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Effects of Games-Based Biofeedback Training on the Attentional Demands of Balance Tasks in Older Adults
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MSc. Thesis Report

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Abstract

The objectives of this study were to determine whether games-based computerized biofeedback training using the NeuroGym system reduces the attention demands of balance tasks in active community-dwelling older adults. Specifically, this study examined whether postural sway, reaction time, functional balance, and composite fitness changed following the training. Sixteen community-dwelling adults over the age of 65 who were experienced chair exercise participants were assigned to either a training group (n=9) or a control group (n=7). Participants in the training group followed an 8-week training program (2 x 30 minute sessions each week) consisting of five separate exercise routines using the NeuroGym system. The training routines required participants to play a computerized tennis game by shifting their body weight. Postural sway, reaction time, functional balance, and composite fitness were evaluated prior to training, after completion of the training and following a two week retention period.

Introduction

Accidental falls constitute a major health concern for older adults. Recent studies have estimated that up to 40% of people over the age of 65 living at home will experience an accidental fall (Rubenstein, 2006), and the rate is estimated to be much higher for older adults living in institutions (American Geriatrics Society, 2001). Older adults also have a higher susceptibility to injury following an accidental fall. The incidence of hospital admission, fracture, and other serious health consequences, including death following an accidental fall are much greater for adults over age 65 (Rubenstein, 2006). Furthermore, the fear of falling constrains the daily activity and adversely affects the quality of life of many older adults (Rubenstein, 2006; American Geriatrics Society, 2001). In many cases, accidental falls and their associated health consequences are recognized as preventable (Rubenstein, 2006) and recent research has focused on the prevention of falls as a means to maintain the independence and quality of life of an aging population.

Studies of fall prevention have identified a number of factors both environmental and physiological that contribute to the risk of accidental falls. Among the physiological factors that contribute to fall risk are weakness and deconditioning (Rubenstein, 2006; American Geriatrics Society, 2001; Carter et al., 2001). Although changes in physical capacity are associated with the aging process, there is clear evidence that weakness and deconditioning can be managed to some extent by voluntary physical activity (American College of Sports Medicine, 1998). A great deal of study has thus been directed into exercise programs intended to reduce the risk of accidental falls in older adults (Carter et al., 2001; Spirduso & Cronin, 2001).

Review of Literature

In a review examining the rationale and evidence for using exercise programs to prevent falls, Carter and colleagues (2001) identified four key dimensions of training: muscle strength, endurance, flexibility, and balance. Spirduso and Cronin (2001) identified similar dimensions of muscle strength, muscle endurance, aerobic fitness, flexibility, and balance in their attempt to quantify a dose-response effect of exercise on fall prevention. Of these dimensions, muscle strength and endurance, aerobic endurance and flexibility currently support specific recommendations from the American College of Sports Medicine (1998) and the Canadian Public Health Agency (2004). Balance, however, remains a relatively elusive construct (Howe et al., 2007; Silsupadol et al., 2006) and at the present time, balance training guidelines for older adults have yet to be conclusively established (Howe et al., 2007; American Geriatric Society, 2001; American College of Sports Medicine, 1998). Nonetheless, there is general agreement that balance training is an important dimension of physical activity programs for fall prevention and recent studies continue to explore balance as a construct (Fraizer & Mitra, 2007; Silsupadol et al., 2006; Dualt et al., 2003; Maylor et al., 2001, Maki et al., 200; Quant et al., 2001; Redfern et al., 2001; Teasdale & Simoneau, 2001) and methods to train balance (Bisson et al., 2007; Lajoie, 2004; Shimada et al., 2003; Steadman et al., 2003; Geiger et al., 2001; Wolf et al, 1996) in older adults.

Balance as a Construct

Berg and Kairy (2003) define functional balance as an individual's ability to maintain upright posture while making adjustments in response to voluntary movements and reacting to environmental stimuli. Newton (2003) provides a somewhat more practical definition of functional balance as the "ability to maintain one's lifestyle without falling." Posture has been defined by Balasubramaniam and Wing (2002) as a geometric relation between body segments, and the relation of body segments to the environment. The task of the nervous system in controlling posture is to manage these relations in the various contexts of human movement. Posture is maintained in the face of gravity, external forces, and self-movements by generating a series of muscle torques that result in the equilibrium we known as balance.

Most waking situations experienced by human beings require some degree of postural control in order to maintain balance. Control of the body's center of mass (COM) within the body's base of support is frequently used as a quantitative measure of postural control (Frazier & Mitra, 2007; Baratto et al., 2002; Teasdale & Simoneau, 2001). Control of the COM itself is often assessed by tracking the body's center of pressure (COP). COP provides a measure of the vertical ground reaction forces at the support surface and thus an indirect measure of COM movement (Frazier & Mitra, 2007; Baratto et al., 2002).

Control of the body's COM/COP is regulated by a complex interaction of several body systems; including vision, proprioception, and vestibular information as well as various muscles and, over long periods of time, energy delivery systems (Balasubramaniam & Wing, 2002). Each of these systems independently has been shown to exhibit some form of decline as a result of the aging process (Boulgarides, et al., 2003; Lord et al., 2003; Carter et al., 2001; Rikli & Jones, 1997). Indeed, age-related deficits in the physiological systems that underlie the control of posture are closely linked to physiological risk factors for accidental falls (Rubenstein, 2006; American Geriatrics Society, 2001). More recently though, the capacity of the central nervous system to process and integrate information from various sources, and age-related changes in this ability, has also been investigated as a critical factor in the control of balance and the prevention of accidental falls (Lajoie & Gallagher, 2004; Teasdale & Simoneau, 2001; Lajoie, 1993). The ability of the central nervous system to regulate posture in the context of voluntary movement and environmental stimuli also exhibits age-related deficits that likely contribute to fall risk (Woolacott & Shumway-Cook, 2001). Recent studies have examined this processing capacity as a potential target for fall prevention training (Bisson et al., 2007; Lajoie, 2004; Shimada et al., 2003)

Attentional Demands of Balance Tasks

The regulation of the sensory information and motor commands that control posture had been thought to be controlled primarily by sub-cortical reflex responses (Balasubramaniam & Wing, 2002; Canedo, 1997). While reflex actions do appear to play an important role in very early responses to perturbations of posture (Maki et al., 2001), evidence indicates that the complex regulation of sensory and motor information used to maintain posture is controlled at the level of the cortex (Balasubramaniam & Wing, 2002; Woollacott & Shumway-Cook, 2001; Canedo, 1997). Cortical representation and regulation of the body's posture involves a widely distributed network of brain functions (Balasubramaniam & Wing, 2002; Canedo, 1997) and thus requires varying degrees of cognitive resources, or attention. The processing demands of regulating posture depend on the degree of difficulty in the postural task, the performance of the systems involved in regulating posture, and the presence or absence of other tasks requiring processing resources (Woolacott & Shumway-Cook, 2001).

The control of balance depends on the flow of information from distributed areas of the nervous system (Balasubramaniam & Wing, 2002; Woolacott & Shumway-Cook, 2001). Attention and its role in the control of posture can be thought of in terms of the processing demands that accompany this flow of information as well as the resources required to select and execute responses or to maintain ongoing movements. Two separate theories of attention have been advanced to explain the interference of multiple tasks based on resource allocation and structural interference (Temprado et al., 2001). Briefly, resource allocation theory posits that separate tasks compete for processing resources because individuals have limited processing capacity. While according to structural interference (or bottleneck) theory; two independent responses cannot be selected at the same time (central interference), and tasks interfere because aspects of one task are discordant with aspects of another (peripheral interference) (Temprado et al., 2001).

Temprado and colleagues (2001) conducted an experiment involving a bimanual coordination task (moving a pair of joysticks in a pre-defined pattern) and a reaction time task (pressing a foot switch as quickly as possible after hearing an auditory signal) which supports a harmonized view of resource allocation and structural interference. By studying the coordination patterns (phase relationship) of the arm movements, the authors found evidence of both a resource allocation effect and an interference effect. They concluded that any condition where multiple tasks are being performed represents a unique assembly of subsystems that are coupled by the central nervous system to produce the dual task performance. Thus the attention demands of multiple tasks can be thought of as a function of both the task demands (resource allocation) and the degree of fit (or misfit – interference) between the tasks Temprado et al., 2001).

Computational theories of motor control provide some insight into the types of demands that the control of posture and balance place on the nervous system, and the resources that they require. According to computational theories, the nervous system continuously models possible movements based on estimating the context or state of the movement environment (Wolpert & Ghahramani, 2000; Wolpert and Flanagan, 2001). The response that best fits the movement goals and the movement context is selected for action, and the consequences of the selected response are monitored to update both the movement context, and the internal representation of the movement (Wolpert & Ghahramani, 2000; Wolpert and Flanagan, 2001). The neural mechanisms and structures involved in representing a particular context and modeling potential responses are not exclusive to postural control or movement (Balasubramaniam & Wing, 2002; Gazzaniga et al, 1998; Canedo, 1997; Kramer, 1995). The same process of selecting an appropriate response based on an observed context is also thought to underlie cognitive tasks (Balasubramaniam & Wing, 2002, Kramer et al., 1995). Since movement and cognition depend to a large degree on the same neural circuitry for decision making (Gazzaniga et al, 1998; Canedo, 1997), a clearer understanding of the interference between cognitive and balance tasks begins to emerge.

Quant and colleagues (2001) used a dual-task paradigm to provide some empirical evidence for cortical interference of balance regulation and a secondary task. Using young participants, the authors employed electroencephelography (EEG) to measure cortical activity. The EEG wave N1, the first negative peak in cortical electrical activity following a perturbation of balance, was chosen as the index of attention to balance (the primary task). While engaged in a visual tracking task (the secondary task), participants had their posture perturbed. The authors found that the N1 wave was decreased in magnitude and that the body's centre of pressure moved farther after perturbation compared to trials with no secondary task. These results indicate that processing the tracking task interfered with the postural response (N1) that would normally occur to regulate the centre of pressure following an unexpected perturbation. The authors concluded that because the processing capacity of the central nervous system is limited; attention functions as a means of gating, or selectively processing, the information that is always flowing in. In this model attended stimuli are enhanced, and unattended stimuli are suppressed. Hence the suppression of N1 following the balance perturbation indicates that the attention of the participants was directed to the tracking task (Quant et al, 2001).

Dual task paradigms continue to provide the primary means of investigating the attentional demands of postural and balance tasks (Frazier & Mitra, 2007; Woolacott & Shumway-Cook, 2001). Dual task strategies employ a primary postural task and some form of secondary task. Secondary tasks can take many forms including simple (single response to a single stimulus) or choice (one or more possible responses to a number of possible stimuli) reaction time, memory task, a perceptual task (tracking an object in space) or a cognitive task (adding numbers) (Frazier & Mitra, 2007; Woolacott &

Shumway-Cook, 2001). If the combination of the tasks exceeds the attentional resources, performance of one or both tasks is expected to suffer (Woolacott & Shumway-Cook, 2001). The effects on attention of dual task conditions can be studied by the effect of the secondary task on the primary task, the effect of the primary task on the secondary task, or simultaneous effects on both tasks (Woollacott & Shumway-Cook, 2001; Lajoie et al, 1993). Typically, the participant's goal is to maintain the primary task condition (remain standing) while attempting to perform the secondary task as quickly and/or accurately as possible (Woolacott & Shumway-Cook, 2001). Primary task performance, movement of the body's COM/COP is used to measure the participant's engagement in the task (that they are concentrating on the primary task), while secondary task performance, speed/accuracy of responses, provides an index of task interference (Frazier & Mitra, 2007; Woolacott & Shumway-Cook, 2001). In addition to providing insight into the neural mechanisms of postural control, studies employing dual task paradigms have also revealed significant age-related differences in dual task abilities (Woolacott & Shumway-Cook, 2001).

