows: 1) center point coordinate determination; 2) peak detection of self-induced oscillatory movement; and 3) bound indication. The following paragraphs discuss these steps in detail.

In the first step, the patient stands still for a period of approximately 5 seconds. During this time, the ML and AP coordinates for the center point of their movement are recorded. The recorded center values are then averaged.

Next, the patient is instructed to begin oscillating in the indicated direction (either ML or AP). A line is then displayed indicating the center value for the given direction. A peak is recorded as the maximum value of an oscillation on a given side of the center line. Five peaks are determined per side, with the average value being recorded as the bound. In the AP direction, top and bottom bounds are determined. Similarly, in the ML direction, left and right bounds are determined. Finally, the determined bounds are indicated on the screen and game play can begin. The cursor movement for the game is then set to be within these bounds.

As movement in the game Under Pressure has only 1 degree, the direction of the oscillation will correspond to the mode of the game; if horizontal, the direction will be ML and if vertical, the direction will be AP. In Tic-Tac-Toe and Memory Match, movement has 2 degrees; therefore, step 2 is first performed in the ML direction and then in the AP direction.

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. This value is entered in separately for each of the bounds, in fields located in the games Configuration Dialog. If the bounds can be easily reached, entering a value greater than 100% will make the playing area larger. Likewise, if the patient is having difficulty reaching the bounds, entering a value less than 100% will decrease the play area.

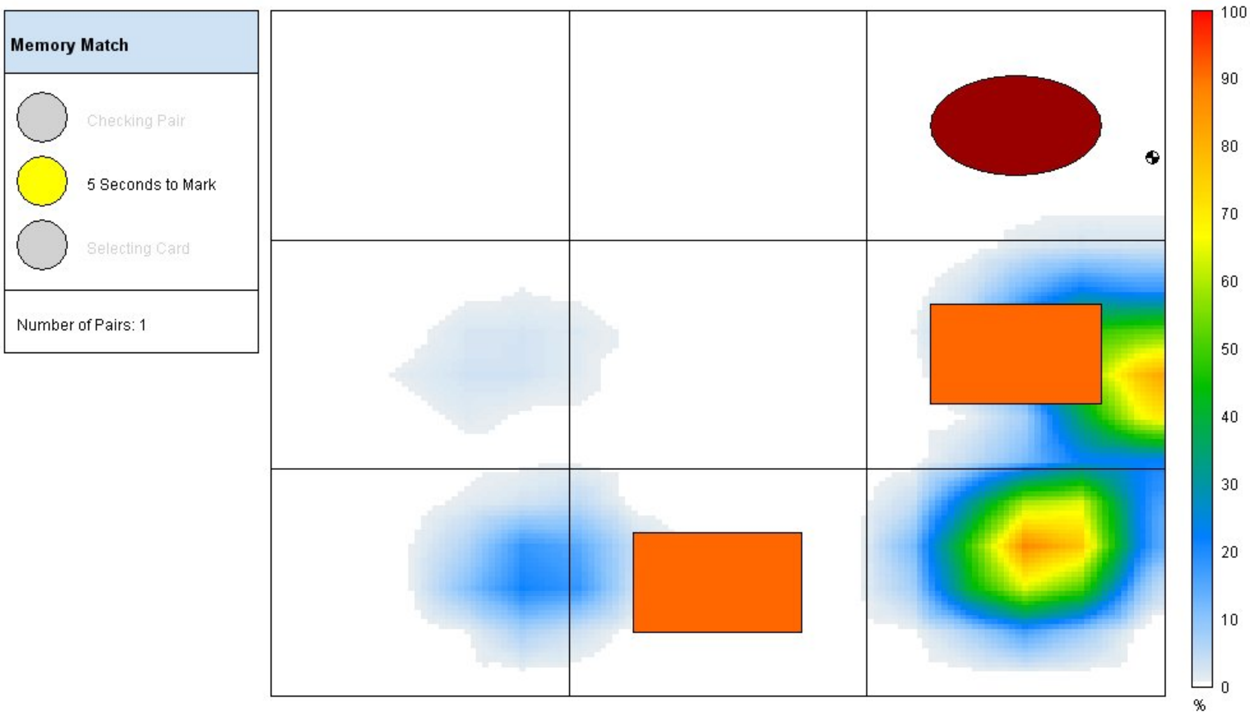

Figure 2. Screenshot of Memory Match: the game is set for 9 squares. Currently, the user has found 1 pair and has 5 seconds left to select the second card.

