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Development and User Evaluation of a Virtual Rehabilitation System for Wobble Board Balance Training

Diarmaid Fitzgerald, Nanthana Trakarnratanakul, Lucy Dunne, Barry Smyth, Brian Caulfield

Abstract—We have developed a prototype virtual reality-based balance training system using a single inertial orientation sensor attached to the upper surface of a wobble board. This input device has been interfaced with Neverball, an open source computer game to create the balance training platform. Users can exercise with the system by standing on the wobble board and tilting it in different directions to control an on-screen environment. We have also developed a customized instruction manual to use when setting up the system. To evaluate the usability our prototype system we undertook a user evaluation study with twelve healthy novice participants. Participants were required to assemble the system using an instruction manual and then perform balance exercises with the system. Following this period of exercise VRUSE, a usability evaluation questionnaire, was completed by participants. Results indicated a high level of usability in all categories evaluated.

I. INTRODUCTION

VIRTUAL reality technology is increasingly being used as a tool for physical rehabilitation in many patient groups [1]. Virtual rehabilitation systems provide a real time computerised simulation of a patient in a two or three dimensional virtual environment to enhance feedback and improve enjoyment during exercise. Usability evaluation studies must be carried out on prototype virtual rehabilitation systems to maximize their potential. Many different methodologies, both quantitative and qualitative, for usability evaluation have been reported such as cognitive walkthroughs, formative evaluation, heuristic evaluation, post-hoc questionnaires, interviews and summative evaluations [2]. These studies can be undertaken with either experts in a related area or subjects from the end user group and can be part of a multi-step evaluation process. In this paper we describe a usability evaluation performed on a prototype virtual reality-based balance training system with a sample of

healthy novice participants. This study was carried out to measure usability in an end user population and identify areas where refinements to the system may be required.

Balance training has been prescribed for many years by therapists for a range of conditions such as musculoskeletal injuries [3, 4], neurological pathologies [5] and management of elderly care [6-8]. Balance programmes involve activities and/or use of devices that challenge a patients' static and/or dynamic balance. A commonly used device to facilitate balance training is a wobble board which is composed of a hemispherical shaped undersurface and flat upper surface on which a user stands (Fig 1 and 2).

Recent studies have reported positive outcomes for virtual reality-based therapeutic exercise programmes [6, 9, 10]. We have developed a virtual balance training system with the aim of harnessing the interactive benefits of a virtual reality computer game-type system. This was done in attempt to improve enjoyment during exercise for users and to provide a tool for therapists to aid compliance with exercise programmes. We interfaced a wobble board with a computer game using a single orientation sensor as is described in section II.

Similar balance training systems have been previously developed which come under the overlapping categories of virtual reality, augmented reality, exergaming (video games incorporating a form of exercise as input control) and biofeedback systems. Video games such as the recently launched Nintendo balance board, a peripheral device for the Nintendo Wii (Nintendo, Washington, USA), which uses pressure sensors embedded in a platform, allow players to interact with an onscreen avatar to play games and exercise. Audio and visual-based biofeedback systems such as the Biodex Balance System SD™ (Biodex Medical Systems, Shirley, New York, USA) uses a standing platform and screen providing real time feedback to correct balance deviations during static and dynamic tasks.

The next section will describe the development of our balance training system. Section III will outline the user evaluation methodology with results reported in Section IV. Finally the section V will outline the findings of the study, suggest modifications to improve the system and any discuss other issues encountered during the study.

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II. SYSTEM ARCHITECTURE AND SETUP

A. Hardware

The virtual balance training system was developed solely using off-the-shelf components. These included a wobble board (concept wobbler, Jakobs, Germany), an orientation tracker (Xsens MTx Motion Tracker, Xsens Technologies, The Netherlands), an RS-232 USB communication cable (Xsens Technologies, The Netherlands), a laptop (Dell Inspiron 6400, USA), sticky tape (Blenderm™ surgical tape, 3M, Minnesota, USA) and a custom written user manual, all shown in figure 1. To render the wobble board an input controller for the system we simply attached an MTx motion tracking sensor to its upper surface by using sticky tape. The MTx motion tracker is an inertial-based orientation sensor allowing 3 degrees of freedom therefore tracking the 3D



Fig. 1. System components dismantled prior to evaluation session. These include in clockwise from top left corner the instruction manual, wobble board, Xsens MTx motion tracker, Xsens RS-232 cable, Blenderm™ surgical tape, Dell Inspiron laptop.



Fig 2. Setup for the virtual balance system during exercise.

orientation of the wobble board using the exercise setup as shown in Figure 3. Motion data is relayed to the computer through the RS-232 USB cable allowing real-time tracking.

