Development of an interactive stepping game to reduce falls in the elderly

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ABSTRACT

More than one-third of people over the age of 65 experience falls each year, and those who fall once are two to three times more likely to fall again. A fall can significantly limit a person's ability to remain self-sufficient. Fall injuries are responsible for significant disability, reduced physical function, and loss of independence. However, falls are not an inevitable result of aging. Systematic reviews of fall intervention studies have established that prevention programs can reduce falls. Physical activities, including strengthening exercises, tai chi, dancing and walking have been demonstrated to improve balance and decrease risk of falls in older adults. Modified dance-based exercises that include step-based movements have been demonstrated to improve endurance and balance in older adults. Dance video games, using a dance mat with areas that the player must step on in time with cues on the screen, have been demonstrated to improve activity and mood and reduce weight in children and youth. However, these dance games often include fast paced music, frequent jumping and an overload of visual information, movement and colors on the screen. This paper outlines the development of a prototype rhythm game that leverages the benefits of step-based exercise and dance video games to improve balance and reduce falls in older adults.

1. INTRODUCTION

Balance is the ability to maintain the body's center of gravity (COG) over the base of support (BOS) and requires full integrity of an elegant and complicated biological system. Balance can be described as being either static (maintaining postural stability while standing quiet) or dynamic (maintaining postural control during voluntary movement) (Shumway-Cook and Woolacott 2007). Postural control is the ability to maintain an upright position (in sitting or standing) when stationary or performing activities. The postural control system incorporates 1) sensory detection (through the visual, vestibular, auditory, kinesthetic and somatosensory systems), 2) integration of sensorimotor information within the central nervous system and comparison with external environment and, 3) proper coordinated movement patterns and responses (Shumway-Cooke and Woolacott 2007).

Balance relies on the visual, somatosensory and vestibular sensory systems. When damage occurs to one or more of these systems, balance impairment will result. An inability to correctly maintain COG over the BOS results in impaired balance. More specifically, loss of the ability to accurately assess (or sense) the position of the COG relative to the BOS will disrupt balance. When automatic movements to maintain balance are triggered too slowly or ineffectively, balance will become distorted.

Impairments impacting balance, such as muscular weakness, proprioceptive deficits, limitations in range of motion and visual/vestibular deficits, can lead to falls and restrict an individual's normal motor activities, limiting independence and affecting quality of life (Laughton et al., 2003). Changes associated with aging include a decrease in visual acuity, hearing, muscle strength, coordination and reflexes. These changes can make older adults more likely to fall. More than one-third of people over the age of 65 experience falls each year, and those who fall once are two to three times more likely to fall again. A fall can significantly limit a person's ability to remain self-sufficient. Fall injuries are responsible for significant disability, reduced

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physical function, and loss of independence. However, falls are not an inevitable result of aging. Systematic reviews of fall intervention studies have established that prevention programs can reduce falls (Sherington et al., 2008).

Physical activities, including strengthening exercises, Tai Chi, dancing and walking have been demonstrated to improve balance and decrease risk of falls in older adults. Dancing is a fun, physical and an expressive activity open for participation by people with all levels of coordination. Modified dance-based exercises that include step-based movements have been demonstrated to improve endurance and balance in older adults (Hopkins et al., 1990; Shigematsu et al., 2002; Hui et al., 2008). Dance involving stepping in time to a beat can improve and maintain strength, balance and coordination. Dancing can also increase body awareness, kinesthetic awareness, challenge attention and improve self-esteem and confidence (Hopkins et al., 1990; Shigematsu et al., 2002; Hui et al., 2008).

Dance video games, using a dance mat with areas that the player must step on in time with cues on the screen, have been demonstrated to improve activity and mood and reduce weight in children and youth (Unnithan et al., 2005; Tan et al., 2002; Hindery 2005). These dance games often include fast paced music, a frequent jumping and an overload of visual information, movement and colors on the screen and have not been tested in elderly populations. Furthermore, the use of a dance-pad limits the amount and versatility of the stepping pattern.

The objective of this study was to develop low-cost camera tracking technology for multiple limbs in order to develop a step-based rhythm game that caters specifically to adults over the age of 65 years.

2. METHODS

2.1 Existing Technology

A number of step-based games are currently available for commercial video game consoles. The objective of Dance Dance Revolution style games, available on the Nintendo® Wii™, Microsoft® Xbox and PlayStation®(PS2 and PS3) platforms, is to either tap or step on a sensor located on a soft mat/pad or platform under the player's feet (Figure 1). Points are scored if the player taps or steps on the sensor at precisely the right time and in time with the music. The cues on the screen indicate the direction in which the player is required to move their feet in order to score points. The player must step on the corresponding sensor as the moving cue arrow on the screen overlaps the stationary target arrow (Figure 1). The levels range from 1 – 10; the most difficult levels have increasingly fast moving arrows. Dance Dance Revolution style games are fast paced and require speed (often over 110bpm), coincident timing, attention and intact balance. However, even at the lowest game level, the movements are likely to be difficult for some older adults to complete successfully and safely. The background and graphics can be distracting and there is limited ability for alteration in speed, music style, and visual stimuli.