Age Related Changes in the Attentional Demands of Balance Tasks

Computational models of motor control provide some further insight into the reasons why dual task paradigms generally show greater interference effects in older adults. According to computational theories, movements are represented by forward models stored in the central nervous system. Actual movements are guided by the forward models, and the sensory consequences of the movement are compared to anticipated sensory feedback. It is the comparison between anticipated and actual consequences that effectively guides the movement and keeps it appropriate to the context (Wolpert & Ghahramani, 2000; Wolpert and Flanagan, 2001). Age related declines in sensory function increase the noise, or inaccuracy, present in the process. With increasing noise, comparison of planned and actual sensory feedback requires greater processing and thus demands more attention (Redfern et al., 2001; Teasdale & Simoneau, 2001).

Age related changes in the control of posture and balance have been implicated as a factor that contributes to falls in the elderly (Rubenstein, 2006; American Geriatrics Society, 2001). The aging process is associated with changes in the performance of many of the body's systems, including those essential to posture and balance (Woolacott & Shumway-Cook, 2001; Teasdale & Simoneau, 2001, Lajoie et al., 1993). The visual, proprioceptive, and vestibular systems are known to provide information that is essential for controlling posture and maintaining equilibrium (Gazzaniga et al, 1998; Canedo, 1997). The muscular system, acting on information provided by the sensory systems, provides the actual means to regulate the position of the body's centre of pressure (Balasubramaniam & Wing, 2002). The performance of each of these systems are known to decline with advancing age, suggesting that the difficulty in maintaining equilibrium that leads to fall risk comes from a number of sources (Rubenstein, 2006; American Geriatrics Society, 2001). In addition to these systems, the central control and processing of information has also been investigated for age related slowing (Lajoie & Gallagher, 2004; Woollacott & Shumway-Cook, 2001).

The sequence of information processing for the control of posture consists of a series of steps (Haywood, 1993), each requiring a certain period of time to complete, and depending on both the amount and quality of information available from the environment

(Redfern et al., 2001; Teasdale & Simoneau, 2001). Since the central nervous system compares multiple sources of information to determine an appropriate response, processing is expected to be quicker when an optimal amount of quality information is available (Wolpert & Flanagan, 2001; Wolpert & Ghahramani, 2000). The relationship between processing speed and available sensory information is thought to follow a curvilinear path, with too much or too little sensory information resulting in slowed processing (Teasdale & Simoneau, 2001). Studies of older adults indicate that age-related changes leading to decreased or less reliable information from sensory channels (Redfern et al., 2001; Teasdale & Simoneau, 2001), coupled with changes in central processing capacity (Lajoie & Gallagher, 2004; Woolacott & Shumway-Cook, 2001) contribute to postural instability and fall risk in older adults.

Accordingly, recent studies of fall prevention have begun to examine whether the attentional demands of postural control and balance can be improved in older adults through targeted exercise training programs (Bisson et al., 2007; Lajoie, 2004; Shimada et al., 2003; Steadman et al., 2003; Geiger et al., 2001; Wolf et al, 1996). Learning effects have been demonstrated in older adults on a variety of motor and cognitive tasks (Etnier et al., 2001; Kramer, 1995). As a novel motor task is learned and refined, attention is increasingly focused to relevant channels of information (Magill, 1993). Well learned movement patterns appear to be less demanding of attentional resources in situations where multiple tasks are being performed (Temprado et al., 2001). The training of postural movement patterns through specific exercises may therefore provide a means of reducing the attentional demands of balance in older adults and thus reduce the risk of accidental falls.

Balance Training with Computerized Biofeedback

Although poor balance is recognized as a contributing factor for accidental falls, specific guidelines for balance exercise are less clear than for other potential risk factors such as muscle strength and aerobic conditioning. (Rubenstein, 2006; Silsupadol et al., 2006; American Geriatric Society, 2001; Carter et al., 2001; American College of Sports Medicine, 1998). However, research examining the attentional demands of balance tasks indicates that the ability to control posture in multi-task situations is central to maintaining balance (Lajoie & Gallagher, 2004; Maylor et al., 2001; Andersson et al., 1998). Reducing the attentional demands of postural control through specific training may indeed prove to be a valuable tool for improving balance and reducing the risk of accidental falls in older adults. Such training may serve to strengthen the internal representations of postural movements. Postural responses that are strongly represented in the nervous system may prove more resistant to secondary task interference.

The results of Temprado and colleagues (2001) suggest that the strength of the representation of a movement, which the authors term 'stability', largely determines the processing resources required to perform or maintain the movement in the face of competing tasks. The stability of movement patterns related to the control of posture may be reduced as a consequence of age-related changes in the sensory and motor systems that contribute to movement control. However, evidence of age-related changes being modified through specific training suggests that representations of movement within the central nervous system can be strengthened. Beilock and colleagues (2002) found that physical fitness was positively associated with the rate of learning for a novel motor task in older adults. Waddington and Adams (2004) demonstrated improvements in proprioceptive discrimination in older adults following a five-week training program for ankle movements. Such data indicates that age-related changes in the body systems underlying postural control are amenable to training, and that improving the 'stability' of postural movement patterns may effectively improve the stability of older adults and reduce the risk of accidental falls. To this end, training with computerized biofeedback appears to be a promising means of achieving enhanced representations of postural movements.

Training with computerized biofeedback provides a conceptually attractive means of strengthening the representation of postural movements. Biofeedback devices attempt to provide information about the body's state and/or position in space in a form that is more recognizable than information that may be available from intrinsic sources. For example, an older adult with a reduced ability to discriminate small changes in the location of his or her centre of pressure can stand on a platform equipped with force transducers which relay a real-time tracing of the COP position to a video screen. This form of computerized biofeedback serves to highlight information about the COP that may not be immediately recognizable from proprioceptive or vestibular cues. The repeated use of this type of biofeedback is thought to improve body awareness through the repeated association of the biofeedback signal with internal perceptual cues (Lajoie, 2004; McKenna et al., 1999; Nativ, 1993). Computerized biofeedback training has shown a positive impact on measures of functional balance in a number of studies (Bisson et al., 2007; Lajoie, 2004; Steadman et al., 2003; Geiger et al., 2001; Wolf et al., 1996). Studies by Lajoie (2004) and by Bisson and colleagues (2007) both demonstrated improved secondary task performance (simple reaction time) in a dual task paradigm following computerized biofeedback training.

Studies by Steadman and colleagues (2003), Geiger et al. (2001) and Wolf et al. (1996) compared training with computerized biofeedback to practice on a range of functional mobility tasks (Steadman et al., 2003; Geiger et al., 2001) and to Tai Chi (Wolf et al., 1996). In each of these studies, the authors found improvement on measures of functional balance, but computerized biofeedback training did not result in significantly greater improvements than any of the other training modes. It should be noted, however, that none of these studies employed a dual task paradigm or any measure of reaction time (Steadman et al., 2003; Geiger et al., 2001; Wolf et al., 1996).

Recently, Bisson and colleagues (2007) compared computerized biofeedback training to a games-based virtual reality (VR) program. The VR program functions in principle as a form of biofeedback. Participants in VR training watched a real-time image of their bodies projected onto a video screen and were able to interact with a video game by making specific reaching movements. The VR participants watched a virtual ball appear on the video screen and were able to 'juggle' the ball by moving their bodies (Bisson et al., 2007). The games-based element present in the VR condition is an interesting departure from previous uses of biofeedback which focus either on keeping the COP within a defined area (Lajoie, 2004) or moving the COP to a specific location (Bisson et al., 2007; Steadman et al., 2003; Geiger et al., 2001; Wolf et al., 1996). The games-based environment requires the participant to generate an appropriate postural movement, but also places a specific time requirement on that movement.

Nativ (1993) explores the concept of games-based biofeedback training in a review of motor skills retraining following brain trauma. Biofeedback information (in the form of COP location, muscle electrical signals, or any other relevant information) supplements the closed-loop neural processes which are known to underlie motor skill learning. The additional requirements imposed by a game environment add a speed-specific element to the movement being practiced. Games also provide intrinsic motivation for the task and may promote a greater intensity of effort than other practice situations (Herndon et al., 2001; McKenna et al., 1999; Nativ, 1993). The type of games-based biofeedback training system described by Nativ (1993) has been developed into a commercial training tool called NeuroGym. The NeuroGym system consists of a flexible arrangement of biofeedback sensors which provide control inputs to a computer game. The NeuroGym system combines the augmented sensory feedback of traditional biofeedback systems with the games-based element of the VR simulation studied by Bisson and colleagues (2007). In addition, the NeuroGym system allows for multiple arrangements of biofeedback sensors, making it capable of creating biofeedback training situations that are specific to any number of postures or movements. Games-based biofeedback training with the NeuroGym system may thus provide an effective means to train postural control in older adults. Such training would be expected to reduce the attention demands of posture, improve functional balance and may ultimately reduce the risk of accidental falls.

Functional Balance Measure

Most studies of biofeedback training in older adults have incorporated some measure of functional balance in order to provide some indication of whether changes in some discrete ability, such as reaction time in a dual task paradigm, can be related to a practical outcome, such as reducing fall risk. In their study of computerized biofeedback and VR training, Bisson and colleagues used the Community Balance and Mobility Scale (CB&M) to measure functional balance. The CB&M was originally designed to evaluate balance deficits and treatment outcomes for ambulatory patients with traumatic brain injury (TBI) (Howe, 2006). Content and construct validity, as well as inter-rater and test-retest reliability have been reported by Howe and colleagues (2006) for populations with TBI. The CB&M is designed to evaluate balance components such as multi-tasking, sequencing and complex timing. These components represent relatively high levels of functional balance and are thus most appropriately used with populations that are independently mobile (Howe et al., 2006).

Boulgarides and colleagues (2003) used the Dynamic Gait Index (DGI) as a functional balance measure for community dwelling older adults. The authors found a pronounced ceiling effect in DGI scores and concluded that the test items were not sufficiently difficult to assess balance in community dwelling older adults. Chiu and colleagues (2006) examined the measurement properties of the DGI and concluded that many of the DGI items could be modified to incorporate multi-task dimensions, but such dimensions were not well represented in the test's present form.

Although it was not initially designed for use with older adults, the multiple task and timing elements of the CB&M provide an attractive measurement tool for examining the effects of a training program on the attentional demands of balance tasks older adults. Community dwelling older adults show age-related deficits in proprioception, vision, and muscle function that are at least qualitatively similar to those of TBI patients (Rubenstein, 2006; Howe et al., 2006; Nativ, 1993). The high level balance components tested by the CB&M can thus be expected to provide a reasonable indication of any changes in the attentional demands of postural control that may occur in older adults as a result of a training program.

Composite Fitness Measure

Etnier and colleagues (2001) studied the acquisition of a novel motor task (the star mirror trace) in older adults. Comparing older learners (60-80 years) to younger learners (20-40 years) the authors found that the older group needed more practice trials to achieve a criterion level of accuracy on the task. Interestingly, learning and retention of the task was correlated with aerobic fitness in both groups of learners. Participants with higher levels of aerobic fitness (measured by VO_{2max}) achieved criterion performance in significantly fewer practice trials (Etnier et al., 2001). These results suggest that the motor abilities which underlie postural control and balance, and their response to training will depend to some extent with the learner's aerobic fitness.