Another difficulty arises with patients who have weight-bearing disorders. In these cases, the weight distribution between their legs is asymmetric and 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; the value is entered separately for the ML and AP directions, in fields located in the games Configuration Dialog. Entering a value greater than 0% offsets the center to the right or bottom and entering a value less than 0% offsets the center to the left or top.

If the bounds cover a small number of sensors, the resulting movement of the COP may appear jerky. In order to smooth the movements, the COP value can be averaged over the number of samples set in the Window Size field in the games Configuration Dialog.

2.4.2 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 AP and ML directions concurrently, by having the user move the cursor via their COP movement.

A screenshot of Tic-Tac-Toe, with X marking the user's play and O marking the computer's play, is given in Figure 1. In the upper left corner is the Tic-Tac-Toe display showing 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 will play 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, "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.

In the Configuration Dialog for Tic-Tac-Toe, a value can be entered for the number of seconds the user has to move the COP marker to the square they wish to mark. This parameter 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. However, this game is easier as the computer also marks squares.

2.4.3 Memory Match

In Memory Match, the patient must select cards (two at a time) and find all of the pairs. This game attempts to provide an increased range and speed of movement in the AP and ML directions concurrently, by having the user move the cursor via their COP movement.

A screenshot of Memory Match with 9 squares is given in Figure 2. In the upper left corner is the Memory Match display 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

Figure 3. Screenshots of Under Pressure: Apple Drop, horizontal (ML) game mode. Currently, the user has caught 1 apple out of 7 and the basket is set to the largest size.

sound will play 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.

In the Configuration Dialog for Memory Match, a value can be entered for the number of seconds the user has to move the COP marker to the square they wish to mark, and for the total number of squares (cards).

As with Tic-Tac-Toe, the number of seconds to mark parameter 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. 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.

2.4.4 Under Pressure

Under Pressure is comprised of two games: 1) Apple Drop: if horizontal (ML) mode is selected in the Configuration Dialog; and 2) Target Practice: if vertical (AP) mode is selected in the Configuration Dialog. In Apple Drop, the user must catch the falling apples in a basket. Similarly, in Target Practice, the user must make the arrows hit the target. 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, by having the user move a cursor in either the AP or ML direction via their corresponding COP movement.

Screenshots of Under Pressure are given in Figures 3 and 4. In the upper left corner of Figure 3 is the Apple Drop display showing the number of apples dropped so far and the current score, i.e., how many apples have been caught in the basket. Likewise, in the upper left corner of Figure 4 is the Target Practice display showing the number of arrows launched so far and the current score, i.e., how many arrows have hit the target. The game is over when the number of objects reaches a maximum number as indicated in the Configuration Dialog. Performance is then measured by how many objects are caught by their respective receptacles; 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.

In the Configuration Dialog for Under Pressure, the user can choose from 5 different receptacle sizes and 5 different object speeds. For the object speed, a value between 0 and 4 is entered, with 0 being the slowest and 4 being the fastest. For the receptacle size, a value between 0 and 4 is entered, with 0 being the smallest and 4 being the largest. 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.

