ORIGINAL ARTICLE

Video Game–Based Exercises for Balance Rehabilitation: A Single-Subject Design

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ABSTRACT. Betker AL, Szturm T, Moussavi ZK, Nett C. Video game–based exercises for balance rehabilitation: a single-subject design. Arch Phys Med Rehabil 2006;87:1141-9.

Objectives: To investigate whether coupling foot center of pressure (COP)–controlled video games to standing balance exercises will improve dynamic balance control and to determine whether the motivational and challenging aspects of the video games would increase a subject's desire to perform the exercises and complete the rehabilitation process.

Design: Case study, pre- and postexercise.

Setting: University hospital outpatient clinic.

Participants: A young adult with excised cerebellar tumor, 1 middle-aged adult with single right cerebrovascular accident, and 1 middle-aged adult with traumatic brain injury.

Intervention: A COP-controlled, video game–based exercise system.

Main Outcome Measures: The following were calculated during 12 different tasks: the number of falls, range of COP excursion, and COP path length.

Results: Postexercise, subjects exhibited a lower fall count, decreased COP excursion limits for some tasks, increased practice volume, and increased attention span during training.

Conclusions: The COP-controlled video game–based exercise regime motivated subjects to increase their practice volume and attention span during training. This in turn improved subjects' dynamic balance control.

Key Words: Balance; Biofeedback (psychology); Exercise; Movement; Posture; Pressure; Rehabilitation; Therapy, computer-assisted.

REHABILITATION EXERCISES ARE essential in progressing the recovery of people with diminished motor control skills. Many uncontrollable factors can contribute to the degradation of our balance system, such as a decrease in processing efficient sensory information with age[1] and disabling neurologic and musculoskeletal conditions. Repeated falls or near falls can also lead to a decline in self-efficacy; in turn, this may result in self-induced functional limitations.[2] Standing and walking balance involves many essential sensory and motor processes. Feed-forward cognitive controls initiate preparatory movements used to maintain balance for anticipated disturbances. Feedback information is used in response to unexpected disturbances or when preparatory movements fail. Experience plays a role in being able to better anticipate disturbances.[3] The central nervous system (CNS) interprets sensory information from visual, vestibular, and somatosensory inputs; the CNS can then take preventive and corrective actions and mediate between conflicting sensory information.[4,5] Each sensory input provides unique information regarding the alignment and relative motions of internal or external references. In the absence of one these inputs, balance can still be maintained; however, the compensatory actions become larger.

Balance impairment, mobility restriction, and falling are serious problems facing older adults and many people with neurologic disorders (eg, stroke, traumatic head injuries, incomplete spinal cord injuries, Parkinson's disease, multiple sclerosis, diabetic peripheral neuropathy).[6-9] For many of these populations, even small disturbances result in a fall, increasing the likelihood of an injury. Increased fall risk and mobility limitations will precipitate patient dependency in instrumental and basic activities of daily living; this in turn results in reduced levels of physical activity.

Medical research related to the treatment and management of neurologic conditions has focused on minimizing brain injury in the acute phase, promoting early reperfusion of the ischemic brain, developing neuroprotection drugs, and replacement drug therapy. Another treatment strategy is to promote functional improvement in balance and mobility through rehabilitation. Recovery of function and long-term maintenance are strongly influenced by: (1) regularity and volume of training and physical activity and (2) task specificity, that is, matching training and environmental conditions to function. Conventional therapy programs generally include standing activities, steppers, and overground and treadmill walking (with and without body-weight support). Messier et al[10] found that an aerobic walking and strength training program helped to decrease postural sway of elderly subjects with knee osteoarthritis. This type of exercise becomes important when we move from standing balance control (stationary base of support) to situations where the center of mass (COM) must remain within a moving base of support. These exercises will be performed at a given rate for a specified duration, dependent on the type of disorder.[11]

There is now notable evidence from studies that targeted physical training reduces disability and increased training produces better outcomes.[12-16] Various theories have been advanced to explain behavioral recovery after central and peripheral nervous system disorders or lesions.[17-20] Neural reorganization serves as the foundation for learning, the acquisition of new skills, and is the basis of functional recovery. The changes in neurologic organization are driven by the changes in demand and type and amount of training experience. Modern concepts of motor learning and neuroadaptation after CNS lesions favor

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a task-specific, repetitive approach.[21,22] For example, Dean et al[21] studied the effects of using a circuit of task-oriented exercises, along with group races and relays. They found that the subjects exhibited improvement in walking speed, endurance, and force production in the affected limb; these findings remained consistent when subjects were retested 2 months posttreatment. One emerging method to increase functional recovery of the upper extremity after stroke is constraint-induced movement therapy (CIMT).[23-26] This approach compels stroke patients to use their affected upper extremities in natural motor activities, while the healthy arm and hand is constrained by a sling or cast. In controlled studies, CIMT has been shown to produce a substantial long-term improvement in the amount of use of the paretic extremity. CIMT is believed to produce its therapeutic effect through large volume of practice. Although in a motivated patient conventional treatments may be effective, in other cases patients quickly lose interest in performing repetitive tasks; as a result, the treatment program is not fully completed. Lack of interest or attention span can also impair the potential effectiveness of the therapeutic exercise. This is particularly true when a large volume of practice is essential, as is the case in many CNS disorders. Conversely, the use of rewarding activities has been shown to improve a patient's motivation to practice.[27,28]