Aerobic fitness is often expressed as general conditioning or endurance, and has been identified by a number of authors as a parameters underlying functional mobility (Carter et al., 2001; Spirduso & Cronin, 2001; Rikli & Jones, 1997). As such, exercises which promote aerobic endurance are often the foundation of exercise interventions for older adults (Baker et al., 2007; Carter et al., 2001; Spirduso & Cronin, 2001; Mazzeo et al., 1998). In a recent study of an exercise program to improve functional mobility in older adults Baker and colleagues (2007) used the six minute walk test as a composite measure of aerobic fitness. The test measures the distance covered in a self-paced walk over a six minute time period (Lord & Menz, 2002). The six minute walk test has been found to correlate well with longer tests of aerobic capacity, such as the 12 minute walk and other treadmill-based tests (Bautmans et al., 2004). The 6 minute walk test has also been shown moderate correlations with a number of other physical parameters, including muscle strength, flexibility, age and general health status (Baker et al., 2007; Bautmans et al., 2004; Lord & Menz, 2002).

Recent studies examining the effects of exercise training on the attentional demands of balance tasks in older adults have not used an index of general physical conditioning (Bisson et al., 2007, Lajoie, 2004; Shimada et al., 2004). However, given the results of Etnier and colleagues (2001) the aerobic fitness of training participants may be an important predictor of training outcomes. The use of an index of general fitness in postural control training may also provide important information regarding the source of any observed training effects. Any change in dual task performance that is independent of an increase in the general fitness index may be more confidently ascribed to changes in attentional demands.

Hypotheses

Based on the preceding review, a training program of games-based biofeedback exercises using the NeuroGym system would be expected to effectively reduce the attention demands of balance tasks in a group of community dwelling older adults. Similar findings have been reported following computerized biofeedback by Bisson and colleagues (2007) and by Lajoie (2004). The NeuroGym system may provide an enhanced form of training due to the games-based nature of the training task, and the flexibility of the system to allow training in several different postures. Previous studies have focused training on a limited number of postures, most frequently standing with the feet together, and standing with the feet shoulder width apart (Bisson et al., 2007, Lajoie, 2004; Geiger et al., 2001; Wolf et al., 1996). A review by Howe and colleagues (2007) has identified standing in tandem and single leg standing as additional postures which are frequently assessed in functional balance scales. The NeuroGym system allows training in multiple postures during a single session and may thus be expected to provide some additional advantage to a training program.

Changes in the attentional demands of balance tasks can be assessed through a dual task paradigm of the type used by Bisson and colleagues (2007) and by Lajoie (2004). Primary task performance, measured by analyzing the movement of the body's COP, is expected to remain unchanged following the training program. Secondary task performance, as measured by simple reaction time, would be expected to decrease - indicating that the attentional demands of the primary task have been reduced by the training program (Bisson et al., 2007; Lajoie, 2004).

Reducing the attentional demands of balance tasks would be expected to lead to an improvement in functional balance. As a measure of functional balance, the CB&M is designed to detect changes in abilities such as multi-tasking, sequencing, and complex timing (Howe et al., 2006), thus making the CB&M an appropriately sensitive tool for assessing changes in functional balance related to attentional demands. Following a training program of games-based biofeedback, the scores of older adults on the CB&M scale would be expected to increase, indicating that changes in attentional demands are also associated with changes in functional balance (Bisson et al., 2007).

Aerobic fitness and muscle strength are recognized as important contributors to functional balance (Carter et. al. 2001). Aerobic fitness may also contribute to motor skill acquisition in older adults (Etnier et al., 2001). A balance training program used in conjunction with an ongoing program of physical activity which targets aerobic fitness and muscle strength should provide the greatest benefit to functional balance in older adults (American Geriatric Society, 2001; American College of Sports Medicine 1998). In a group of older adults who are already physically active, the addition of games-based biofeedback training would be expected to improve functional balance independent of aerobic fitness and muscle strength. Thus the 6 minute walk distance, a composite measure of fitness, should remain unchanged following a training program of games-based biofeedback training - providing a further indication that any changes in functional balance are the result of changes in attentional demands.

Methods

Participants and Recruitment

The study was approved by the Research Ethics Board of the University of Ottawa (Appendix A). A convenience sample of community dwelling adults over the age of 65 was recruited from the Heron Road Community Center. Study participants were enrolled in a twice-weekly chair exercise program offered by the community center, and had been continuously attending a similar exercise program for at least the previous two sessions (approximately 16 weeks). All of the participants continued to attend the chair exercise sessions for the duration of the study. The chair exercise program focused on aerobic fitness, muscular endurance, and flexibility exercises done while seated or while standing and using the chair for stability. None of the participants were enrolled in any other exercise programs involving specific balance training during the study. A minimum score of 20 on the Folstein Mini Mental State Exam (MMSE) was required to ensure the participants' comprehension of instructions and the training tasks (Appendix B). Volunteers were excluded from the study if they reported any neurological or sensory disorders, heart disease or stroke, diabetes, uncorrectable vision problems, recent upper or lower body injury, severe arthritis or chronic back pain (Appendix C).

All participants provided informed consent prior to beginning the study (Appendix D). Participants were made aware in advance that participation in the training group would require a substantial time commitment for training sessions. The final group assignment was controlled by the researchers, but determined in consultation with the participants in order to ensure compliance with the training program schedule of two 30 minute sessions, twice weekly for eight weeks. Nine participants (5 females and 4 males, mean age =77.44 years SD=6.48) were assigned to the training group. Seven participants (6 females, one male, mean age 77.43 years SD=7.59) were selected from nine volunteers for the control group. Selection criteria for the control group were based on matching with the training group for age, MMSE score, and baseline measures for endurance and functional balance.

Design and Testing Procedures

Testing was conducted for both groups at three separate points over the course of the study. Pre testing occurred before the training group started their program of games-based biofeedback. Post testing was conducted immediately following the final training session for the training group, and after a period of eight weeks for the control group. Retention testing was conducted two weeks after post testing for both groups. Each testing session included measurements of postural sway and simple reaction time combined in a dual task paradigm, functional balance, and composite fitness.

Dual Task Paradigm

Postural sway and simple reaction time were measured in three postures; standing with the feet together, standing in tandem with the dominant leg behind, and standing only on the dominant leg. Each participant's dominant leg was identified during the pre test using the method employed by Mikheev and colleagues (2002). Participants stood with eyes open and arms at their sides for each posture. Three trials lasting one minute each were collected for each posture. Two chairs, placed on either side of the participants, were available for postural support during each of the standing trials. Participants were instructed to use the chairs only as necessary to prevent a loss of balance. The order of the trials was randomized for each participant and each session began with a two minute trial of seated reaction time to familiarize the participants with the reaction time stimulus. At each testing session participants were instructed to focus primarily on swaying as little as possible and to consider reaction time as their second priority after maintaining a steady posture.

Postural sway data was collected from an AMTI force platform and sampled at a rate of 500Hz to an online digital program. The root mean square (RMS) of the displacement of the body's COP in the anterior-posterior (A/P) and lateral (Lat.) directions were chosen for the analysis of postural sway. RMS captures the oscillation amplitudes of the COP in the A/P and Lat. directions, and is representative of the participants' ability to minimize sway and maintain a steady posture. RMS for the A/P and Lat axes were calculated over the duration of each trial, averaged across the three trials for each posture and used as dependent measures of primary task performance.

The secondary task required the participants to answer verbally "TOP" as quickly as possible following an auditory stimulus ("BEEP" - 1000Hz, 80msec duration) produced by a digital speaker. The auditory stimulus and the spoken response were captured in mp3 format on a digital recorder. Reaction time was calculated from the difference between the beginning of the auditory stimulus and the beginning of the participant's spoken response. On average, 8 reaction time stimuli were presented at unpredictable intervals over the course of each 1 minute trial. Reaction times were averaged across the three trials for each posture and used as the dependent measure of secondary task performance.

Functional Balance

The Community Balance and Mobility Scale (CB&M) was used as the dependent measure of functional balance. The CB&M consists of 13 items ranging from timed one-leg stance to descending eight steps (Appendix E). Each item is scored on a scale from 0 to 5 points with points being awarded for qualitative aspects of the movement (controlled vs. uncontrolled motion) and time to complete an item. The scale is rated out of a total of 96 points. The CB&M scale was administered by the researchers and videotaped for subsequent scoring. Videos of the CB&M tests were then numerically coded and randomly ordered and scoring was completed by a Certified Kinesiologist who was experienced in the use of the CB&M and blinded to group membership and test period.

Composite Fitness

Six minute walk distance was used as a dependent measure of composite fitness following the protocol used by Bautmans (2004) and by Lord and Menz (2002) (Appendix F). The six minute walk test was administered by the researchers using a track of known distance in the gymnasium of the Heron Road Community Centre. Each participant was instructed to walk at his or her own pace and to cover as much distance as possible during the six minutes without running. A researcher followed slightly behind the participant, so as not to influence the participants' walking pace, and provided statements of encouragement ("You're doing well", "Keep going only X minutes to go") approximately every 30 seconds. At 6 minutes, the total distance covered was recorded to the nearest centimeter. Test location, direction of travel (clockwise or counter-clockwise) and approximate time of day (morning or afternoon) were kept constant for each participant across the testing sessions.

Games-Based Biofeedback Training Protocol

In addition to the chair exercise program, participants in the training group received two sessions per week of games-based biofeedback training for eight weeks. Each session lasted approximately 30 minutes and consisted of 5 separate training routines, each 4 minutes long. Participants were allowed to rest between games if they felt fatigued. The NeuroGym system was used to create the 5 training routines.

The components of the NeuroGym system are illustrated in Figure 1. The system consisted of two pressure sensing platforms (25cm long, 10cm wide and 1.5cm high containing a single load cell) on which the participants stood. Pressure data from each of the pressure sensing platforms was relayed to a laptop computer and sampled at 400Hz with an integration period of 20msec. The NeuroGym software used an algorithm to calculate the difference in pressure between the two platforms. The difference in pressure between the two platforms was relayed to the paddle of a computerized tennis game (pong) projected on the computer monitor. In this configuration, an increase in pressure on platform A relative to platform B would cause the game paddle to move toward the right along the bottom of the screen. Conversely, an increase in pressure on platform B relative to platform A would cause the game paddle to move toward the left side along the bottom of the screen. An equal increase in pressure on paddles A and B would result in no movement of the game paddle. When standing on the platforms, participants were able to move the game paddle by shifting their body weight. The game paddle was programmed to move in proportion to the difference in pressure between the platforms – with greater differences in pressure resulting in larger movements. The computerized tennis game consisted of the game paddle and a randomly bouncing ball. The object of the game was to move the paddle - by changing the pressure difference between the platforms – in order to hit the randomly bouncing ball.