B. Software and Game Play

We employed an open source computer game known as Neverball [11] to provide the on-screen virtual environment for the system. Once the com port number for the RS-232 cable is configured in Neverball application files, game setup is straight forward requiring the user to mouse-click on a desktop shortcut and game levels. Game play during Neverball requires the player to tilt the on-screen floor to roll a ball through an obstacle course and collect virtual coins before time runs out (Fig 3). As the MTx tracker is fixed on the wobble board, tilting the wobble board will tilt the on-screen floor allowing the user to play the game. Many progression levels and features are available.

III. METHODOLOGY

A. Participants

Twelve healthy participants of mean (SD) age of 25.4 (5.8) years of age volunteered for this study (six female and six male). Prior to testing a participant information leaflet was read, informed consent was signed, and each subject completed the Physical Activity Readiness Questionnaire [12].

B. Data Collection

Usability evaluation was conducted by using VRUSE, a computerised usability questionnaire designed specifically for the evaluation of virtual reality applications [13]. VRUSE is composed of 100 five-point Likert scale-type questions divided into 10 separate usability categories:

- 1) Functionality
- 2) User Input
- 3) System Output (Display)
- 4) User Guidance and Help



Fig 3. Screen shot of the Neverball game environment.

- 5) Consistency
- 6) Flexibility
- 7) Simulation Fidelity
- 8) Error Correction/Handling and Robustness
- 9) Sense of Immersion/Presence
- 10) Overall System Usability

Each section is made up of 6-20 questions and was used to systematically examine participants' perceptions during this usability evaluation.

The questionnaire has two distinct types of questions. Participants must select strongly agree, agree, undecided, disagree or strongly disagree for specific usability questions. These makes up all of the questions apart from the last question in each category in each category which is designed as an overall assessment of the particular category where participants must chose very satisfactory, satisfactory, neutral, unsatisfactory or very unsatisfactory for each overall usability statement. An optional comment section is also provided beside each question for participants to describe any problems they encountered or suggestions for improvement of the system.

For this particular study the section on 'user guidance and help' was omitted as there was no functionality in the game to provide any user help. A high reliability level has been previously reported for VRUSE and the questionnaire author states this capability to disregard complete sections prior to evaluation if required for evaluation experiments [13]. VRUSE was administered in a Microsoft Excel file format (Microsoft Corporation, Redmond, Washington, USA) with a drop down box for easy data entry by participants.

C. Experimental Protocol

All system components were provided in a dismantled fashion prior to testing as shown in fig 1. We designed an instruction manual which described a step by step method of how to set up and use the system so as to test usability from just-out-of-the-box through to exercising/game play. The instruction manual was pilot tested with two subjects and refinements made prior to the usability study. During testing, each subject was instructed to use the instruction manual, setup the system, and play level 1 and 2 using the wobble board interface. All participant questions and comments were noted during evaluation, and appropriate answers provided by the researcher. Immediately following completion of the balance exercises, the abridged VRUSE questionnaire was completed by each subject, and a transcript of any comments they posed was subsequently saved to their Excel file.

D. Data Analysis

All participant scores for each of the nine sections evaluated were exported to another spreadsheet and mean scores and standard deviations for each category were calculated. User comments were tabulated into groups with a common theme/topic.

TABLE I
MEAN AND STANDARD DEVIATION FOR SPECIFIC
USABILITY SCORES

Usability Category	Max*	Min ⁺	Score ± SD
Functionality	35	7	29.67 ± 2.77
User Input	70	14	54.25 ± 5.01
System Output	100	20	83.67 ± 6.08
Consistency	40	8	34.92 ± 3.09
Flexibility	30	6	22.67 ± 2.42
Simulation Fidelity	55	11	45.25 ± 6.18
Error Correction	35	7	24.67 ± 3.23
Sense of Immersion	50	10	37.75 ± 5.53
Overall System Usability	55	11	48.00 ± 3.49

*Figures indicates the maximum possible score for individual categories

⁺ Figures indicates the minimum possible score for individual categories

TABLE II
MEAN AND STANDARD DEVIATION FOR OVERALL
USABILITY SCORES

Usability Category	Max*	Min ⁺	Score ± SD
Functionality	5	1	4.42 ± 0.67
User Input	5	1	4.25 ± 0.87
System Output	5	1	4.75 ± 0.62
Consistency	5	1	4.75 ± 0.62
Flexibility	5	1	4.17 ± 0.83
Simulation Fidelity	5	1	4.25 ± 0.87
Error Correction	5	1	4.42 ± 0.79
Sense of Immersion	5	1	4.08 ± 0.90
Overall System Usability	5	1	4.83 ± 0.58

*Figures indicates the maximum possible score for individual categories

⁺ Figures indicates the minimum possible score for individual categories

TABLE III
SUMMARY OF PARTICIPANT COMMENTS DURING USER
EVALUATION

No.	Participant comment*
1	a. There was a delay between initiation of movement and reaction of the ball b. It was difficult to control the ball c. The sensor should be more sensitive
2	The statement in question 33 (When I move my head the image update was acceptable) is not applicable for this game/system
3	The game did not work initially due to a problem with the USB connection
4	Provide a definition sheet to accompany VRUSE to explain difficult terminology
5	Prior to beginning provide instruction on what type of footwear to wear during exercise

*Many comments were repeated by different evaluators and so the main point is only stated once to avoid repetition.