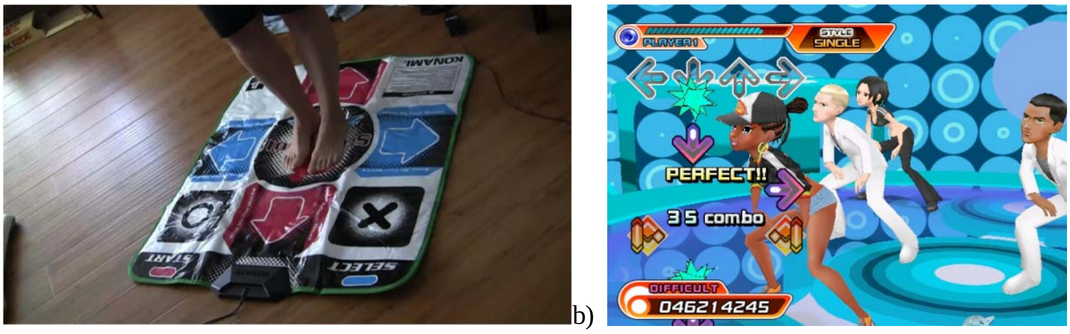
a) 

Figure 1. *a) Dance Dance Revolution (DDR) dance pad, b) Screenshot of DDR SuperNova game.*

The Hasbro U-dance™ has taken dance games away from the standard mat format and introduced the ability to play a step-based game without being limited to the dance mat. Hasbro released this free style dancing game in 2008. It is not a traditional console game; the infrared camera tracking system plugs directly into the TV. With reflectors attached to their shoes, the player sees a representation of their feet on the screen. The goal of the player is to move their foot so that the representation of their foot moves to the corresponding area on the screen where a target foot is located. Whilst providing more freedom for step-based training, the U-dance™ has a limited choice of songs, contains a large amount of jumping movements, and provides negative feedback if the player is not performing well.

Figure 2. Udance^{TM} *system (www.u-dance-game.com).*

Although commercially available options exist for step-based training, the games do not cater to varying levels of ability. The use of commercially available games for physical/balance training could provide participants with a negative experience in which the tasks they are required to perform are too difficult, potentially reducing motivation and self-confidence.

Researchers have begun to explore the use of modified Dance games for older adults in which the key aspects of balance training can be controlled and measured. Smith et al. (2009) developed a modified version of Dance Dance Revolution, using a dance pad and computer based interaction programmed in MatLab. A series of studies was performed in older adults over the age of 70 years. During the simple step task, drift speed and step rate of visual cues were modified. The results of the study confirmed that performance errors (poorly timed steps, incorrect targets) increased with an increase in speed and step rate. Optimal step rate for the sample was found to be one step every two seconds.

Touchtown's Dancetown Fitness system® incorporates assessment tools (Senior Fitness test, Timed Up and Go, Tinetti Balance and Gait Test and Six-Minute Walk Test), slower dance step movements and age-appropriate music for training older adults using a Dance Dance Revolution dance pad system. However, no published literature exists supporting the effectiveness of the system to assess and train balance in older adults.

2.2 System Development

The objective of this study was to develop low-cost camera tracking technology for multiple limbs in order to develop a step-based rhythm game that caters specifically to adults over the age of 65 years. The use of a dance pad can limit weight-shift from limb to limb, encouraging a step and tap task to be performed. A functionally realistic step pattern is rarely performed when using a dance pad. Therefore, this computer based activity interfaces with camera tracking equipment that sends real time information about the player's foot movements to the game. The system consists of a PC, two Logitech web cameras and two different colored LED devices (Figure 3). The LED devices have been designed to attach to the right and left shoe of the user with an adjustable band (Figure 4). The system incorporates an algorithm of feature point based motion tracking using two web cameras. The algorithm was developed to track two LED objects independent of one another in real-time 3D space. The steps involved in this process were to correctly indentify the feature points in an image sequence, find the trajectories of these points and model the tracking result and use epipolar geometry to construct these points in 3D environment.