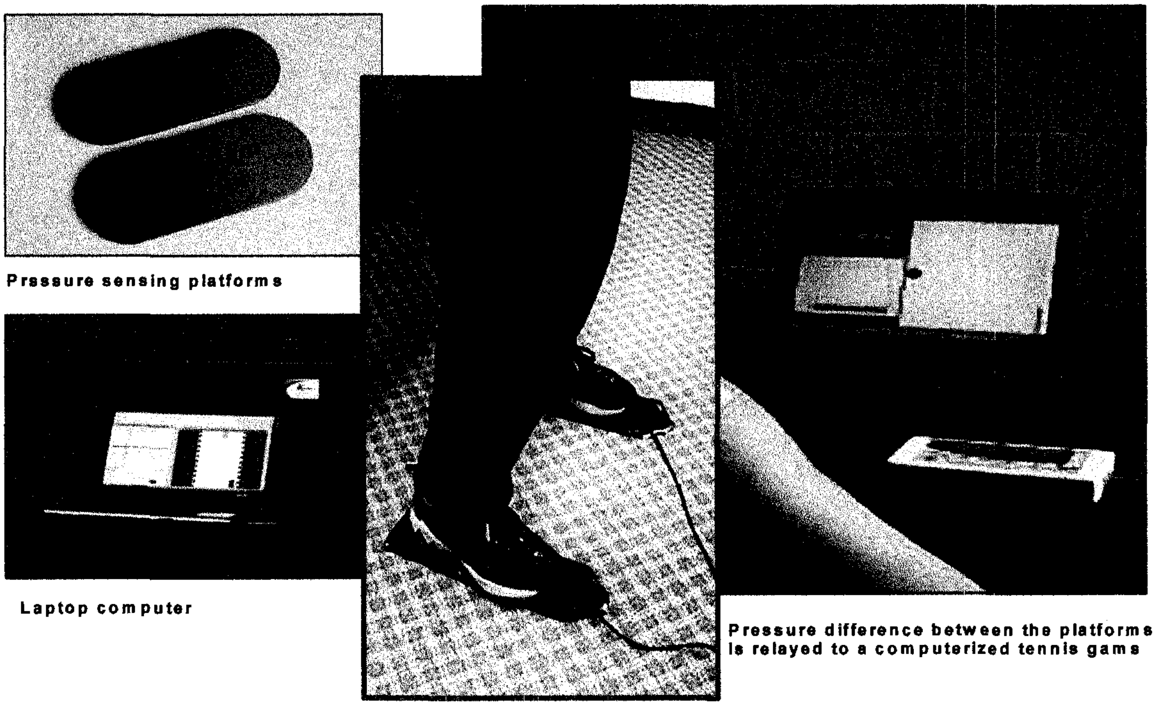


Figure 1: The NeuroGym training system consisted of two pressure sensing platforms and a computer game screen. The pressure difference between the two platforms was relayed to the game screen and used to by the participants to control the movement direction of a paddle in order to hit a randomly bouncing ball

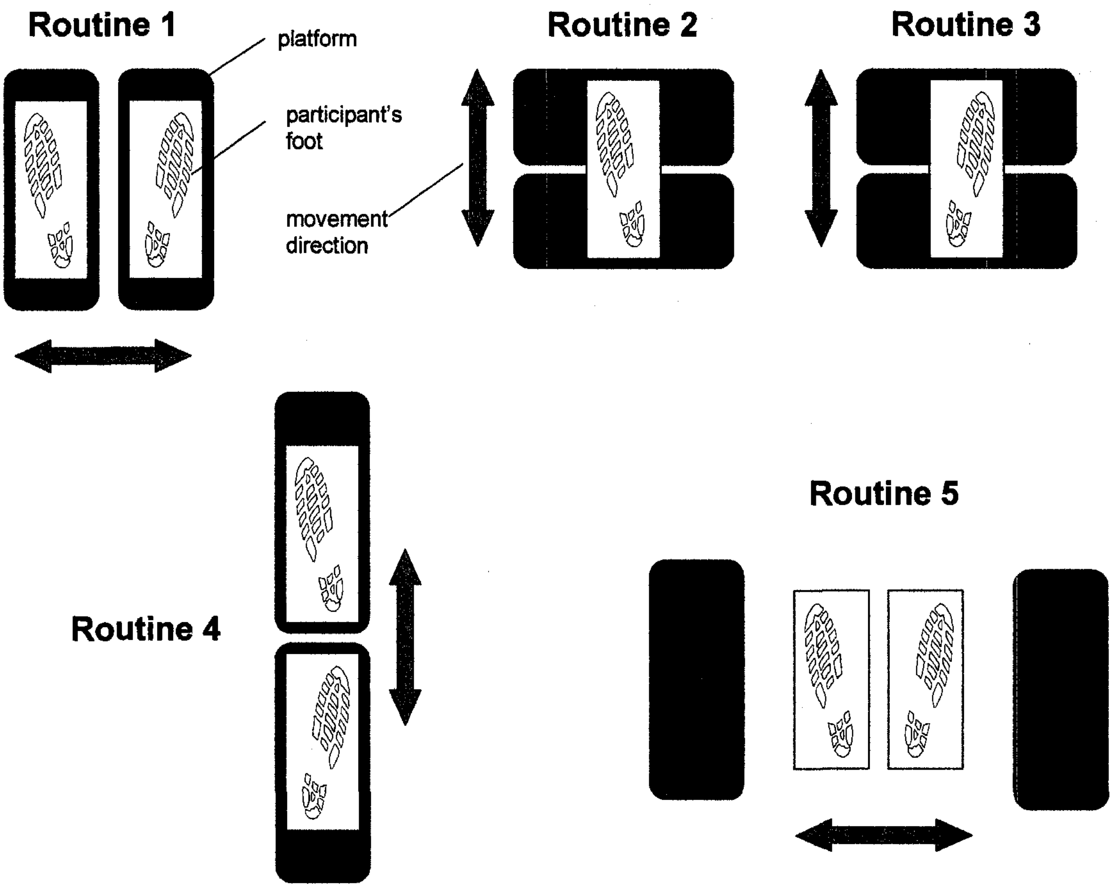


Figure 2: The training group participants practiced five routines using the NeuroGym training system. Participants stood on top of the platform as indicated by the footprints and shifted their weight in the directions indicated by the red arrows. In Routine 5, participants stood between the platforms and stepped to either side

Figure 2 illustrates the five training routines practiced by the training group. The size and portability of the pressure sensing platforms allowed them to be placed quickly and easily in any number of possible orientations. Four separate orientations of the platforms were used to create the 5 routines practiced by the training group, these included:

1) Standing on the platforms with the feet shoulder width apart – shifting weight in the Lat direction

2) Standing on the platforms with the left foot – shifting weight in the A/P direction

3) Standing on the platforms with the right foot – shifting weight in the A/P direction

4) Standing on the platforms in tandem with the dominant leg behind – shifting weight in the A/P direction

5) Standing in between the platforms (placed at 2x shoulder width) – stepping in the Lat direction

All of the training sessions were conducted individually with each participant and supervised by a researcher. The four minutes devoted to each routine comprised a single game of computerized tennis. During each game, postural support was available to the participants in the form or two chairs placed near their hands on either side. Participants were free to use the chairs as they felt necessary and the frequency of use was recorded by the researcher as continuous (one or both hands on the chairs for the entire routine), frequent (one or both hands on the chairs for more than half the game), occasional (one or both hands on the chairs for less than half the game) or none (Appendix G). The NeuroGym software recorded participants' accuracy in each game as a percentage of the balls that were successfully hit with the game paddle.

The speed of the randomly bouncing ball was initially set at level 3 (approximately 5cm/sec) for all of the participants. When an accuracy score above 80% was achieved for two consecutive sessions, the speed of the ball was increased by one level. When participants reached speed level 5 (approximately 7.5cm/sec) there were no further increases in ball speed. Instead, participants were encouraged by the researcher to attempt to play the game with a reduced degree of postural support. While individual rates of progression varied slightly, all of the participants were using speed level 5 by the mid point of the training program. All of the participants were able complete routines 1) and 5) with no hand support at speed level 5 by the end of the training program, and all participants were using frequent, occasional or no postural support for routines 2), 3) and 4) at speed level 5 by the end of the training program. All of the participants achieved accuracy scores above 80% in each routine over the final 4 training sessions.

Data Analysis

All data analysis procedures were performed using SPSS 15.0 for Windows. The distributions of the averaged data for each of the dependent variables were within the range of normality, with measures of skewness and kurtosis falling within a range of +/- 2.0 times the standard error of the respective statistic.

Independent samples t-tests were used for baseline comparisons between the training and control groups on the dependent measures of functional balance and composite endurance. Unequal variances adjustment was used in the case where Levene's test for equality of variances indicated a significant difference in the variability of scores.

An analysis of variance (ANOVA) with repeated measures was used to test for changes in the dependent variables for postural sway, reaction time, functional balance, and composite fitness. In cases where the sphericity assumption of the ANOVA was not met, a Huynh-Feldt correction was used to adjust the degrees of freedom used to calculate the F statistic. The Bonferroni adjustment for multiple comparisons was used for all within-subjects contrasts. All statistical analyses were completed using a p value of 0.05.

Results

Group Characteristics at Baseline

Baseline measures for the training group and the control group are summarized in Table 1. At the initial testing time the nine participants in the training group had a mean CB&M score of 55.4 (SD=9.52) which did not differ significantly from the seven participants in the control group (M=55.00, SD=20.44), t (8.02) =0.58, p>0.05 (equal variances not assumed). There was no significant difference in 6-minute walk distance between the training group (M=502.4, SD=70.9) and the control group (M=480.4, SD=112) at the initial test, t (14) =0.98, p>0.05. There were no differences in Age (t(14) =0.99, p>0.05) and Mini Mental State Exam scores (t(14) =0.90, p>0.05) between the two groups.

Table 1: Group Characteristics at the Pre Test Period

	Group	Mean	Std. Deviation	N
CB&M Score	Training Group	55.44	9.52	9
	Control group	55.00	20.44	7
Six Minute Walk Distance (m)	Training Group	502.35	70.89	9
	Control group	497.64	121.15	7
Age (years)	Training Group	77.44	6.48	9
	Control group	77.43	7.59	7
Mini Mental State Exam	Training Group	29.33	1.00	9
	Control group	29.29	1.11	7

Dual Task Paradigm

Postural Sway

Measures of Postural Sway are summarized in Figures 3a (A-P axis) and 3b (Lateral axis). An ANOVA Group (training group vs. control group) X Time (pre test, post test, retention test) X Position (feet together, tandem, one-leg) X Sway Direction (anterior-posterior, lateral) with repeated measures on the last three factors and planned comparisons for main effects, Group and Time interactions was used to analyze the root mean square (RMS) of the displacement of the centre of pressure. There was a significant main effect of Sway Direction ($F(1, 14) = 48.42$, $p<0.05$) with sway in the lateral direction being greater than sway in the anterior-posterior direction. There were no other significant main effects ($p>0.05$) and no significant interaction effects ($p>0.05$). The absence of significant Group or Time effects indicates that both groups of participants maintained a stable posture as their primary task for each position at each testing period.

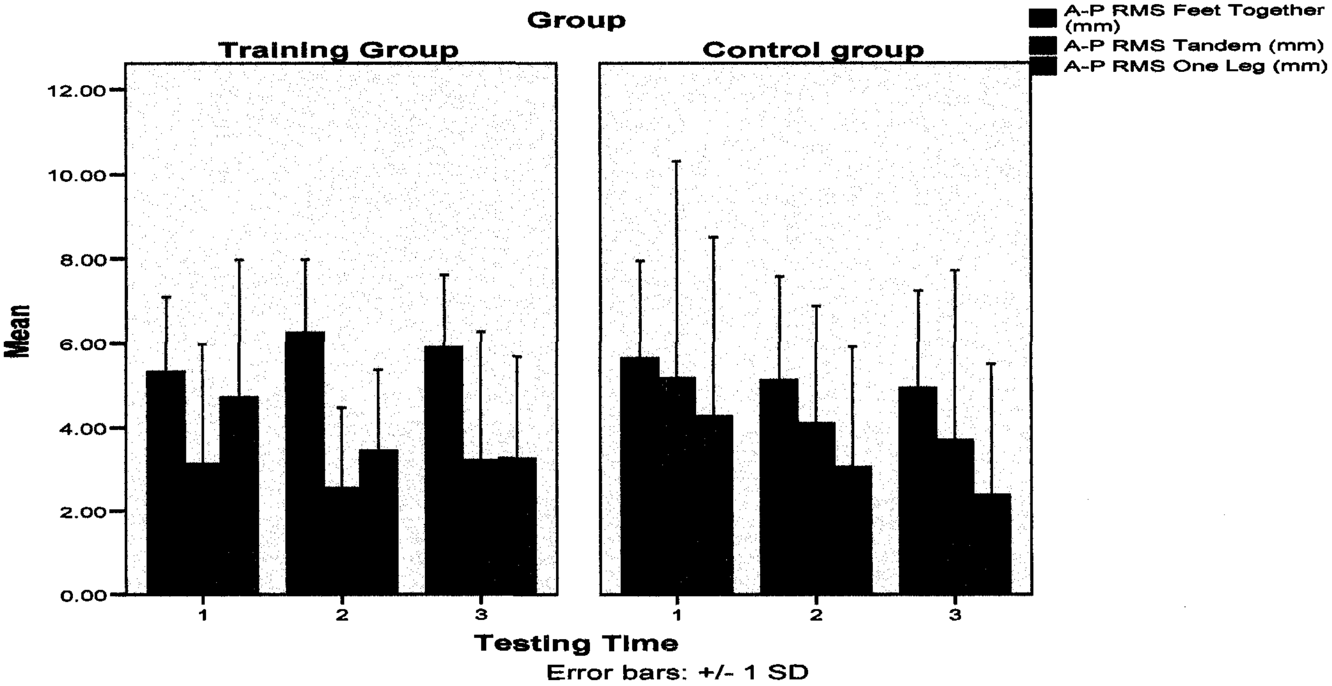


Figure 3a: Postural sway in the anterior-posterior direction shown for the training group (left panel) and the control group (right panel) across three positions at pre test (time 1), post test (time 2) and in the retention condition (time 3). Sway measures are expressed in mm with error bars representing 1 standard deviation.