IV. RESULTS

Mean and standard deviation values for specific scores are listed in table 1 and a graphical representation of including dynamic ranges as shown in Fig 4. Overall scores are listed in table 2 and user evaluation comments are shown in table 3.

V. DISCUSSION

The virtual balance training system demonstrated a high level of usability in all evaluation categories, as shown in tables 1 and 2. Inspection of the usability scores show 'sense of immersion' and 'flexibility' are the lowest scoring categories. In our virtual reality system the users were only partially immersed using an on-screen environment as they could still see the real world environment around them i.e. the walls, floor and table in the room etc. Full immersion can only be achieved using a head mounted display or CAVE setup (Cave Automatic Virtual Environment which is a room sized cube with a virtual world projected onto all walls). This may explain why sense of immersion scored slightly below other categories although in general scoring high with 4.08 out of a maximum of 5 in the overall usability (table 2). The flexibility score was also slightly below the other categories (4.17 out of 5) and may have been due to users only being allowed to play one game and not many options were provided. This was due to the fact that we only intended to evaluate one particular game.

User comments (table 3) identified five specific issues to be addressed. The first comment reports the delay in change in direction of the ball following tilt of the wobble board. This occurred because the sensor controls the tilt of the on-screen floor and not the movement of the ball directly resulting in a slower change of direction of the ball. Another possible factor that could alter the accuracy of the simulation may be drift in the motion tracking sensor which, although minimised by the sensor design, can reduce the accuracy of the sensors if operated in close proximity to ferromagnetic materials [14]. A study to compare usability of our system interfaced with a different computer game, which allows a greater level of control of the on-screen object directly, may be useful e.g. a racing car game.

The second participant comment arises due to a problem with question 33 in VRUSE which has been designed to assess the accuracy of the image update of a head mounted display unit and therefore not applicable for assessing this game/system. The questionnaire author recommends that only complete sections and not individual questions can be discarded for experiments [13] so the question was left in the questionnaire as the other category questions provided an important evaluation of the display during game play.

The third comment reported an error that occurred with the USB connection as it was not fully plugged in for one participant and in another case the com port number was not properly configured in the Neverball application files.

A possible system modification would be to provide a warning sign if input control is not sensed and on-screen instruction of how to fix the problem by adjusting com port number.

The fourth comment indicates the difficulty some participants had in comprehending some of the virtual reality language used in questions. Some of these needed explaining for our non-computer science participant population e.g. sense of immersion/presence. A simple definition list could make the questionnaire more user friendly and easier for participants to complete.

The last comment addresses the issue of footwear to worn while performing this challenging exercise on the wobble board. Advice should be provided in the user manual to wear running shoes with good grip as opposed to shoes that may be uncomfortable or slippery during exercise.

This investigation has demonstrated the value of a systematic approach to usability evaluation in the process of development of virtual rehabilitation systems. We have employed a standardised questionnaire that has previously been subject to psychometric testing [13]. This will allow comparison with subsequent versions of the system and comparison with other systems that employ the same usability evaluation approach. However, the different dynamic ranges used to quantify specific usability categories in VRUSE did not render easy comparison between categories and a questionnaire with the same scoring system for sections would allow more accurate between category comparisons.

From our experience in this study we have found that user comments provide essential insight into specific usability scores. These comments allow evaluators to gather precise user feedback such as modification suggestions and problems they encountered during system use. Researchers carrying out these experiments should encourage participants to make comments while completing the questionnaire and also probe participants for details of their thoughts on the system following completion of the questionnaire.

The clinical implications of this research are that the system described showed a high usability score and therefore after final refinements could potentially be used as part of a home exercise programme for balance training. Caution must be taken with certain patient populations with altered balance that may require further support during exercise for neurological patients and elderly care e.g. exercise between parallel bars.

VI. CONCLUSION AND FUTURE WORK

Usability evaluation is an essential step in the development process of virtual rehabilitation systems and VRUSE is a useful method of quantitatively benchmarking and evaluating the interaction of potential users. Future work with this balance system will involve modifications as discussed above and a training effects study that will compare virtual reality methods to the

conventional methods of wobble board balance training. This study will assess measures of balance, physical function and motivation to exercise in the two study groups before and after completion of a balance exercise programme to examine the benefits of using virtual reality during exercise.

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