Tsang and Hui-Chan[29] investigated whether the learning of enjoyable, complex tasks (Tai Chi, golf) improved joint proprioception. The joint proprioception acuity and standing stability bounds of experienced elderly Tai Chi practitioners and golfers were compared with healthy elderly and young adults with similar physical activity levels. They found that both Tai Chi and golf improved the dynamic standing balance control.[29] However, not all patient populations will be able to complete these tasks; thus, another method of providing motivation must be found.

Biofeedback has long been used clinically to augment training.[30,31] While the subject is performing a task, a biologic signal is recorded and presented to them (in real time). In most cases, a visual or auditory feedback representation of the input signal intensity is used. A commonly incorporated biofeedback signal is the foot center of pressure (COP).[32-36] For example, in Lee et al,[33] the load for each leg was displayed on a light-emitting diode. A line indicated if the weight was equally balanced or toward which leg the balance was skewed. This association between the pressure signal and the visual and auditory feedback strengthens or creates awareness of a given activity or performance level, in order to regain or learn an activity that would assist in their daily lives.

To enhance the level of biofeedback, virtual reality (VR) has been developed for and applied to rehabilitation.[37-41] Cited studies have observed positive effects of VR training on upper-extremity and locomotor functions. An important and highly valued property of VR training is that it is interactive and can be fun; therefore, patients are more likely to achieve regular and long-term practice. The fun experiences associated with video games differ fundamentally from those associated with signal biofeedback or simple movement simulation inside a virtual environment. Thus, many VR environments have been developed to include video games. For example, Broeren et al[42] made use of a game in a virtual environment, along with a force-feedback haptic device, to improve control of a stroke subject's left hemiparetic arm. Their results showed that the subject was motivated to practice and exhibited improved dexterity, grip force, and motor control. The positive effects are particularly observed when a game is incorporated into the immersed virtual environment.[42,43] However, using biofeedback video games outside a VR environment eliminates the need for elaborate and expensive display systems. Thus, by coupling exercises directly to video games, the subject can be competitive and engaged in "fun"; in turn, this can increase practice time and volume and therefore recovery.[44-46]

Using these ideas and results, we created 3 video games, which are controlled via COP signal biofeedback. In a preliminary study, a questionnaire was administered to 15 subjects (7 patients) after playing a 10-minute session of each game.[47] The results were very encouraging. Subjects indicated that the games were challenging, fun, and would be a welcome addition to current treatment programs. Thus, the goal of this study was to investigate if our COP-controlled video game–based exercises would improve dynamic balance control in 3 different subjects. We hypothesized that the inclusion of motivational and functional gaming to rehabilitation should increase the patient's desire to perform their rehabilitative exercises; therefore, the patients should exhibit improved dynamic balance control postexercise.

METHODS

This section first gives an overview of the COP-controlled video games and their integration with the Force Sensitive Applications (FSA) pressure mapping system.[a] Next, the exercise program is discussed, detailing the research design, test protocol, and outcome measures used to validate the video game tool as an effective exercise program.

COP-Controlled Video Game Overview: System Integration and Design

We developed the COP-controlled video game–based exercise tool for use with the FSA software and pressure mat.[a] A commercial prototype of the software is currently being developed, with a targeted release date in summer 2006. When released, the COP-controlled video games will be included with the pressure mapping system (≈US $8700).

The COP signal input is acquired via a flexible pressure mat of dimension 53×53×.036cm, containing a 16×16 grid of piezoresistive sensors spaced 2.8575cm apart. Note that other mat sizes are available. An interface box captures the pressure data from the mat for display on a personal computer containing the FSA software (fig 1). The flexibility of the pressure mat permits the games to be performed on solid, fixed surfaces or on compliant surfaces. This adds increased balance requirements as appropriate and allows for the emulation of unpredictable outdoor terrains.

We designed the games to be competitive, while fully exercising the patient's range and speed of movement. This is important to prevent the subject from becoming frustrated and quickly losing interest. Our games offer the following values for rehabilitation: (1) goal directed and intended behavior, with random presentation and target motion; (2) multitasking: gaze control (head and smooth pursuit), attention to game play strategy (target motion, predicting final location), and body movements and balance control; and (3) rewards with moment to moment goal attainment. We accomplished this by having configurable difficulty level parameters; for example, object speed and size could be fully adjusted to increase the precision of the task. Mapping of the COP motion to game target motion or tracking controls could also be scaled, in order to adjust the amount of movement required to play the games. Smoothing of the COP trajectory was also added to help eliminate jerky movements and overshooting of game targets. This allows a full range of patients, from slightly to severely disabled, to play the games competitively.[47]