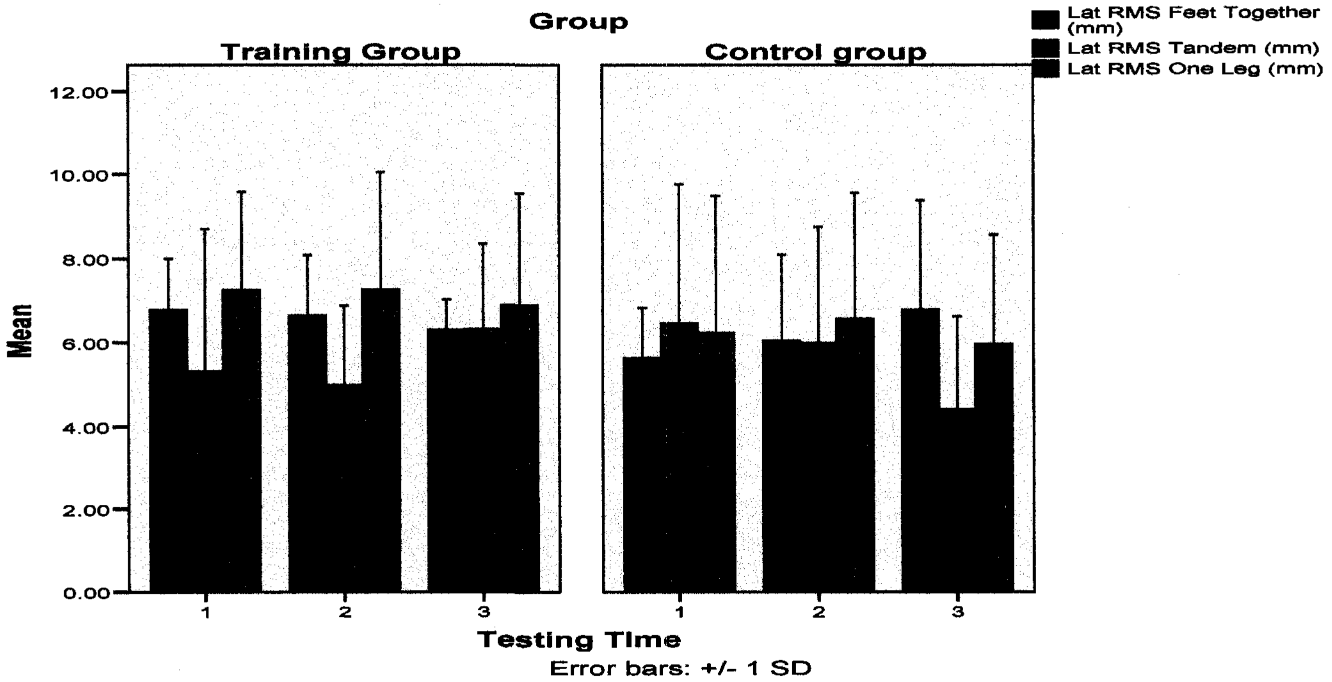
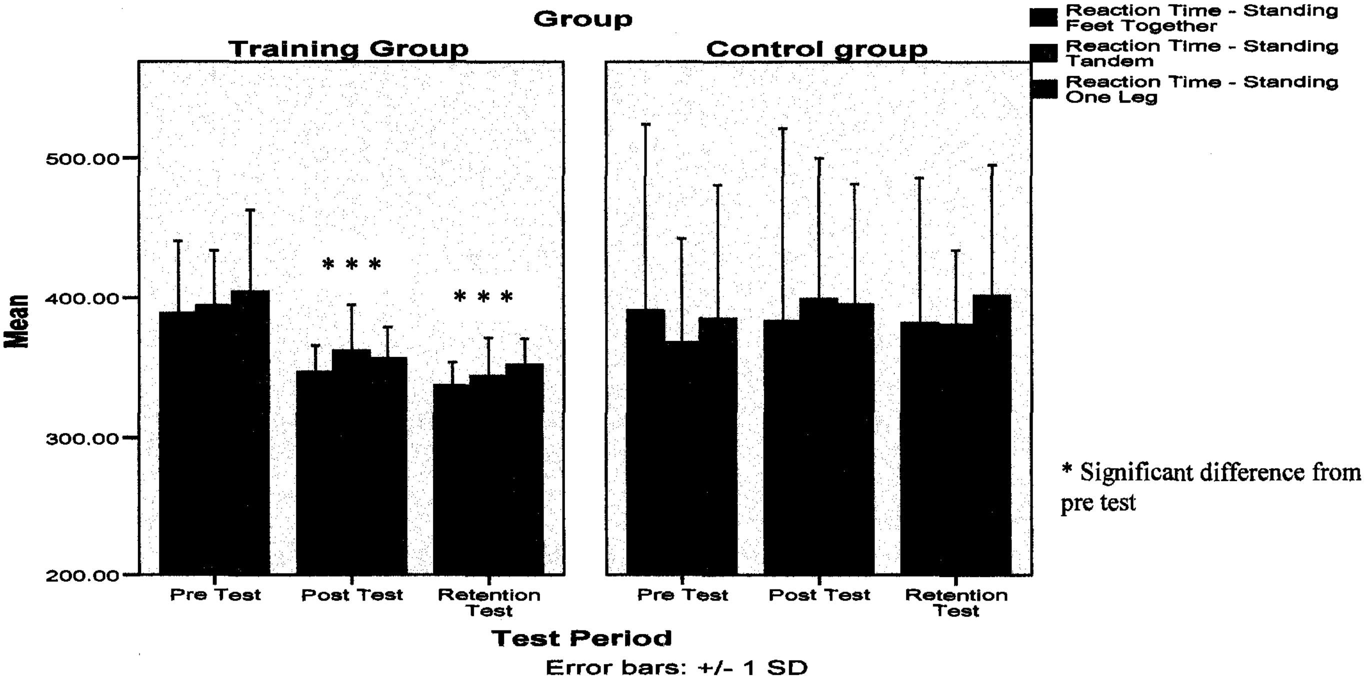


Figure 3b: Postural sway in the lateral direction shown for the training group (left panel) and the control group (right panel) across three positions at pre test (time 1), post test (time 2) and in the retention condition (time 3). Sway measures are expressed in mm with error bars representing 1 standard deviation.

Measures of reaction time are summarized in Figure 4. A three-way ANOVA Group (training group vs. control group) X Time (pre test, post test, retention test) X Position (feet together, tandem, one-leg) with repeated measures on the last two factors was used to examine reaction time. The ANOVA revealed a significant main effect of Time (F (2, 28) =4.29, $p<0.05$) and a significant Group X Time interaction (F (2, 28) =8.54, $p<0.05$). The sphericity assumption was not met for the Position factor so the Huynh-Feldt correction was applied. There was no significant main effect of Position (F (1.25, 17.45) =1.05, $p>0.05$), no significant interaction of Time X Position (F (3.40, 47.62) =2.43, $p>0.05$) and no significant interaction of Group X Time X Position (F (3.40, 47.62) =0.95, $p>0.05$). There was no significant main effect of Group (F (1, 14) =0.44, $p>0.05$).



* Significant difference from pre test

Figure 4: Mean reaction times are shown for the training group (left panel) and the control group (right panel) across three positions at pre test (time 1), post test (time 2) and in the retention condition (time 3). Reaction time measures are shown in ms with error bars representing 1 standard deviation.

Within-subjects contrasts for the Group X Time interaction indicate that mean reaction time decreased significantly for the training group relative to the control group from pre test to post test (F(1, 14)=12.31, p<0.05). Mean reaction time did not change significantly from post test to retention test (F (1, 14) =0.25, p>0.05) in the training group, suggesting that the training effect was maintained over the retention period. The absence of a significant effect of Position suggests that the training effect occurred across the three positions.

Functional balance

Functional balance scores are summarized in Figure 5. A two-way ANOVA Group (training group vs. control group) X Time (pre test, post test, retention test) with repeated measures on the last factor revealed no significant effect of Group (F(1, 14)=0.42, p<0.05). There was a significant main effect of Time (F (2, 28) =8.32, p<0.05) and a significant interaction of Group X Time (F (2, 28) =6.75, p<0.05).

Within-subjects contrasts for the Group X Time interaction revealed that the training group showed significant improvement relative to the control group from pre test to post test (F(1, 14)=11.17, p<0.50). This improvement did not change significantly from post test to retention test (F (1, 14) =0.58, P>0.05), which suggests that the training effect was maintained over the two week retention period.

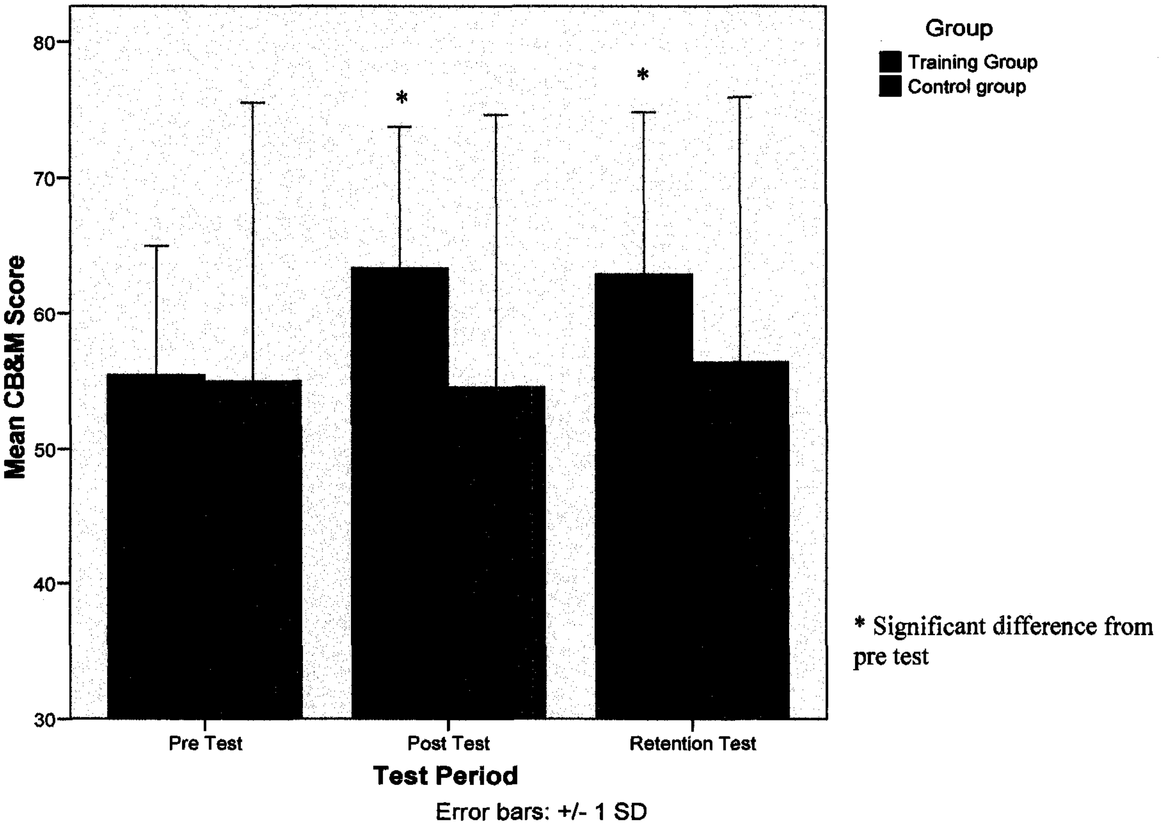


Figure 5: Mean scores on the Community Balance and Mobility Scale are shown for the training group (left panel) and the control group (right panel) across three positions at pre test (time 1), post test (time 2) and in the retention condition (time 3). Scores are out of a possible 96 points. Error bars represent 1 standard deviation.