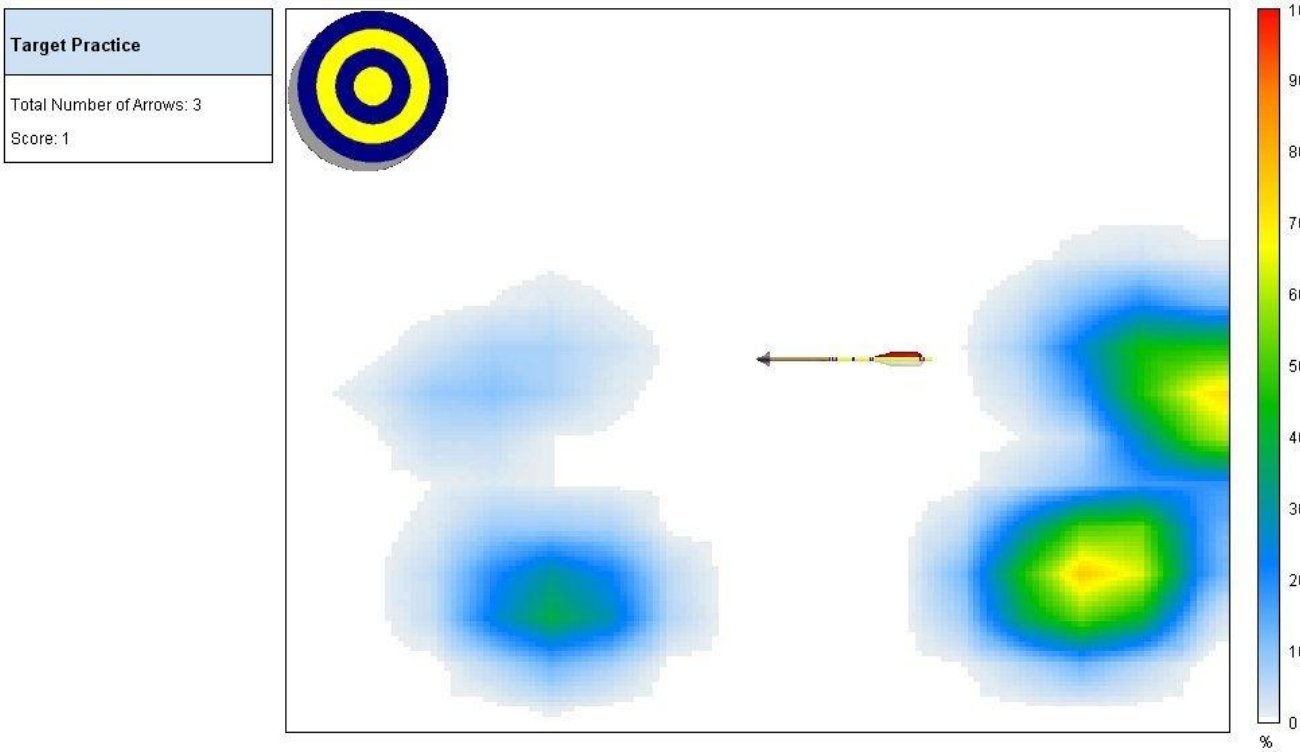

Figure 4. Screenshots of Under Pressure: Target Practice, vertical (AP) game mode. Currently, the user has caught 1 arrow out of 3 and the target is set to the largest size.

2.5 User Testing

2.5.1 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, possibly a small stroke and peripheral vestibular disorder. Ethics approval was granted prior to recruiting subjects by The University of Manitoba, Faculty of Medicine, Ethics Committee.

2.5.2 Experimental Setup

The forces from each sensor were sampled at 3072 sensors per second, in the AP and ML planes, utilizing an UltraThin FSA OrthoTest 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.

2.5.3 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 [10].

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 School of Medical Rehabilitation students and faculty members consisted of 2 questions: 1) the game was fun to play; and 2) would you incorporate these games into your exercise regime.

3. 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.

Table 1. Questionnaire results for patient and normal subjects; subject responses were unanimous for all questions.

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

The normal subjects also unanimously agreed that the games would be a welcome addition to their current treatment regimes.

4. DISCUSSION

In [10] they state that in order for a game to be appealing it must offer a challenge. 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 environment that is fun and motivational [10]. 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 [14]. Firstly, in Tic-Tac-Toe and Memory match, games where items must be selected, the 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 must 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. It should be noted, however, that eventually the subject should learn to bear the weight entirely in their legs [5]. In addition, having support removes some of the dynamics of the balance task; 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 [15]. In addition, the patient could offset some of their weight through the use of their hands [5]; and 3) some patients (for example stroke 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 UltraThin OrthoTest Mat. Therefore, the UltraThin OrthoTest Mat will be available to a wider range of clinics and will thus benefit a larger population. Lastly, the UltraThin OrthoTest 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 [1].

5. CONCLUSIONS AND FUTURE WORK

In this work, 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 games interact in real-time with the Vista Medical Force Sensitive Applications (FSA) software and UltraThin Orthotest 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, fun and more appealing than their traditional exercises. In addition, the normal subjects also agreed that the game was fun and would enhance their rehabilitation programs. The results of the questionnaire also indicate that inclusion of biofeedback that was not only functional but also motivational will increase the amount of time that a patient performs their rehabilitative exercises. It is thus hypothesized that since the exercises are performed for a longer duration, the patient's amount of recovery should increase. Thus as future work, evaluation of the games 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. Methods of evaluating the amount of recovery will include: 1) utilizing the Berg Balance Scale [2]; and 2) the Sensory Organization Test [20].

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 [13]. Currently, the load values and pressure maps can be displayed during game play; an extension would be to represent these signals so they are not as prevalent and thus do not interfere with game play. 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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