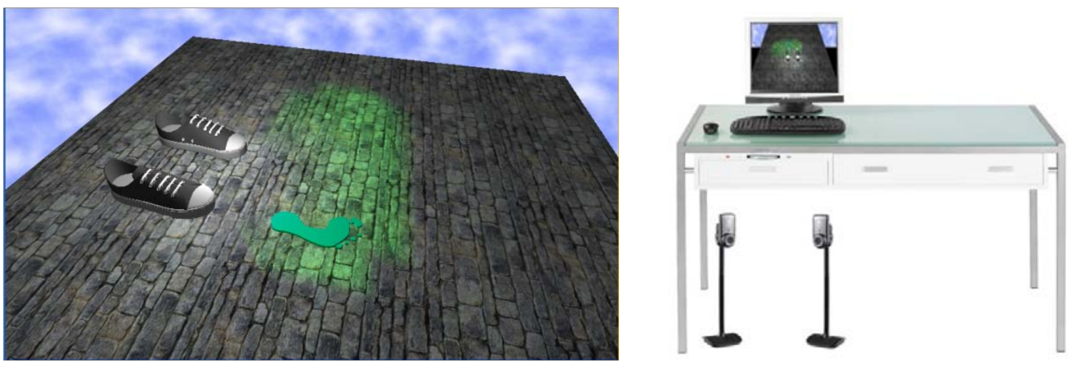


Figure 3. *a) Screen shot of game prototype, b) Set up of screen and cameras.*

Figure 4. *LED devices attached to right and left shoes of the user (tracked by web cameras).*

The game-based interaction was developed using Microsoft Visual Studio 2008 and Ogre3D, an open source gaming engine. At this early prototype stage, the goal of the game is for the player to control two shoes on the screen. The player is given cues on the screen to move the left and right shoe toward green and orange targets respectively. The resulting interaction involves the player using their own foot movement to control the shoes on the screen in time to a steady beat. The user must follow a set of color-coded footprints on the screen. When the target footprint is captured a sound effect is generated to provide extrinsic knowledge of performance to the player.

A key aspect of the development of this interaction is the gameplay options menu, in which players can adjust the speed, target pattern and difficulty level. The user has the option to change the speed of the stimuli, the step length, the color of the shoes, the pattern of movement and the background, allowing the game prototype to be individualized for the user. The available backgrounds range from a simple grey background, to more complicated brick patterns and a distracting flashing light pattern (figure 5). The features within the footprint pattern that can be controlled are the direction where the footprint will move to (left, right, up, down, diagonal), speed of cues and step length. The footstep sequence for the user, including step length and moving pattern can be calculated via a look-up table. Figure 6 demonstrates examples of possible step patterns.

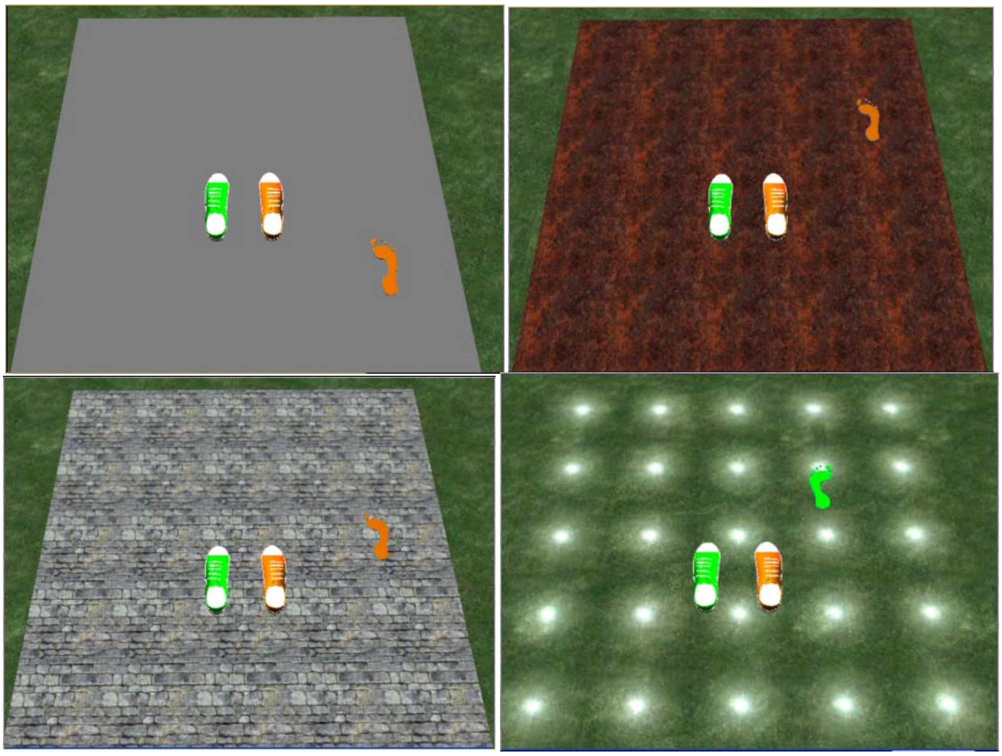
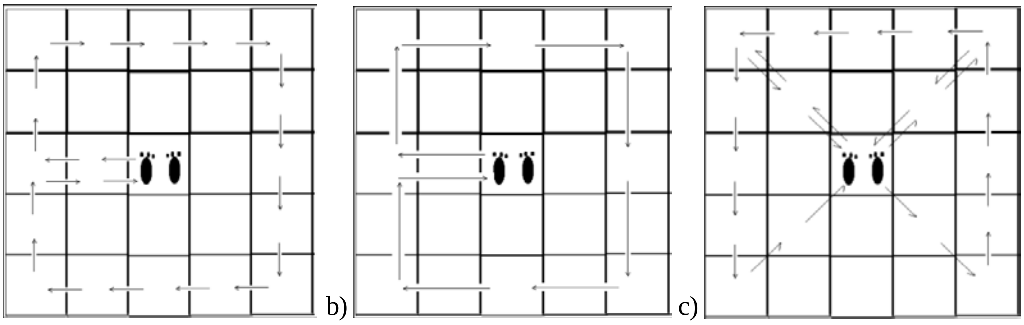