Composite Fitness

Composite fitness measures are summarized in Figure 6. A two-way ANOVA Group (training group vs. control group) X Time (pre test, post test, retention test) with repeated measures on the last factor was used to examine 6-minute walk distance. The ANOVA revealed no significant main effect of Group (F (1, 14) =0.75, $p>0.05$). There was a significant main effect of Time (F (2, 28) =7.17, $p<0.05$), but no significant Group X Time interaction (F (2, 28) =1.38, $p>0.05$).

Within-subjects contrasts for the main effect of Time revealed that there was a significant increase in 6-minute walk distance from pre test to post test (F(1, 14)=8.29, p<0.05) and a non-significant increase from post test to retention test (F(1, 14)=0.35, p>0.05). The absence of a significant Group X Time interaction suggests that both the training group and the control group showed equivalent improvements in 6-minute walk distance and that there was no significant effect of the training program.

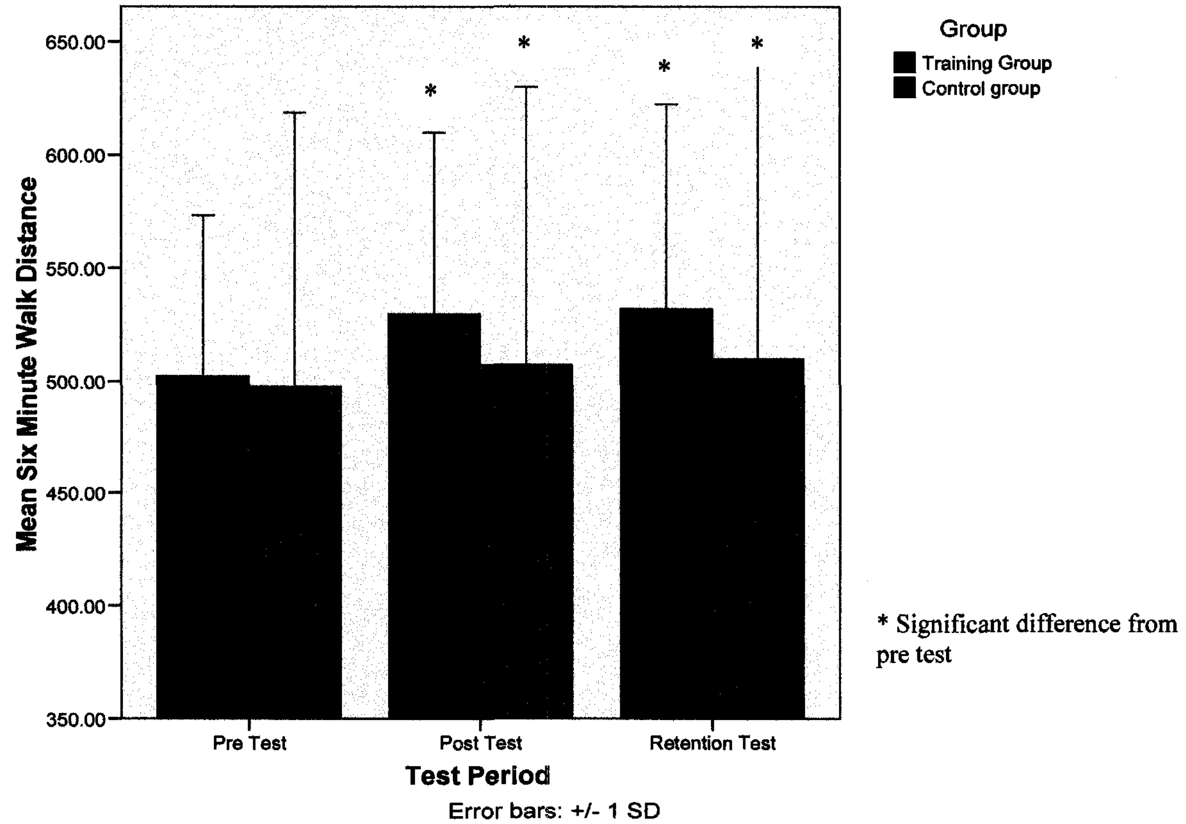


Figure 6: Mean six minute walk distances are shown for the training group (left panel) and the control group (right panel) across three positions at pre test (time 1), post test (time 2) and in the retention condition (time 3). Distance is shown in m with error bars representing 1 standard deviation.

Discussion

Dual Task Paradigm

Postural Sway

Figure 3a shows the root mean square (RMS) of the displacement of the body's COP for the anterior-posterior (A/P) axis and Figure 3b shows RMS for the lateral (Lat.) axis. The results of the postural sway analysis did not reveal any significant differences between the training group and the control group over the course of the study. The consistency of sway measures suggests that all of the participants followed the task instructions and considered maintaining postural stability as their primary task in the dual-task paradigm. Furthermore, the absence of group differences suggests that both the training group and the control group had similar abilities to maintain postural stability when instructed to stand as still as possible. These results are in agreement with those of Bisson and colleagues (2007) and Lajoie (2004). Neither of the previous studies recorded significant training effects on measures of RMS of the COP (Bisson et al., 2007) or frequency mode Lajoie, 2004) following computerized biofeedback training in community dwelling older adults.

It is important to note that the instructions given to participants in a dual task paradigm have been shown to influence the dependent measures of primary and secondary tasks (Frazier & Mitra, 2007; Woolacott & Shumway-Cook; 2001). In a recent review of dual task methodologies, Frazier and Mitra (2007) highlight the problems of comparing postural sway results of dual task paradigms which use different instructional sets, and note that consistent instructions regarding task priorities facilitate comparisons of results across studies. The instructional set used in the dual task paradigm of the present study is the same as that used by Bisson and colleagues (2007) and by Lajoie (2004); participants were explicitly directed to consider maintaining a steady posture as their first priority.

Postural sway was found to be significantly greater for the Lat. axis compared to the A/P axis. This difference was significant in both the training group and the control group; it did not change over the course of the study, and appeared consistently in each of the testing positions (Table 2b). Bisson and colleagues (2007) also found significantly greater RMS for the Lat. axis during standing with the feet together. Lajoie (2004) found a higher dominant frequency of postural sway in the Lat. axis compared to the A/P axis for standing with the feet together. Bisson and colleagues (2007) also tested standing with the feet shoulder-width apart and found that sway RMS was significantly higher in the A/P axis compared to the Lat. axis. Relative values of postural sway in the A/P axis relative to the Lat. axis change as a function of the dimensions of the body's base of support (Kirby et al., 1987). A wide base of support, such as in standing with the feet apart, provides for a greater control of the COP in the Lat. direction while a narrow base of support, such as tandem standing, provides for a greater control of the COP in the A/P direction but reduced control in the Lat. direction. When instructed to minimize sway, a person standing in tandem (a narrow base of support) is able to control the COP more tightly in the A/P direction relative to the Lat. direction. In the present study, all of the test positions (feet together, tandem, single leg) specified a narrow base of support, explaining the consistent finding of greater sway in the Lat. axis relative to the A/P axis.

Reaction Time

Figure 4 shows mean reaction times in milliseconds for the training group and the control group across the testing periods. For the training group, mean reaction time decreased significantly for each of the testing positions following eight weeks of training with games-based biofeedback, and this training effect was maintained following the two week retention period. In the context of the dual task paradigm, improved performance on the secondary task (reaction time) accompanied by no change in the primary task (postural sway) indicates that the attentional demands of maintaining the test positions decreased following eight weeks of games-based biofeedback training. The results suggest that training participants were able to reduce the attentional demands of standing in each of the three testing positions, thus allowing them to react more quickly to the auditory stimulus. Decreases in mean reaction times of 30-50msec were found for each of the testing positions. Similar decreases were reported by Bisson and colleagues (2007) and by Lajoie (2004).

The faster reaction times recorded following training with games-based biofeedback suggest an increased level of automaticity for the postural tasks. Biofeedback training may improve body awareness and heighten attentiveness to sensory cues that are used to control posture (Steadman et al., 2003; Geiger et al., 2001; Wolf et al., 1996) thus reducing the attentional resources required to maintain these postures and allowing for greater multi-tasking ability (Bisson et al., 2007; Lajoie, 2004). Games-based biofeedback creates a practice environment that provides an intrinsic motivation to practice (Herndon et al., 2001; McKenna et al., 1999; Nativ, 1993) and potentially increases the intensity of practice leading to a greater learning effect. A review by Taub

(2004) highlights the importance of a high volume of practice and a motivation to practice (intensity) as critical factors for shaping motor skills. Games-based biofeedback may provide an effective means of creating learning environments that support a high volume and intensity of practice (Nativ, 1993). Although the reductions in reaction time in the present study were comparable to those reported in studies of computerized biofeedback that did not use games, further study seems warranted on this aspect of training.

Functional Balance

Functional balance performance for the training group and the control group over the testing periods is shown in Figure 5. The training group significantly increased their scores on the CB&M Scale following eight weeks of training with games-based biofeedback. The training group's improvement in functional balance remained following the two-week retention period. The control group showed no improvement in CB&M scores over the course of the study.

Improvement in functional balance following biofeedback training have been reported in a number of studies (Bisson et al., 2007; Lajoie, 2004; Steadman et al., 2003; Geiger et al., 2001; Wolf et al., 1996) using various measures to assess functional balance. Bisson and colleagues (2007) reported improvements on the CB&M Scale of 5.7 points and 5.6 points respectively following training with computerized biofeedback and games-based virtual reality. In the present study, the training group increased their CB&M scored by an average of 7.89 points following eight weeks of training with games-based biofeedback. The larger improvements in the present study may be due to the number of balance positions used in the training program. The flexible arrangement of training routines made possible by the NeuroGym system allowed participants in the present study to train in a variety of positions, including tandem and single leg as well as dynamic movements (sideways stepping). These positions represent a wider range of CB&M items than the training routines used by Bisson and colleagues (2007).

While the CB&M Scale does not have a normative database for older adults, Howe and colleagues (2006) noted that CB&M scores below 50 were associated with low scores on a Community Integration Questionnaire. The authors suggest that the 50-point score on the CB&M may provide some indication of a threshold above which individuals are better able to function independently (Howe et al., 2006). In the present study, three of the nine training group participants began the study with CB&M scores below 50 points and finished with scores higher than 50 points. These results suggest that the training effect observed in the present study represents a change in functional balance that is relevant to the participants' ability to function safely and independently. Howe and colleagues also suggest that an improvement of 5 points on the CB&M scale represents a clinically significant change in functional balance (as cited in Bisson et al., 2007), further indication that the present training effect (an average increase of 7.89 points) does indeed represent a functional improvement for the participants.

