

Interactive Video Game–Based Tool for Dynamic Rehabilitation Movements

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INTRODUCTION

In being seated, standing, and walking, many uncontrollable factors contribute to the degradation of our balance system. The maintenance of balance involves many essential sensory (visual, vestibular, and somatosensory) and motor processes. Each sensory input provides unique internal and external reference frame information to the central nervous system (CNS). The CNS interprets the sensory information, from which preplanned and/or preventative (feedforward controls) and corrective (feedback controls) actions can be taken and conflicting sensory information can be mediated (Peterka, 2002). In the absence of a sensory input, balance can still be maintained; however, the compensatory actions become larger and different balance strategies may be employed.

Serious problems facing older adults and many people with neurological disorders (e.g., stroke, traumatic head injuries, incomplete spinal cord injuries, Parkinson's, multiple sclerosis, diabetic peripheral neuropathy, and osteoarthritis) are balance impairment, mobility restriction, and falling (Gill et al., 2001; Harris, Eng, Marigold, Tokuno, & Louis, 2005). In these cases, even small disturbances may result in a fall and injuries are very likely to occur. This increased risk of falling combined with mobility limitations precipitates patient dependency in instrumental and basic activities of daily living; in turn, this results in reduced levels of physical activity.

Due to the many problems associated with reduced balance and mobility, providing an effective rehabilitation regime is essential to progress recovery from impairments and to help prevent further degradation of motor skills. Thus, we developed a tool which uses

a computer-based gaming system to facilitate the rehabilitation process for restoration of weight bearing and balance control, for persons with neurological or musculo-skeletal disorders.

BACKGROUND

There are many aspects to consider when developing therapy programs for balance impairments and mobility limitations. Rehabilitation regimes often include cycling, standing activities, steppers, and over-ground and treadmill walking. Dependent on the type of disorder, these exercises will be performed at a given difficulty level (e.g., rate, tension, or incline settings) for a specified duration (Carr & Shepherd, 1998). The effectiveness of these regimes is proportional to the: (1) intensity and volume of training; and (2) task specificity of the exercises (Carr & Shepherd, 1998; Kwakkel, 2006). Constraint-induced movement therapy (CIMT) is a program that directly addresses these two issues (Marklund & Klassbo, 2006). For example, Marklund and Klassbo (2006) applied CIMT to chronic stroke patients, targeting the lower limb. The knee of the less-affected limb was restricted, requiring the tasks to be performed with the affected limb. Results demonstrated that the subjects showed improved dynamic balance and motor ability. While results of these studies are encouraging, repetitive, time-intensive therapies can become tedious, causing a lack of motivation; in turn, the patient may not complete the rehabilitation program. Thus, an important factor of a successful exercise program is maintaining the patient's interest and motivation (Betker, Szturm, Moussavi, & Nett, 2006; Cogan, Madey, Kaufman, Holmlund, & Bachy-Rita, 1977).

One method to add motivation is through the selection of exercise tasks that are in themselves fun. For example, Tsang and Hui-Chan (2004) found that learning both Tai Chi and golf improved dynamic standing balance control. However, as these are complex tasks, not all patient populations will be capable of participating; thus, methods must be found which will allow even severely disabled individuals to play and be competitive. A promising example is the incorporation of biofeedback into virtual environments or video games, which are based on conventional therapies (Back-y-Rita et al., 2002; O'Connor et al., 2000; Sveistrup, 2004). Biofeedback augmented training presents a functional, task-oriented signal to the subject in a simplified format in order to enhance movement, weight bearing status, or balance awareness (De Weerd & Harrison, 1985; Glanz, Klawansky, & Chalmers, 1997; Huang, Wolf, & He, 2006). Both virtual environments and video games cognitively engage the patient when they are training, in fun and challenging tasks; in turn, this can increase practice time, volume, and recovery (Bachy-Rita et al., 2002; Cunningham & Krishack, 1999). In general, video games have been employed less than virtual environments, as the input systems are less developed (e.g., converting center of pressure signal into a mouse signal).

Another consideration is the availability of the system. In order for the tools to be available to a wide range of clinics (for example low and moderately funded clinics) and for at-home use, the equipment should be easy to use, should not incur a large cost, and should be portable. Another aspect, essential for at-home use, is a method to embed the assessment into the treatment regime. Embedded assessment will also remove performance pressure from the patient and automatically log their practice time and performance. Our interactive video game based tool, which adopts the aforementioned ideas, is described in the following section.

VIDEO GAME-BASED EXERCISE TOOL

Biofeedback Signal Selection and Presentation

The center of pressure (COP) was selected as the biofeedback signal and outcome measure, as it reflects global instabilities of both balance disturbances and

reactions (Cheng, Wu, Liaw, Wong, & Tang, 2001; Lee, Wong, & Tang, 1996). For example, in Zambarbieri, Schmid, Magnaghi, Verni, Macellari, and Fadda (1998), insoles were used to determine the COP trajectory; a tactile stimulation device was then used to inform the subject when their COP fell outside an accepted normal range. The amount of load for each leg was displayed on an LED (Cheng et al., 2001; Lee et al., 1996), with a line indicating whether the weight was equally balanced or towards which leg the balance was skewed. In Femery, Moretto, Hespel, and Lensel (2001), 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 Urhan and Dincer (2001), the force at the heels was displayed on an LCD, with an audio tone indicating if the correct force is being applied. In Rougier (2004), 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. These functional associations between the COP and biofeedback strengthened and created the awareness of the tasks and performance levels, for both the patient and clinician.

As previously mentioned, the COP biofeedback is incorporated into video game-based exercises. A flexible pressure mat (Verg Inc., Winnipeg, MB, Canada) is used to determine the user's COP, which the video game software acquires from the pressure mat's interface box (Figure 1). The COP coordinate acts as the game cursor, emulating either a mouse (analog input) or a joystick (digital input). This is done by mapping the physical COP position signal into a corresponding on-screen pixel coordinate. In order to ensure that the games fully exercise the user's full range of movement, a method is provided to dynamically determine the user's movement range. First, the center point coordinate is determined, that is, the user's overall pressure center point. Next, the peaks of self-induced oscillatory movements are found. These ranges are then displayed on the screen, indicating the portion of the pressure mat which can be activated by the user. As appropriate, the maximal range values can be scaled by a percentage value and the center point coordinates may be offset. For example, if a user's stance was asymmetric, the center value could be offset to try and bias the pressure towards the paretic leg. In order to allow individuals with even small movement ranges to play, only the physical COP positions within the determined move-

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