Figure 5. *Background options for game prototype: simple grey, brick pattern, rusty pattern, flashing light pattern.*



a) b) c)

Figure 6. *Possible step patterns calculated using the look-up table. Patterns can be set before starting the game. a) Footprint pattern move around a full circle with 1 unit length for each step (total steps of both left and right feet is 42); b) Footprint pattern moves around a full circle with 2 unit length for each step (total steps = 22); c) More complex footprint pattern with diagonal directions (total steps = 50).*

3. RESULTS

3.1 Initial Assessment of System

3.1.1 Procedure. The prototype system underwent preliminary usability assessment with a sample of three physical therapists and four young healthy participants (aged 16-43 years). Four of the seven participants had previous experience of playing Dance Dance Revolution. Each of the participants were asked to attach the LED devices to the left and right feet, stand in front of the camera (a one camera system was tested in this initial assessment) and follow the instructions on the screen. The participants were asked to comment on their experience through a semi-structured interview consisting of open-ended questions. The researchers also manually recorded observations of the interaction. All participants were able to attach the LED devices to their shoes, without assistance and performed the interaction following a short learning period. Participants experienced slow (0.5 step/sec), moderate (1 step/sec) and fast (2 steps per second) cue rate, all four background options and performed two different movement patterns.

3.1.2 Outcomes. All participants reported enjoying the experience. For two therapists and one adult participant, the devices became unattached during the interaction. The strap was easily repositioned. Physical Therapists supported the further development of this system for use as a balance-training tool. Two therapists indicated that the step length was not large enough and requested a larger step length option. One therapist suggested that an outline of possible step patterns be added to the lookup table for a wider variety of movements. Participants offered suggestions for a number of potential improvements to the prototype. First, each of the participants reported the fast cue rate was too fast to follow. When asked to compare this device with Dance Dance Revolution (DDR), the participants described the freedom of foot movement as a benefit of the prototype, however the music and variety of game play in DDR was still more appealing. Some participants provided other timing based themes for gameplay to be considered and brainstormed in more detail by the research team.

The investigators noted many smiles and laughter while interacting with the device and software. In order to increase the step area, the investigators noted during the interactions that camera placement would require a stand that can be altered in height and angle to allow for better range of movement within the interaction space (area covered by the camera view).

3.2 Planned enhancements and improvements

Based upon the suggestions from the participants, further enhancements of the device include a re-design of the LED strap for the shoe, design of a height-adjustable camera stand for optimum and individualized camera placement, enhanced clinician user-interface menu and enhanced step pattern selection look-up table/drop down menu.

4. CONCLUSIONS

Following improvements, this low-cost tracking system and interactive stepping game prototype will be further assessed for usability with a sample of healthy older adults. Iterations of the game will involve improving upon the game content and interaction goals. Differences between this prototype step-based game and existing commercially available games include the ability to adjust the gameplay difficulty level to tailor the game for a range of levels of ability. Changes, such as the removal and addition of distractions on the screen, the speed of the interaction, the amount of feedback provided and the pattern of movement required, will provide a flexible system that can cater to users at a variety of levels of ability. The player will be provided with a variety of feedback. First, unlike many off-the-shelf games, the feedback will always be positive and supportive so as to encourage and motivate continued use. Second, the player will be provided with knowledge of performance feedback regarding accuracy of step placement. Lastly, third, upon completion of the game, the player will receive knowledge of results feedback regarding overall-game score/mean accuracy for each foot. Once completed, this low-cost tracking system and interactive stepping game will undergo formal functional outcome assessment of a four week training period with pre/post balance assessments (Timed Up and Go Test, Berg Balance Scale, Single Limb Stance, Romberg Test) in a sample of 15 older adults.

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