The training participants began the present study with an average CB&M score of 55 points (SD=9.52). It is possible that the training effect of games-based biofeedback may depend to some extent on the baseline abilities of the participants. However, unpublished data from Wright and colleagues (2006, slide 22) indicated that lower baseline scores on the CB&M scale were associated with greater training effects in children with traumatic brain injury. Further studies of games-based biofeedback training should examine older adults over a wider range of functional abilities in order to determine if this type of training may also be of benefit to frail older adults.

Composite Fitness

Composite fitness performance for the training group and the control group over the testing periods is shown in Figure 6. Mean distance covered on the six minute walk test increased significantly over the duration of the study. However, both the training group and the control group showed similar increases in six minute walk distance, suggesting that the observed increases in walk distance may be the result of familiarization with the test, rather than a training effect. Rubenstein and colleagues (2000) used the six minute walk to assess the effect of an exercise training program in older adult males. The authors reported an increase in walk distance of 48m for the training group, which was interpreted as a significant training effect, compared to a non-significant increase of 15m for a non-exercising control group (Rubenstein et al., 2000). In the present study the training group increased their average six minute walk distance by 27.36m from pre test to post test and the control group increased their average six minute walk distance by 9.69m from pre test to post test. Interestingly, both groups continued to improve their six minute walk distance in the retention test by 2.06m and 2.67m respectively for the training group and the control group.

The larger increases in six minute walk distance observed for the training group may indeed indicate a non-significant training effect of the games-based biofeedback program. The training routines involved sustained bouts of one-leg standing which could conceivably lead to increases in hip and ankle strength which may contribute to gait speed. However, the absence of a significant training effect in the present study and the continued increases in walk distance in the retention condition suggests that the observed increases in walk distance are largely the result of participants becoming familiar with the pacing requirements of the test.

Conclusions

The NeuroGym system of games-based biofeedback provides a flexible and effective means of training postural control for active community dwelling older adults. Participants in the present study used the NeuroGym system to practice a wide variety of postural responses within a 30 minute training session. The functional balance improvements recorded in the present study exceeded those reported in a previous study of computerized biofeedback and virtual reality training (Bisson et al., 2007). The larger improvements recorded in the present study may have been the result of a greater variety of training positions and/or the motivational benefits of games-based activities. Additional studies comparing equivalent games-based and non games-based training methods may provide further insight into this area.

The present study suggests that training with games-based biofeedback significantly reduces the attentional demands of balance tasks in active community dwelling older adults. Furthermore, this reduction in attentional demands is associated with improved functional balance performance and occurs independently of general fitness. Participants in the present study were able to reduce the attention demands of postural control while standing with the feet together, in tandem, and on one leg, positions which represent key components of functional balance (Howe et al., 2007). These reductions in the attentional demands of postural control were associated with significant improvements on a scale of functional balance which has been designed specifically to evaluate the multi-tasking and complex timing aspects of balance (Howe et al., 2006). The improvements in functional balance appeared to occur independently of the participants' muscular strength and aerobic endurance, suggesting that these improvements represent an increased automaticity of postural control resulting from the games-based biofeedback program. For improving the functional balance of older adults, games-based biofeedback appears to provide a valuable addition to traditional exercise programs which target muscular strength and aerobic endurance. By increasing the automaticity of postural control, an older adult is able to react more quickly to changes in the external environment which may otherwise result in an accidental fall.

Limitations of the Present Study

It is important to note that the results of the present study are limited with respect to the three postures tested in the dual task paradigm. Postural support was available to the participants in the form of two chairs placed on either side of the force platform. Although the participants were instructed to use the chairs only to prevent a loss of balance, the amount of contact with the chairs was not measured. While none of the participants was observed to touch the chairs during the feet together posture, it is likely that participants did use the chairs for varying degrees of postural support during the tandem and one-leg standing trials. As such, the data collected from these postures should not be regarded as representing distinct levels of difficulty in the primary task. It is more likely that the participants used the available postural support to attenuate the difficulty of the tandem and one-leg postures and thus the three positions measured in this study represent a similar level of difficulty.

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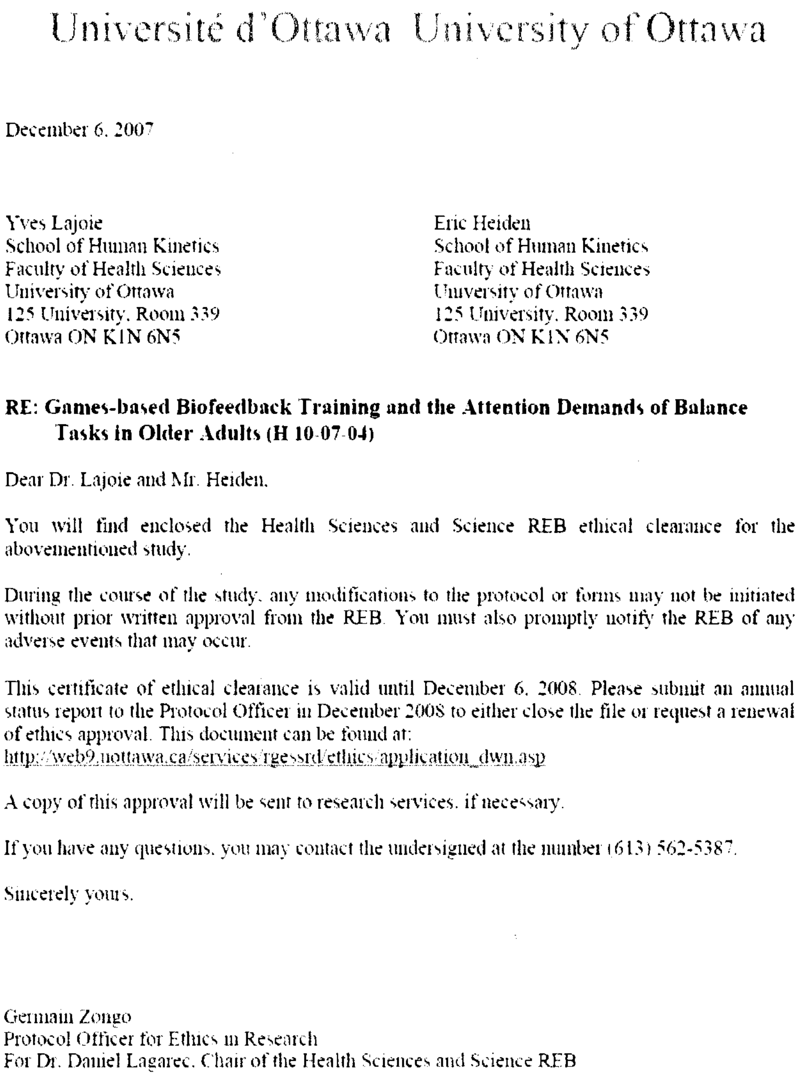
Appendices

Appendix A – Ethics Approval



Université d'Ottawa University of Ottawa

December 6, 2007

Yves Lajoie
School of Human Kinetics
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RE: Games-based Biofeedback Training and the Attention Demands of Balance Tasks in Older Adults (H 10-07-04)

Dear Dr. Lajoie and Mr. Heiden,

You will find enclosed the Health Sciences and Science REB ethical clearance for the abovementioned study.

During the course of the study, any modifications to the protocol or forms may not be initiated without prior written approval from the REB. You must also promptly notify the REB of any adverse events that may occur.

This certificate of ethical clearance is valid until December 6, 2008. Please submit an annual status report to the Protocol Officer in December 2008 to either close the file or request a renewal of ethics approval. This document can be found at:
http://web9.uottawa.ca/services/rgessrd/ethics/application_dwn.asp

A copy of this approval will be sent to research services, if necessary.

If you have any questions, you may contact the undersigned at the number (613) 562-5387.

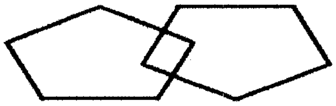
Sincerely yours,

Germain Zongo
Protocol Officer for Ethics in Research
For Dr. Daniel Lagarec, Chair of the Health Sciences and Science REB

Appendix B – Folstein Mini Mental State Exam

Patient's code__________________________: Date:__________________________

Instructions: Score one point for each correct response within each question or activity.

Maximum Score	**Patient's Score**	**Questions**
5		"What is the year? Season? Date? Day? Month?"
5		"Where are we now? State? County? Town/city? Hospital? Floor?"
3		The examiner names three unrelated objects clearly and slowly, then the instructor asks the patient to name all three of them. The patient's response is used for scoring. The examiner repeats them until patient learns all of them, if possible.
5		"I would like you to count backward from 100 by sevens." (93, 86, 79, 72, 65, ...) Alternative: "Spell WORLD backwards." (D-L-R-O-W)
3		"Earlier I told you the names of three things. Can you tell me what those were?"
2		Show the patient two simple objects, such as a wristwatch and a pencil, and ask the patient to name them.
1		"Repeat the phrase: 'No ifs, ands, or buts.'"
3		"Take the paper in your right hand, fold it in half, and put it on the floor." (The examiner gives the patient a piece of blank paper.)
1		"Please read this and do what it says." (Written instruction is "Close your eyes.")
1		"Make up and write a sentence about anything." (This sentence must contain a noun and a verb.)
1		"Please copy this picture." (The examiner gives the patient a blank piece of paper and asks him/her to draw the symbol below. All 10 angles must be present and two must intersect.) 
30		TOTAL

Interpretation of the MMSE:

Method	Score	Interpretation
Single Cutoff	<24	Abnormal
Range	<21 >25	Increased odds of dementia Decreased odds of dementia
Education	21 <23 <24	Abnormal for 8th grade education Abnormal for high school education Abnormal for college education
Severity	24-30 18-23 0-17	No cognitive impairment Mild cognitive impairment Severe cognitive impairment

Interpretation of MMSE Scores:

Score	Degree of Impairment	Formal Psychometric Assessment	Day-to-Day Functioning
25-30	Questionably significant	If clinical signs of cognitive impairment are present, formal assessment of cognition may be valuable.	May have clinically significant but mild deficits. Likely to affect only most demanding activities of daily living.
20-25	Mild	Formal assessment may be helpful to better determine pattern and extent of deficits.	Significant effect. May require some supervision, support and assistance.
10-20	Moderate	Formal assessment may be helpful if there are specific clinical indications.	Clear impairment. May require 24-hour supervision.
0-10	Severe	Patient not likely to be testable.	Marked impairment. Likely to require 24-hour supervision and assistance with ADL.

Source: Folstein MF, Folstein SE, McHugh PR: "Mini-mental state: A practical method for grading the cognitive state of patients for the clinician." *J Psychiatr Res* 1975;12:189-198.

Appendix C – Health Screening Questionnaire

Participant's code: ______________________________

Height (cm): ____________

Weight (kg): ____________

Date of Birth (dd/mm/yy): ____________

Sex (M / F)

Have you fallen in the past six months? YES __________ NO _________

If you answered yes, please describe the circumstances that led you to fall. If you have fallen more than once, please use the backside of this sheet to describe the circumstances.

____

____

____

____

Do you have any of the following medical conditions?

	YES	NO
An illness of the nervous system such as Parkinson's or Huntington's.		
Heart disease or a past heart-attack or stroke.		
Diabetes		
Injury to your upper-body in the past 6 months.		
Injury to your lower-body in the past 6 months.		
Loss of sensation (peripheral neuropathy)		
Arthritis in your lower body.		
Severe back pain.		
Uncorrectable problems with your vision.		

Appendix D - Consent Form

Name of Researcher (Supervisor): Yves Lajoie, PhD.

Institution, Faculty, Department: University of Ottawa, Health Sciences, School of Human Kinetics

Telephone number: (613) 562-5800 ext. 4273

Email address: ylajoie@uottawa.ca

Name of Researcher (Masters Student): Eric Heiden

Institution, Faculty, Department: University of Ottawa, Health Sciences, School of Human Kinetics

Telephone number:

Email address:

I am invited to participate in a research study conducted by Eric Heiden, a master's student studying at the University of Ottawa, Faculty of Health Sciences, School of Human Kinetics. The project is being conducted under the supervision of Yves Lajoie, PhD.

PURPOSE OF THE STUDY:

The purpose of this study is to learn more about how training with computerized biofeedback affects the balance of seniors. I understand that the aim of this study is to verify the improvement of certain characteristics of my balance following a supervised program of computerized biofeedback training. The researchers want to demonstrate that balance training can decrease the attention level required to maintain physically challenging postures, and improve measures of functional balance.

ELIGIBILITY:

To participate in this study I must be over 65 years old. I must be free of any heart condition. I must be free of any neurological disorder. I must not suffer from any vision problems that cannot be corrected by wearing glasses. I must have participated in an exercise program (chair exercise) for a period of at least eight weeks prior to joining the study.

PARTICIPATION:

My participation will consist of testing and training sessions over a twelve week period. The sessions will consist of four evaluation sessions and sixteen training sessions. Each evaluation session will last approximately 45 minutes and each training session will last approximately 30 minutes. The following table summarizes the twelve week study. If I am selected to participate in the control group, I will not participate in the training portion of the study, but only in the four evaluation sessions.

Research Timeline	
Week 1	Questionnaires, Evaluation
Week 2-9	Training, Evaluation
Week 12	Evaluation

Questionnaires

1. Health Questionnaire: To determine if the evaluation or training sessions could pose any potential health risks to me, the participant.
2. Mini-Mental State Evaluation: To ensure that I am mentally compatible with the requirements of the training activity.

Evaluation

1. Simple Reaction Time: Responding to a beep while sitting in a chair.
2. Postural Sway: Standing on a flat device that will track the location of my body's centre of pressure.
3. Attentional Demand: Measurement of reaction time while standing.
4. Balance Test: I will be asked to perform a series of thirteen balance tasks which include: walking, climbing stairs, and bending down to pick something up while walking. The researchers will videotape my performance of these tasks. The videotape will be used by the researchers in order to score my performance on each of the tasks – the videotape will be kept completely confidential.
5. General Fitness Test: I will walk as far as I can in six minutes to assess my general fitness.

Computerized Biofeedback Training

Computerized biofeedback training is a type of training which uses my body's movement to control a computer game. During training exercises, I will stand on two pressure sensing plates. By shifting my body weight, these sensors will relay my movement to a computer, allowing me to play a computer game.

1. I will perform five exercises with computerized biofeedback lasting approximately four minutes each.
2. Training will be guided and supervised by the researcher.
3. I will have a chair on either side of me to be used as a safety device.

POTENTIAL RISKS:

I understand that I may feel tired during or following a training session due to the physically demanding nature of the training. I understand that the researcher will allow me to take breaks as needed when I feel tired. I realize that I will not be judged if I cannot perform all of the exercises requested by the researcher.

I realize that all of the participants will not be at the same skill level during the training sessions. Therefore I may feel inferior to others if I have difficulties with the exercises. However, I know that the researchers will encourage all of the participants equally and that I will not be judged personally on the basis of my performance.

I know that training with computerized biofeedback is physically challenging. I will be standing in postures that require significant physical effort and there is a risk of falling while performing certain exercises. I will have safety supports on either side to prevent me from losing my balance and falling. I may continually use these supports if I feel the need to.

POTENTIAL BENEFITS:

During the study, I will have the potential to improve my balance if the exercises are executed properly and I attend all of the sessions. Any improvements in my balance may help prevent falls and related injuries.

This study also has the potential to contribute to our general knowledge of balance training. The researchers may be able to determine which aspects of balance improve with computerized biofeedback training and validate the use of such training to improve balance in seniors. This knowledge may help trainers, physiotherapists, and other health professionals develop more effective exercise programs.

CONFIDENTIALITY AND DATA KEEPING:

I have the assurance from the researchers that the information I will share with them will remain strictly confidential and will be used for research only. The videotapes and all of the questionnaires will be kept in a locked filing cabinet located in the office of the research supervisor (Yves Lajoie) for a period of five years, after which it will be destroyed. The collected data will be kept on a computer accessible only to the researcher and the supervisor under the protection of an access code.

ANONYMITY:

My anonymity will be protected by the use of terms such as "the participant." No names will be mentioned on any reports or documents related to the study. The researchers will use numbers to differentiate between participants.

COMPENSATION:

There is no monetary compensation for participating in this study. For my participation in this study, I will benefit only from the advantages of training with a health professional.

VOLUNTARY PARTICIPATION:

I realize that I may withdraw from this study at any time, even after I have agreed to participate; without providing any reason, without consequence. If I withdraw from the study, any of my collected data will be destroyed.

INFORMATION ON THE RESULTS:

Once the study has been completed and the results have been analyzed, the researcher will offer to provide me with information based on my balance assessment. Should I wish to receive my results in writing, the researcher will provide me with the results in person at my center.

MORE INFORMATION ABOUT THIS STUDY:

If I have any other questions or require more information about the study itself, I may contact the researcher or the supervisor at the numbers mentioned above.

If I have any questions with regards to the ethical conduct of this study, I may contact the Protocol Officer for Ethics in Research, University of Ottawa, Tabaret Hall, 550 Cumberland Street, Room 159, Ottawa ON K1N 6N5, tel.: (163) 562-5841 or ethics@uottawa.ca.

CONSENT:

I, ______________________________, the undersigned, agree to participate in the above research study. The study has been explained to me, I have had the opportunity to ask questions about my involvement and to receive additional details that I wanted to know about the study. I understand that by accepting to participate, I am in no way waiving my right to withdraw from the study at any time.

I have been given a copy of this form.

Participant's name: (*Please print*) ______________________________

Participant's signature: ______________________________ Date: __________

Appendix E – Community Balance and Mobility Scale Administration and Scoring

Physical Setting

Much of the testing of the CB&M is designed to occur within a clinic setting upon a measured track. (The set-up is outlined below.) The therapist must also have access to a full flight of stairs (minimum 8 steps).

The following materials are required for testing:

- Stop watch
- Average size laundry basket or large rigid box of same dimension
- 2lb. & 7.5lb. weights
- Visual target used in Item 7 (a paper circle 20cm in diameter with a 5cm diameter black circle in the middle)
- Bean bag

Clothing

The patient should wear comfortable clothing and enclosed, flat footwear. Footwear should be consistent on subsequent testing. The patient is allowed to use whatever orthotic is customarily worn at the time of testing.

Rating Procedure

Use of Ambulation Aides: All tasks are to be performed without ambulation aides (with one exception in Item 12 – Descending Stairs.

Timed Tasks: Tasks 1, 6, 7, 8, 9, 10, 11, and 13 are timed tasks.

Demonstration Tasks: To ensure understanding of the task, the therapist should demonstrate all tasks while instructing the patient.

Standardized Starting Position: Unless otherwise indicated, the following starting position should be used: standing feet slightly apart, arms at sides, head in neutral position with eyes forward, and toes touching start line.

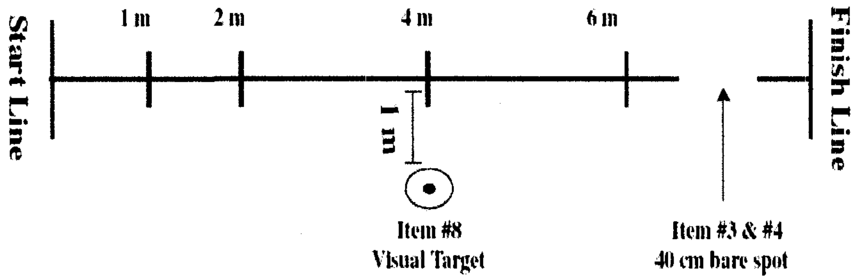
Scoring Patient Performance: One practice trial is allowed to ensure understanding, except for Item 1 – Unilateral Stance.

The therapist should judge the patient's performance in comparison to a young adult with a normal neuromusculoskeletal system.

Scale descriptors are detailed and precise. It is recommended that the grading criteria be reviewed well, including criteria for when the "test is over" prior to performing the tasks.

Patient Safety: If in the therapist's clinical judgment the patient would be unsafe in performing part or all of a task, the patient should not attempt it. Score according to the guidelines if part of the task is attempted or "0" if it is not attempted.

Community Balance and Mobility Scale – Track and Items



- **Unilateral Stance (R & L)***
- **Tandem Walk**
- **180° Tandem Pivot**
  Pivot 180 degrees, beginning & ending in tandem stance.
- **Lateral Foot Scooting (R & L)** – Pivot laterally on one foot to traverse 40 cm.
- **Hopping Forward (R & L)**
  Hop twice on one foot to travel forwards 1 metre and maintain stability on landing.
- **Crouch & Walk***
  Pick up an object from the floor while in the midst of walking forward and proceed without pausing.
- **Lateral Dodging***
  Rapidly cross one foot over the other with precise foot placement while moving laterally along the track and respond to an unexpected command to reverse direction.
- **Walking & Looking (R & L)***
  Maintain gaze on a target placed lateral to the track, as one walks forwards and past the target and attempt to maintain a straight trajectory.
- **Running with Controlled Stop***
  Run for 8 metres and control an abrupt stop.
- **Forward to Backward Walking***
  Rapid change in direction by turning at mid-way point of track to switch from forward to backward walking.
- **Walk, Look & Carry (R & L)***
  As per #8 but performed while carrying weighted bags.
- **Descending Stairs**
- **Step-Ups (R & L)***
  Step rapidly on & off a step.

Figure 1 Community Balance and Mobility Scale track and items. *Items are timed. R, right; L, left.

Source: Howe, J., Inness, E., Venturini, A., Williams, J., & Verrier, M. (2006). The community balance and mobility scale – a balance measure for individuals with traumatic brain injury. Clinical Rehabilitation, 20, 885-895.

Appendix F – Six Minute Walk Protocol

- The 6-minute walk will be conducted on a circular course of a known distance - either an outdoor track or an indoor gym.
- Participants will be instructed to cover as much distance as possible during the six minutes without running.
- Participants will wear comfortable shoes and clothing.
- Participants will be allowed to stop and rest if necessary. However, timing will continue during the rest.
- Each participant will be tested individually.
- The tester will follow slightly behind the participant, so as not to influence the participant's self-selected walking pace.
- Subjects will be encouraged with a standard set of encouraging statements every 30 seconds. The statements to be used will include 1) "You're doing well." 2) "Keep up the good work" 3) "Keep going, only X minutes to go."
- Walking distance will be recorded to the nearest metre.

Source: Bautmans, I., Lambert, M., & Mets, T. (2004). The six-minute walk test in community dwelling elderly: influence of health status. BMC Geriatrics, 4(6).

Lord, S.R., Menz, H.B. (2002). Physiologic, psychologic, and health predictors of 6-minute walk performance in older people. Archives of Physical Medicine and Rehabilitation, 83, 907-911.

Appendix G – Training Record Sheet

Date:				**Participant:**		
Exercise	**Position**	**Time**	**Ball Speed**	**Score**	**Support**	**Notes**
1	**Feet Together**	**4 min**				
2	**Tandem**	**4 min**				
3	**One Leg - Left**	**4 min**				
4	**One Leg - Right**	**4 min**				
5	**Stepping**	**4 min**				

Score: Record % accuracy at the end of the game

Support:
4 =Continuous support (one or both hands throughout game)
3 =Frequent support (one or both hands majority of game)
2 =Occasional support (one or both hands less than half of game)
1 =No support (no hands throughout game)

Notes: Record any pauses or breaks taken during the game